EXPLORING THE PSYCHOPHYSIOLOGICAL INDICES OF PERCEIVED EFFORT AND ITS SELF-REGULATION

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DECLARATION

No part of this thesis has been submitted in support of an application for any other degree or other qualification at the University of Kent, or any other University or Institution of learning.

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ABBREVIATIONS

+15%GET – 15% above gaseous exchange threshold

95%*CI* – 95% confidence interval

CoV – coefficient of variation

fMRI – functional magnetic resonance imaging

fNIRS – near infrared spectroscopy

GET – gaseous exchange threshold

ICC – intraclass correlation coefficient

LMM – linear mixed models regression

MPQ – McGill pain questionnaires

PRI – pain rating index

RCP – respiratory compensation point

RPE – rating of perceived effort

$RPE_{+15\%GET}$ – rating of perceived effort corresponding to 15% above gaseous exchange threshold

RPE_{GET} – rating of perceived effort corresponding to gaseous exchange threshold

SEM – standard error measurement

SRI – subclass rating index

TZ – time zone

$\dot{V}CO_2$ – expired carbon dioxide

$\dot{V}_E$ – minute ventilation

$\dot{V}O_2$ – oxygen uptake

$\dot{V}O_2.kg^{-1}$ – relative oxygen uptake

$\dot{V}O_2max$ – maximum/peak oxygen uptake response

$\dot{V}_T$ – tidal volume

ΔHHb – change in deoxyhaemoglobin

ΔO_2Hb – change in oxyhaemoglobin

ΔtHb – change in total haemoglobin

ΔTSI – change in tissue saturation index

Chapter 1 – GENERAL ABSTRACT

Effort involves the application of physical and mental resources towards a task. Individuals perceive effort during task engagement like exercise with a conscious sensation of *how hard, heavy, and strenuous the exercise consciously feels to drive the working muscles and for breathing*. Accordingly, individuals' decisions are thought to be guided by their perceived effort. In turn, there are numerous psychophysiological characteristics that underpin the perceived effort phenomenon which can also play a role in the overall decision-making processes and self-regulation of behaviour. However, it is often difficult to capture the underlying mechanisms of decision-making processes due to their erratic and complex nature. Consequently, there is scant literature on the psychophysiological indices of set perceived effort intensities and underlying decision-making processes during self-regulation of perceived effort. Yet, a small sample of studies have demonstrated that concurrent mixed-methods/process-tracing approaches can delve more into complex decision-making processes involved with regulating perceived effort and exercise behaviour. Subsequently, the main aim of the present thesis was to explore the psychophysiological indices of perceived effort and its self-regulation.

This thesis comprises three separate studies. In Study 1, the reliability of a novel fixed perceived effort cycling task was investigated. Results demonstrated that a novel fixed perceived effort trial that corresponded ratings of perceived effort to a known physiological threshold was reliably produced over numerous bouts and elicited a consistent psychophysiological response for each perceived effort intensity. A following study (Study 2, Part A) also probed the psychophysiological responses associated with two intensities of fixed perceived effort. During these studies it appeared that physical outputs at a set perceived effort intensity would decrease over time to maintain the same perception of effort. Meanwhile, certain psychophysiological markers showed characteristic increases (e.g., heart rate) or decreases (e.g., affective valence) as the fixed perceived effort exercise progressed. As a result, specific intensities of perceived effort appear to exhibit different power output and psychophysiological responses in terms of magnitude and changes over time. This could possibly then be linked to different ways that perceived effort is self-regulated.

It was also of interest how individuals self-regulated during fixed perceived effort exercise. To achieve this, Study 2 utilised a think aloud protocol to understand the behavioural

and cognitive self-regulatory strategies that were used by participants at different fixed perceived effort intensities (Part A) as well as any differences in self-regulation between experienced and inexperienced cyclists (Part B). Within Part A, it was found that there was a greater change in power output during the higher intensity fixed perceived effort cycle, signifying a greater amount of behavioural self-regulation. Furthermore, the activation of cognitive strategies was also greater in the higher intensity fixed perceived effort task. When assessing differences between experience levels of participants, there were no significant differences in power output or major secondary themes of the think aloud protocol suggesting participants of any experience level may self-regulate perceived effort similarly. However, closer examination of the primary themes from the think aloud data suggest experience level may affect the cognitive self-regulatory strategies that are used during a prolonged fixed perceived effort intensity exercise.

Finally, this thesis then explored any changes in self-regulation of perceived effort after an intervention which involved experimentally induced muscle pain. In addition, this study also incorporated the use of functional near infrared spectroscopy to assess the cognitive effort applied to activate cognitive self-regulation strategies during fixed perceived effort exercise. It was found that the presence of elevated muscle pain due to an intramuscular hypertonic saline injection cause a significantly lower power output than an isotonic placebo-control condition. In addition, near infrared spectroscopy data showed a greater change in deoxyhaemoglobin between condition suggesting a greater use of cognitive self-regulatory strategies as part of executive function when experiencing elevated muscle pain compared to a placebo-control.

Overall, this thesis firstly found a novel fixed perceived effort exercise to be reliable. Using this task paradigm, additional studies show that specific intensities of perceived effort seem to elicit different power output and psychophysiological responses in terms of magnitude (e.g., higher/lower between intensities) and changes over time (condition x time interactions). Subsequently, data concerning the self-regulation of perceived effort shows that participants employ a mixture of behavioural (i.e., changing power output) and cognitive (i.e., engaging in reappraisal and/or self-talk) strategies to self-regulate perceived effort. In addition, there was a difference in self-regulatory strategies between conditions which involved elevated muscle pain (hypertonic saline injection) or a no elevated muscle pain (isotonic saline injection). Therefore, the self-regulation of perceived effort is likely context dependent and there are also likely to be some individual preferences towards how perceived effort is self-regulated.

Chapter 2 – GENERAL INTRODUCTION

2.1. DEFINITION OF PERCEIVED EFFORT

Motor performance encompasses the purposeful production of voluntary action(s) which are judged according to how successfully they are performed (Schmidt & Wrisberg, 2008). Endurance-based activity comprises one of the three categories of motor task performance and involves an individual performing a series of muscular contractions for a prolonged period (>75 seconds) which primarily utilises aerobic over anaerobic metabolic contributions (Gastin, 2001).

With this broad definition and overview, it is evident that many activities of daily living involving exercise classify as endurance-based motor tasks such as walking to the bus or mowing the lawn. Meanwhile, this definition and overview can also stretch into the performance domain such as time-trial racing or larger expeditions across great distances. Subsequently, a deeper insight into endurance-based motor tasks and its regulation has a wide scope to provide meaningful impacts to everyday lives.

Task performance is widely recognised as being dependent on the physical and mental resources that are applied towards the task (Borg, 1962, 1970, 1982; Marcora, 2019; Preston & Wegner, 2009; Steele, 2019). Application of these resources is known as effort (Preston & Wegner, 2009). Further to the actual application of effort, individuals generate a perceptual awareness of applying these resources, known as the perception of effort (Marcora, 2010a).

In his seminal work, Borg (1962), defined the perception of effort as how *heavy, strenuous, and laborious the work associated with the physical task is*. This notion was maintained through one of Borg's subsequent works (Borg, 1970) which clearly denoted perceived effort as a singular construct. In doing so, although there may be similarities in neurophysiological underpinnings and an overall experience between perceived effort and other exercise-related phenomena like pain, fatigue, and discomfort, they remain dissociable.

However, in the original study Borg (1962) unfortunately conflated other psychophysiological constructs like force, pain, fatigue, and discomfort with the definition of perceived effort. As a result, some lines of research believed that constructs like pain, fatigue, or discomfort are the core to the conceptualisation of perceived effort (e.g., Amann et al., 2015) whilst others believe they are correlates to perceived effort (e.g., Marcora, 2008, 2019; Smirmaul, 2012). More precisely, whilst the abovementioned definition of perceived effort had identified it as a singular, dissociable construct, Borg also proposed that perceived effort involved *the integration of various peripheral sensations from the cardiorespiratory, neuromuscular, skin, and joint systems* (Borg, 1962). Thus, perceived effort was simultaneously considered as non-dissociable from other exercise-related phenomena such as force, pain, fatigue, and discomfort (Bergevin et al., 2023; Halperin & Emanuel, 2020). Subsequently, Borg inadvertently set the course of two lines of research (Figure 1) which both claim to be investigating perceived effort but in truth are identifying with separate constructs (Bergevin et al., 2023).

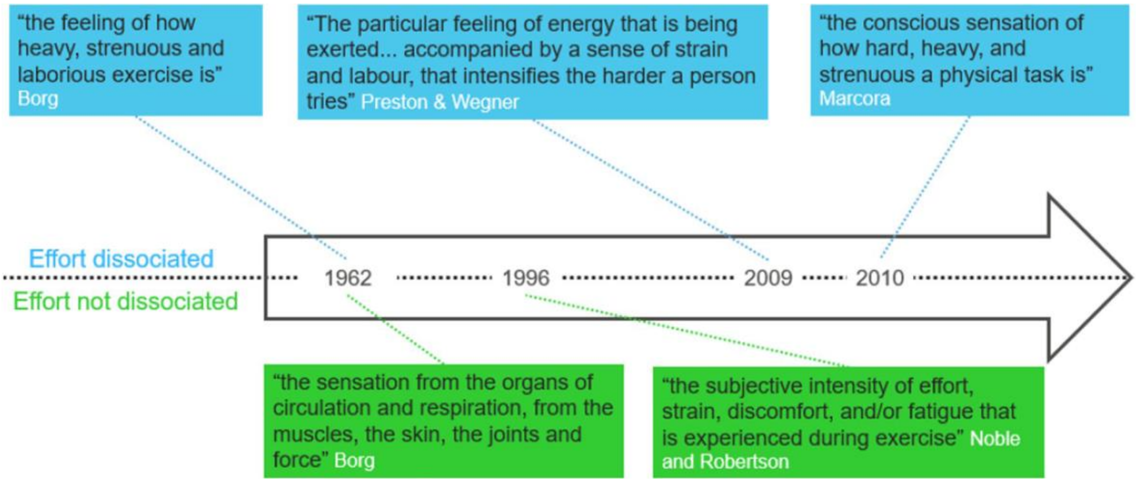


Figure 1. Overview of two lines of research investigating the perception of effort. Taken from Bergevin et al. (2023).

Before progressing with the psychophysiological approach to perceived effort of this thesis, it is essential to provide conceptual and operational clarity concerning the perception of effort. Failing that, several dissociable constructs may then fall within the domain of perceived effort. Thus, it is important to discern the differences between these constructs according to more recent research. By elucidating the differences between effort and force, pain, fatigue, discomfort, as well as a small selection of other exercise-related phenomena, it also becomes apparent how certain studies have erred in their measurement of perceived effort and their subsequent inferences regarding perceived effort's role on exercise behaviour (Pageaux, 2016).

2.1.1. EFFORT AND FORCE DISSOCIATION

Whilst the perception of effort and the perception of force are very closely related, recent findings indicate that they are not the same construct (Pageaux, 2016). To comprehend this difference, a brief understanding of the neurophysiological underpinnings of both constructs is necessary. Discussed in section 3.1, perceived effort is central in origin and is the artifact of the neuronal processing of corollary discharge, an efferent copy of central motor commands that are relayed to muscles to innervate them to contract (de Morree et al., 2012; Pageaux, 2016). Alternatively, perceptions of force represent the neuronal processing of this corollary discharge *in tandem with* the afferent signals that relay sensory information from the working muscles (Monjo et al., 2018; Proske & Allen, 2019; Taylor, 2013). As a result, perceptions of force in part derive from the sensory signals that originate within the periphery such as muscle spindles and/or Golgi tendon organs (Proske & Allen, 2019) unlike perception of effort which is exclusively central in origin (Bergevin et al., 2023; de Morree et al., 2012; Pageaux, 2016). Therefore, whilst perceived effort relates to the perception of heaviness, difficulty, and labour associated with physical and mental work (Borg, 1962; Marcora, 2010b; Preston & Wegner, 2009), in contrast, force does account some of these elements but also corresponds to perceptions of added sensations like tension and coordination (Jones & Hunter, 1983; Monjo et al., 2018; Proske & Allen, 2019).

Thus, it is possible for individuals to dissociate between effort and force perceptions (Pageaux, 2016). For instance, Jacquet et al. (2021) identified that individuals who were asked to imagine performing physical contractions, inevitably experienced no sense of force but did report changes in perceived effort. Furthermore, functional magnetic resonance imaging (fMRI) displayed elevated cortical activities across brain regions associated with physical effort such as the anterior cingulate cortex and motor cortex (Jacquet et al., 2021; Williamson et al., 2001). In addition, Pageaux (2016) indicated that dissociations in effort and force perceptions are more noticeable during fatigue. Proske and Allen (2019) reason that during fatigue the muscle spindles contribute more strongly to the perception of force. Thus, as muscle spindles do not factor into the perception of effort, in situations where muscle spindles feature prominently in an exercise (such as in a fatigued state), it becomes easier to dissociate between effort and force perceptions (Jones & Hunter, 1983; Pageaux, 2016; Proske & Allen, 2019).

2.1.2. EFFORT AND PAIN DISSOCIATION

Though effort and pain are both naturally occurring phenomena during physical activity – particularly during prolonged endurance exercise – they are distinctly different constructs. Perceptions of pain is defined by the International Association for the Study of Pain as *an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage* (Raja et al., 2020). Moreover, pain can be further subcategorised according to its duration, locality, aetiology, and pathophysiology (Thienhaus & Cole, 2002).

One category of pain which features regularly during prolonged exercise engagement is naturally occurring muscle pain (Cook et al., 1997, 1998; Mauger, 2013). During exercise, nociceptive stimulation of free nerve endings supplied by group III and IV afferents detects noxious stimuli such as potassium and hydrogen ions, substance P, histamine, prostaglandins, serotonin, bradykinin, and adenosine within the intramuscular space (Mauger, 2013; Mense, 1993, 2009; O’Connor & Cook, 1999). Furthermore, mechanical changes such as the deformation of tissue and increases in intramuscular pressure as well as increases in thermal temperature of the muscle unit are also detected and contribute to the sensory nociceptive signals that are relayed to the central nervous system (Graven-Nielsen, 2006; Mense, 1993). Particularly, group III nociceptive afferents are activated by application of mechanical and thermal stimuli, whilst group IV afferents are activated by the application of chemical stimuli (Amann et al., 2020; Marchettini et al., 1996).

Importantly, nociceptive signals are *sensory* signals that are conveyed along afferents via the dorsal horn of the spinal cord (Basbaum et al., 2009), and then directed towards the thalamus (Craig, 2003). Whereat, the thalamus discriminates the type of noxious stimuli (Basbaum et al., 2009) and then relays signals onto several cerebral areas such as the insula and somatosensory cortex where the *intensity* of pain is comprehended (Coghill et al., 1999; Hofbauer et al., 2001), or to the anterior cingulate cortex where the *quality* and *affective* dimension of the pain experience is integrated (Paus, 2001; Rainville et al., 1997). As a result, there are varying qualities of pain perception that can be experienced and are based on which groups of afferents are stimulated and where the nociceptive signals are processed (Almeida et al., 2004).

First amongst the literature to dissociate effort and pain perceptions were O’Connor and Cook (2001) who identified that individuals undertaking exercise could withstand 15 minutes of moderate intensity pain whilst providing separate ratings of perceived effort (RPE). Within this study, the researchers adhered to the original definition of effort according to Borg (1962) whilst leg pain was rated according to *the degree of hurt that you are feeling in your quadriceps* (O’Connor & Cook, 1999, 2001). In doing so, the authors set a precedent for other research which also identified that individuals could easily dissociate between effort and pain perceptions. For instance, Pageaux, Angius, et al. (2015), enlisted participants to conduct an isolated leg extensor exercise at 85% of their peak power output in which there were divergent ratings of effort and pain perceptions throughout the exercise. Moreover, a series of studies by Astokorki and Mauger (2017a, 2017b) required cyclists to conduct a fixed perceived effort trial in which perceived effort remained constant, but it was found that perceived pain changed markedly across the exercise bout. As such, the perceptions of effort and pain likely coexist, particularly during endurance-based exercise, yet a wealth of evidence now demonstrates that they are dissociable constructs (Astokorki & Mauger, 2017a, b; O’Connor & Cook, 2001; Pageaux, Angius, et al., 2015). Nevertheless, both effort and pain perceptions may involve similar cerebral centres during their integration such as the anterior cingulate cortex (Basbaum et al., 2009; Rainville et al., 1997). Consequently, there is a neurophysiological link between the two as well as some overlap in neural circuitry, but they do not necessarily *always* share the same pathways and do not necessarily *always* interact.

2.1.3. EFFORT AND FATIGUE DISSOCIATION

Fatigue can present itself in many forms (Enoka & Stuart, 1992). Enoka & Duchateau (2016) indicated that the trait-level of fatigue *is a disabling symptom in which physical and cognitive function is limited by interactions between measured (performance) and estimated (perceived) changes in work capacity (fatigability)*. Precisely, performance fatigability relates to the decrease in an objective motor performance measure, whilst perceived fatigability describes the perceived sensations that regulate the integrity of the performer (Enoka & Duchateau, 2016). Recently, Behrens et al. (2023) built upon the initial framework by Enoka and Duchateau (2016), indicating that task-induced state fatigue is a psychophysiological condition characterised by a decrease in the motor and/or cognitive performance of a task as well as its associated perceptions (e.g., perceived effort). Meanwhile it was theorised that the perception of effort can also act as an important *determinant* of motor and cognitive fatigue (Behrens et al., 2023). Accordingly, this suggests that fatigue has a reciprocal relationship with the perceived effort of an individual, rather than suggesting it is an identical construct (Behrens et al., 2023; Halperin & Emanuel, 2020). Namely, fatigue can elicit changes to the central motor commands and therefore the corollaries that drive the perception of effort. Likewise, the perception of effort can factor into greater perceptions of fatigue according to how intense the perception of effort is at different time-points of an exercise based on prior experience and expectations (Behrens et al., 2023).

In short, Behrens et al. (2023) shrewdly acknowledged that perceived effort arises due to the impacts that psychophysiological changes effect onto either central motor command, neuronal processing of central drive copies, or the motivational dispositions of the individual. The intensity of the perception of effort then subsequently factors into the affective-motivational dispositions of the individual (perceived fatigability) as well as precipitating changes to the decision-making processes to elicit changes in behaviour towards the performance of a task (i.e., performance fatigability) (Behrens et al., 2023; Inzlicht & Marcora, 2016; Marcora, 2019; Venhorst et al., 2018b).

In this manner, naturally, effort and fatigue are closely related (Halperin & Emanuel, 2020; Marcora, 2008; Pageaux, 2016), yet Borg (1982) highlighted that they *must be distinguished even though these two concepts have very much in common*. Namely, engaging in a prolonged exercise typically causes increases in both fatigue and perceived effort with strong correlations (Halperin & Emanuel, 2020; Meeusen & Roelands, 2018; Micklewright, St Clair Gibson, et al., 2017; Tucker, 2009). In context, the accumulation of fatigue impedes the output of an individual during a physical or cognitive task (Behrens et al., 2023). Resultantly, the individual must apply more effort for the same output due to the onset of fatigue (de Morree et al., 2012; Marcora et al., 2008).

To further establish this difference, Micklewright, St Clair Gibson, et al. (2017) developed a rating of fatigue scale that was used alongside the original Borg 15-point scale (1970) which obtains RPE responses. Within this study, the authors determined that immediately after completion of graded incremental trials, individuals rated their perceived effort as *6 – no effort*, whilst fatigue remained high with progressive decreases over time (Micklewright, St Clair Gibson, et al., 2017). Prior to this study, Pollak et al. (2014) also conducted a study which involved an injection of a 'metabolic soup' into a hand muscle. Participants then provided descriptors of the perceptions they experienced due to this injection. Notably, fatigue was reported in 14.5% instances where non-pain descriptors were used, whilst perceived effort was not reported *at all* (Pollak et al., 2014; Smirmaul, 2014). Hence, individuals can clearly demarcate between perceptions of fatigue and effort (Smirmaul, 2014). Whilst authors aimed to counter this supposition (Amann & Light, 2014), they suggested that this is because the *individuals were not requested to contract*. However, this only served to further validate how perceived effort is a product of the central motor command changes associated with exercise and is not reliant on peripheral feedback like force, pain, and fatigue.

2.1.4. EFFORT AND DISCOMFORT DISSOCIATION

Finally, discomfort is highly related to the perception of pain. Indeed, the definition of discomfort plainly incorporates the perception pain - *a slight pain or something that causes an individual to feel uncomfortable* (Collins English Dictionary, 2023). By inference it is logical to assume that as discomfort is representative of pain, and in turn, pain is clearly dissociable from effort (Astokorki & Mauger, 2017a, b; O'Connor & Cook, 2001; Pageaux, Angius, et al., 2015). Hence, discomfort and effort are dissociable too (Pageaux, 2016). Regardless, two studies have extricated the two constructs for clarity. First, Christian et al. (2014) tested participants during a fixed perceived effort trial and recorded their perceived discomfort across two separate bouts in different ambient environments. As expected, the trajectories of discomfort responses differed between conditions indicating that discomfort levels could differ in varying ambient environments whilst perceived effort remained constant. Second, Steele et al. (2016) trialled an RPE-effort and an RPE-discomfort scale during resistance training bouts. Results suggested that participants differentiated between the two scales with weak correlations reported between each scale.

2.1.5. PERCEIVED EFFORT AND AFFECTIVE VALENCE

Although most research since Borg's (1962) paper have dissociated perceived effort and affective valence it is important to clarify the differences between the two also. Affective valence was initially conceived as an antecedent of perceived exertion (Borg, 1962). In short, affective valence involves hedonistic and motivational aspects (Berridge, 2019). Hedonistic components of affective valence are tied closely with the emotional and mood states of the individual and can be split into dimensions of pleasure and displeasure (Berridge & Kringelbach, 2013; Ekkekakis, 2003). Meanwhile, motivational components are associated with the active pursuit or passive avoidance of goals (Berridge, 2019; Richter, 2013). Combined, the hedonistic and motivational aspects constitute a valenced affective state which has a positive or negative direction simply captured on the Feeling scale (Hardy & Rejeski, 1989).

Granted, perceived effort and affective valence are associated with similar physiological cues (Venhorst et al., 2018a). Yet, a simple observation that two individuals can exercise at a perceived effort of *15 – hard* but one could feel good whilst the other feels bad implies that the relationship between affective valence and perceived effort is not causal (Rejeski, 1985). Relatedly, recent neuroscientific evidence reveals that hedonic components of affective valence involves millions of neurons across vast mesocorticolimbic circuits (Berridge & Kringelbach, 2013). Therefore, whilst regions of the brain such as the anterior and middle cingulate cortices may demonstrate similar activities when examining perceived effort and affective valence, there is a distinctive neuronal process involved with each phenomenon (Berridge, 2019). In consequence, affective components have been posed as a mediator of exercise-related decisions (Venhorst et al., 2018b) as they can influence the subjective value of a given situation (Vogel et al., 2020). However, early evidence that individuals can dissociate the two phenomena (Rejeski et al., 1985) supported by recent neuroscientific evidence from fMRI (see Berridge, 2019) implies that perceived effort and affective valence are distinct although interactive during volitional, self-regulated tasks (Venhorst et al., 2018a).

2.1.6. PERCEIVED EFFORT AND OTHER SEMANTIC EXPLANATIONS

Finally, before advancing onto the measurement of perceived effort, there are two further phenomena/semantics that need to be addressed. First, since the onset of the current thesis Halperin and Emanuel (2020) recently argued that heaviness and effort can also be dissociated. This was of particular concern as the main definition to measure perceived effort involved the word heavy (see Marcora, 2010b) which if dissociable could create a misrepresentation in its measurement (Halperin & Emanuel, 2020). In Halperin and Emanuel's (2020) review of RPE and its measurement, the authors highlight that when using resistance exercise-specific OMNI scales, there is a potential misrepresentation of heaviness and perceived effort. To illustrate, the OMNI scale mentioned in the review comes from Lagally and Robertson (2006) which is thought to gather RPE responses during resistance-based exercise and depicts an individual with a barbell held over their head. Included on the scale are 0 – 10 increments thought to represent the *heaviness* of the load the person is holding. Hereat there may be a potential conflation between the *force* that the individual is exerting to resist the load from falling and the perception of effort as to how hard the task is to mobilise resources to meet the demands of the task (Steele, 2019).

However, there are several aspects of this debate which provide a rationale for the use of Marcora's (2010b) definition to not be a cause for concern in this thesis. First, Halperin and Emanuel's (2020) argument about heaviness and effort is highly specific to a singular OMNI scale that is used for resistance-based exercise. Particularly, OMNI scales could be argued as superfluous when appropriate use of the RPE and its category-ratio 10 and 100 scales are implemented (Borg, 1962; Pageaux, 2016). Second, the actual issue between *heaviness/heavy* and *effort* within this argument actually pertains to *force* and *effort* which has already been properly dissociated (see section 2.1.1.). Therefore, the issue lies with the term *force* and not *heaviness/heavy*. Third, the discussion by Halperin and Emanuel (2020) is also entirely centred around resistance-based exercise which imposes different task-based and psychosocial demands on athletes compared to endurance-based exercise tasks that are continuous like cycling. And finally, the findings which Halperin and Emanuel (2020) use to validate their argument are footnoted with a comment which suggests that changes in perceived effort ratings due to different examples of low load-more repetitions or high load-less repetitions is likely a measure of discomfort and not heaviness. In sum, there is yet to be convincing enough evidence to suggest that heaviness is problematic inclusion within the definition of perceived effort.

Next, there has also been some discussion around the semantics concerning *effort* and *exertion* (e.g., Abbiss et al., 2015). Borg's initial works used the terms *effort* and *exertion* interchangeably without discrimination (Borg, 1962, 1970, 1982). Yet some researchers do argue that *effor*t and *exertion* are separable constructs (Abbiss et al., 2015). One reason for the varied terminology within the literature may be the models that different research groups ascribe to. To illustrate, those that predominantly report the term *perceived exertion* in their methodologies tend to promote afferent feedback models (e.g., Amann et al. 2009, 2010, 2015;

Gagnon et al., 2012; Hureau, Weavil, et al., 2018; Noble & Robertson, 1996). Yet Bergevin et al. (2023) argue that some of these studies have conflated the perceived exertion definition with terms such as "*limb discomfort*", "*pain perception*", and "*leg fatigue*" in their respective studies. Meanwhile, those who predominantly ascribe to the central drive/corollary discharge models seem to use the term perceived effort. In turn, Bergevin et al. (2023) argued that these studies have adhered to definitions that communicate perceived effort as a singular, dissociable construct (e.g., Blanchfield et al., 2014a, b; de Morree et al., 2012, 2014; Marcora & Staiano, 2010; Pageaux, Angius, et al., 2015; Pageaux, Marcora, et al., 2015; Pageaux et al., 2013, 2014). Second, Abbiss et al. (2015) make a compelling case that while the Borg scale's (1970) upper anchor represents "maximal effort/exertion", the published criterion for determining a physiological capacity such as maximal aerobic uptake is a rating corresponding to "very hard" or "extremely hard", ergo, below maximal. Consequently, Abbiss et al. (2015) insinuate that physiological constraints such as muscle contractile function may limit an individual's ability to exert their fullest capacity. Therefore, whilst exertion may be maximal (i.e., the individual has completed expended physiological resources), it may be the case that perceived effort is submaximal as the individual could have a remaining desire/motivation to invest resources (Swart et al., 2012; Venhorst et al., 2018b). Therefore, exertion could be conceptualised as a product of the action whereas effort is also a product of the action but also the desire/motivation to put an action into effect, and as such, Abbiss et al. (2015) maintain that effort and exertion are separable constructs.

However, closer inspection reveals that *effort* and *exertion* are synonymous and feature within each other's definitions in the Collins English Dictionary (2023). Furthermore, other fields of study like psychology and neuroscience evidence that *effort* and *exertion* are synonymous constructs which cannot be dissociated with the same scale (Bergevin et al., 2023; Steele, 2019). To add, the body of evidence that Abbiss et al. (2015) cite in their review is rather limited (e.g., Swart et al., 2012; Smirmaul, 2012). In the Swart et al. (2012) paper, the authors utilise a non-validated scale with different definitions for the *effort* and *exertion* constructs. Therefore, it is unsurprising that participants rated two 'constructs' on two different scales differently (Pageaux, 2016). Second, further inspection of the Smirmaul (2012) paper provides no discussion on the dissociation between effort and exertion. As a result, more compelling and empirical evidence is required to fully accept this alternative view for the present. Therefore, whilst one must be scrutable about the perceived effort phenomenon as a singular, dissociable construct from force, pain, fatigue, discomfort, and affective valence, other terms like *exertion* and *heaviness* are not possible to dissociate from *effort,* contrary to some researcher's viewpoints (Abbiss et al., 2015; Halperin & Emanuel, 2020). Thus, hereon the terms *effort* and *exertion* will be used synonymously but with a preference for the term *effort* for consistency for the reader.

2.1.7. TERMINOLOGY AND DEFINITION USED IN PRESENT THESIS

In short, due to Borg's conflation of perceived effort within his seminal paper (Borg, 1962), recent literature has provided numerous arguments for and against the varied definitions that have surfaced within the kinesiology literature (e.g., Abbiss et al., 2015; Halperin & Emanuel, 2020; Pageaux, 2016). Naturally, certain definitions are more consistent with the models and mechanisms that authors ascribe to when considering the concept of perceived effort in an exercise setting. Subsequently, several studies have provided comprehensive assessments of how perceived effort differs from other exercise-related perceptions that arise during endurance-based activities.

In due course the present thesis aims to utilise the most precise, specific, and semantically sound definition of perceived effort based on the existing research. Accordingly, this thesis defines perceived effort as "*the conscious sensation of how hard, heavy, and strenuous a physical task is"* (Marcora, 2010b), which identifies with perceived effort as a singular, dissociable construct. In keeping with suggestions by Pageaux (2016), this thesis also ensures that the definition conveyed to participants was related to the current task – "*the conscious sensation of how hard, heavy, and strenuous the exercise task is to drive the working muscles and for your breathing"* – without conflating the measurement of perceived effort with other dissociable constructs that have been related (e.g., force, pain, fatigue, and discomfort). Although there are lingering drawbacks/issues with this definition (e.g., describing a perception as a conscious sensation seems redundant), evidence indicates that this definition is the closest and most accurate representation (e.g., Bergevin et al., 2023; Halperin & Emanuel, 2020; Pageaux, 2016) of the initial concept that Borg aimed to capture in his initial studies (Borg, 1962, 1970). Thus, providing the rationale for its use within the present thesis.

2.2. MEASUREMENT OF PERCEIVED EFFORT

Following on from his seminal paper (Borg, 1962) concerning perceived effort, Borg devised a 15-point RPE scale intent on capturing the perception of effort in a singular numerical value (Borg, 1970). Later derivates like the category-ratio 10 and 100 scales (Borg, 1982; Borg & Borg, 2002) were also produced but were premised on the same idea that an RPE response provided a numerical representation of the current perceived effort an individual was experiencing (Halperin & Emanuel, 2020). Moreover, several OMNI scales have surfaced within the literature and whilst independent studies appear to validate their use for capturing perceived effort in specific exercise tasks and populations, however, as noted, there use could be argued as superfluous when the appropriate definitions are applied with the original scale(s) (Pageaux, 2016).

In relation to preparation, it is of the foremost importance to ensure that distinct definitions, instructions, and familiarisations are provided to participants during the research process (Halperin & Emanuel, 2020; Pageaux, 2016). Otherwise, varying these elements or failing to appropriately familiarise a participant can hinder the measurement validity of perceived effort and confound the results and conclusions that are drawn (Halperin & Emanuel, 2020). As such, the current body of work adheres to the description that perceived effort in an endurance-based motor task context denotes the *conscious sensation of how hard, heavy, and strenuous the exercise is to drive the working muscle(s) and for breathing* (Marcora 2010b; Pageaux, 2016).

Next, it is equally important to illustrate the upper and lower boundaries of the scale that is being used when delivering instructions to participants. Malleron et al. (2023) recently exhibited that when providing a context-specific, *imposed* anchor (e.g., opening a jar of honey) versus a non-specific, *self-imposed* anchor (e.g., a past experience of a weighted military hike), participants rated perceived effort significantly higher with an *imposed* anchor compared to a *self-imposed* anchor. Plainly, as everyone has varied previous experiences and these previous experiences shape the perceived boundaries of exercise intensity (Anstiss et al., 2020; Bandura, 1997), this can lead to various interpretations of the scale's uppermost boundary (Malleron et al., 2023). Therefore, explicitly stating what corresponds to the relevant anchors prevents any misinterpretation by participants (Halperin & Emanuel, 2020). Likewise, the lowermost boundary must also be clearly stated as misrepresentation may conflate the measurement of perceived effort with other phenomena akin to those that have been discussed.

Related to the present thesis, asking an individual to rate their perceived effort during cycling activity could result in some individuals interpreting it as cycling as hard as possible such as during a Wingate trial, or others could interpret it as cycling to maximal volition like during a graded incremental exercise task; both viable interpretations of a maximal effort (Halperin & Emanuel, 2020; Malleron et al., 2023). Yet, these would yield different ratings of perceived effort. Thus, in the present thesis, participants were always instructed to rate their lowermost effort on the 15-point RPE scale as *6 - no effort, like when you are sat doing absolutely nothing in a rested state*, whereas *20 – maximal effort, relates to giving everything you have got like at the end of* $\dot{V}O_2max$ *test*. Correct use means RPE represents a true rating of the perception of effort and is positioned consistently between participants for that context (Halperin & Emanuel, 2020).

2.3. DIFFERENCES BETWEEN EFFORT AND PERCEIVED EFFORT

Finally, before moving onto the psychophysiological approach to the current thesis, it must be made explicitly clear that effort and perceived effort are *not* the same thing. Effort encompasses the allocation of resources towards a task for its completion towards a goal (Preston & Wegner, 2009; Steele, 2019). Elaborated more in the motivational intensity theory (see Brehm & Self, 1989; Marcora, 2008, 2019) and section 3.2.1 in the present thesis, effort is scaled according to the task demands whereby an individual must be motivated to invest the required effort for the task (Brehm & Self, 1989; Marcora, 2008, 2019; Wright, 1996).

Meanwhile, perceived effort is a subjective representation of the resources that are being applied towards the task in relation to its demands and the current situation (Inzlicht et al., 2018; Steele et al., 2019). Therefore, perceived effort represents the *conscious sensation of how hard, heavy, and strenuous the exercise is* (Marcora, 2010b). As perceived effort is subjective, it differs from the actual resources that are being invested. A key reason behind this is that changes in neuronal processing of effort-driving signals (section 3.1) manipulate the perception of effort (de Morree et al., 2012). Therefore, the linear relationship that exists between effort and task demands can be slightly skewed (Barwood et al., 2008, 2015; Blanchfield et al., 2014a).

Second, the RPE scales provide a medium that allows an individual to rate perceived effort onto a predesigned scale according to which number and/or descriptor most closely representing the individual's current perceived state (Bergevin et al., 2023; Halperin & Emanuel, 2020). Specifically, the 15-point Borg (1970) scale is a linear scale. Thus, ratings on this scale are equally spaced and ratings are always proportional to the minimum and maximum values (Borg, 1970; Halperin & Emanuel, 2020). Therefore, it could reasonably be suggested that changes in potential motivation (a maximal conceived intensity that one is willing to invest effort to) can distort the actual effort (resources applied to the task) at a set RPE (Figure 2). Subsequently, in practice, the actual resources applied towards a task could change but the perception of effort and its rating could remain unaltered (Wright, 1996). In another situation, an individual may enter an event with a low potential motivation (e.g., Figure 2, Bar E) but be incentivised to increase motivation (e.g., money). Thereon, this may cause the individual to have a high potential motivation (Figure 2, Bar D). Evidently, during a transient change between low and high potential motivation, when the same level of resources are applied to the task (effort), it becomes clear why an individual's RPE responses then suddenly change. In this instance, upregulating potential motivation causes a decrease in RPE for a given resource output, whereas downregulating potential motivation causes an increase in RPE for a given resource output (Barwood et al., 2015).

Although this is hypothetical argument, it is relevant to the current thesis as this thesis uses a fixed *perceived effort* exercise. As such, the perceived effort of the individual is required to remain constant. However, it becomes conceivable that the actual outputs (*effort*) of the individual could change whilst perceived effort remains constant. Thus, with all that has been related, it exemplifies how important it is to be precise and specific when defining the perception of effort as well as clearly denoting the upper and lower boundaries of an exercise task when using the RPE scale as highlighted by Malleron et al. (2023). A further explanation of the generation, interpretation, and regulation of effort amidst other relevant factors like motivation is provided in ensuing sections.

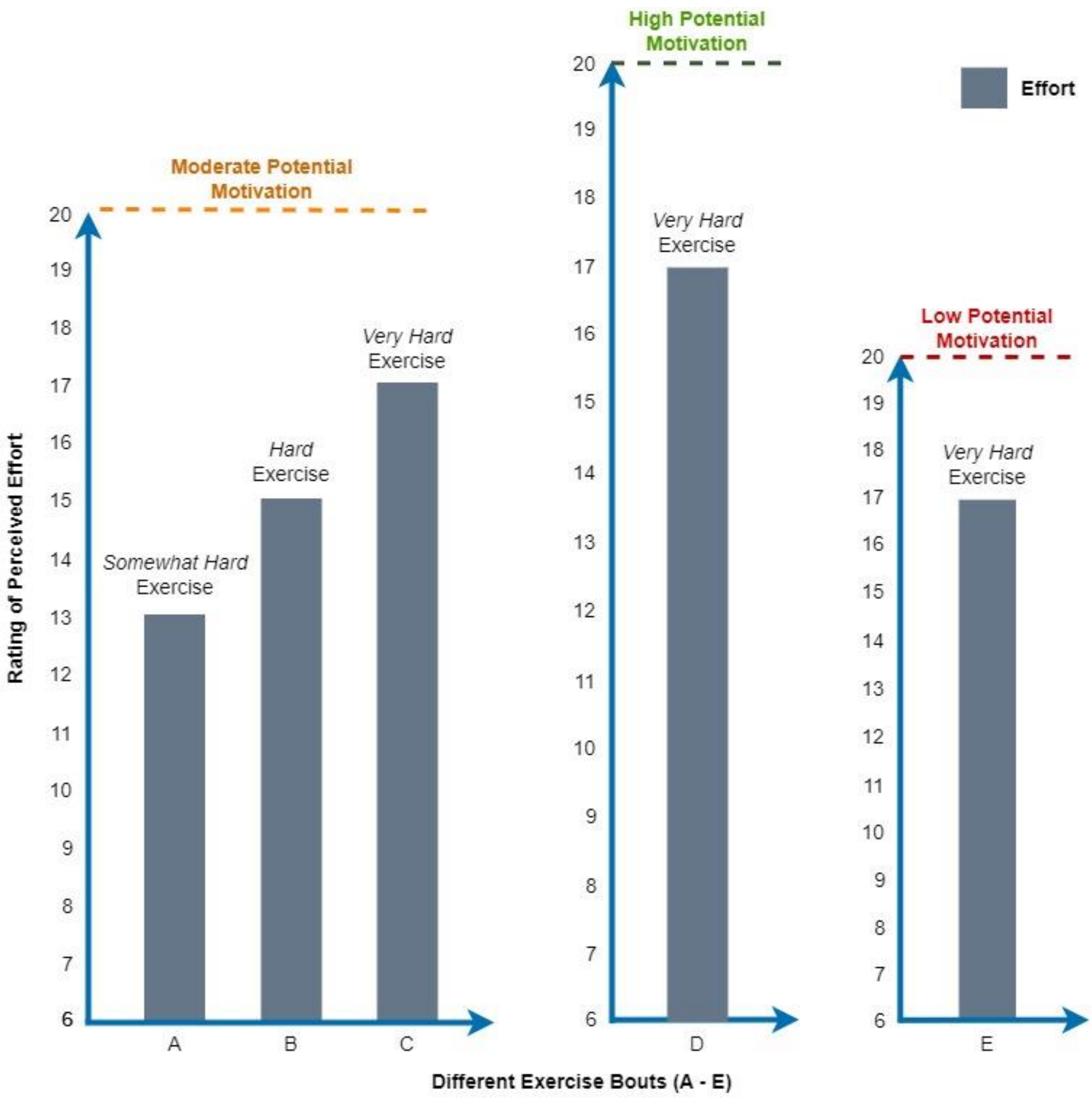


Figure 2. Hypothesised variations in actual effort (resources applied to the task) at set ratings of perceived effort (RPE) that have been linearly scaled on three 15-point Borg (1970) scales during instance of low (red dotted line), moderate (orange dotted line), and high (green dotted line) changes to potential motivation. Bar A represents an RPE *13 – somewhat hard* exercise, Bar B represents an RPE *15 – hard* exercise, Bars C – E represent RPE *17 - very hard* exercises but with different actual efforts according to potential motivation.

2.4. A PSYCHOPHYSIOLOGICAL APPROACH TO MEASURING INDICES OF SET PERCEIVED EFFORT INTENSITIES

Conceptually, perceived effort is a close reflection of the resources that are applied towards a task in aim of the achieving a goal (Preston & Wegner, 2009; Steele, 2019). Consequently, perceived effort factors largely into the decision-making processes associated with engaging in (Inzlicht & Marcora, 2016), continuing, and terminating (Marcora, 2008;

Marcora & Staiano, 2010) exercise activity. Therefore, the following thesis will explore the role perceived effort plays on the decisions involved with endurance-based exercise behaviour. However, in the same instance, individuals also actively decide how to apply their effort during an event. Therefore, how perceived effort itself is self-regulated and the decision-making processes that underpin this regulation are of interest. Subsequently, it is important to allude to the rationale and importance of the psychophysiological approach that this thesis adopts in its investigation of perceived effort.

Andreassi (2013) defines psychophysiology as the measurement of physiological responses as they relate to behaviour. In which, *behaviour* pertains to a broad spectrum of activities which involve conscious decisions to engage with a task such as exercise including the perceptions involved with those undertakings (Andreassi, 2013). In addition, Cacioppo et al. (2012) indicate that the combined investigation of physiological and perceptual phenomena in the wider context promotes a better understanding of the relation between mental and bodily processes. Therefore, the benefit of a psychophysiological approach in comparison to prior scientific endeavours concerning perceived effort and its self-regulation (e.g., Marcora, 2010b, 2019; McCormick et al., 2019; Pageaux, 2014, 2016) is that it stays true to the definition of perceived effort as a centrally, brain-derived phenomena. Namely, perceived effort likely originates from the central motor command projections sent towards working muscles (de Morree et al., 2012; Marcora, 2019; Pageaux, 2016). Nevertheless, peripheral factors can influence the projections of central motor commands. Thus, although the brain is the central organ which determines behaviour through decision-making, it can be influenced by physiological state in the periphery as well as the other perceptions (e.g., force, pain, fatigue, affect) which have been outlined (Andreassi, 2013).

However, it is incredibly important to note that although there is a close interrelation between psychophysiological state(s) and certain behaviours during exercise like pace or intensity (Amann et al., 2020; Burnley & Jones, 2007; Ekkekakis et al., 2011) it is of paramount importance to iterate that psychophysiological state(s) can *influence* the perception of effort and are therefore *associated* with exercise behaviour. They are not the *determinants* of perceived effort and the subsequent self-regulation of behaviour (Andreassi, 2013).

Therefore, this thesis will take a psychophysiological approach by investigating the associated physiological and perceptual responses during a novel fixed perceived effort exercise task across three experimental studies. In succession, the thesis will explore the self-regulation of perceived effort via behavioural and cognitive strategies according to fixed perceived effort exercise intensity (Study 1 and Study 2 [Part A]). Moreover, the differences in self-regulation will be explored between the experience levels of cyclists (Study 2 [Part B]) and after an intervention to increase nociceptive stimulation which aimed to elicit changes in other psychophysiological states such as perceived pain (Study 3).

Chapter 3 - LITERATURE REVIEW

Consistent with the psychophysiological approach above, this literature review will aim to progress through the current literature surrounding the origin of perceived effort, models that explain perceived effort as a determinant – or correlate - of behaviour, and subsequently how perceived effort is self-regulated according to a social-cognitive perspective of self-regulation. Particularly, this review will introduce several models and theories in which perceived effort may feature. After the explanation of these theories, the thesis will aim to provide data in a series of studies which reconciles models of exercise intensity regulation (e.g., psychobiological model) (Brehm & Self, 1989; Marcora, 2008, 2019) and theories that describe the decision-making processes of self-regulation (e.g., cybernetics control theory) (Carver & Scheier, 1982) which explain how perceived effort is regulated and effects subsequent psychophysiological state and task behaviour. For disclosure, whilst numerous models and theories are brought together in this body of writing, they are not all-encompassing and other theories which expand on the perception of effort, associated psychophysiological indices, and self-regulation may have been omitted. Nevertheless, those that are related are consistent with the theoretical basis and psychophysiological approach that has been outlined and championed in section 2.4.

3.1. ORIGINS OF PERCEIVED EFFORT

It seems logical to first distinguish the underlying neurophysiology of the perception of effort before probing into what *influence* additional stimuli will have on it. In doing so, one can be aware of the contributing factors on perceived effort and conscious of how it is self-regulated to impact endurance-based exercise outcomes. However, it is also worth acknowledging that it depends on the model that one identifies with when arguing what *underlies* the perception of effort (i.e., how it is generated as a perception) and therefore what *influences* the perception of effort due to changes on these underlying factors. A larger narrative on these models will provide a more clarity on this topic.

At present, there are three main models (Figure 3) that aim to explain the *generation* of perceived effort. All the models concur that neuronal processing of sensory signals are the foundation to perceived effort (Pageaux, 2016) and that this processing occurs in brain centres upstream of motor cortex such as the pre-supplementary motor area, supplementary motor area, anterior and middle cingulate cortices, and anterior insula (Amann et al., 2022; de Morree et al., 2012, Williamson et al., 2001, 2002; Zénon et al., 2015). Furthermore, models are unanimous in agreement that this neuronal processing can be affected by both physiological and psychological systems (Hettinga et al., 2017) as well as psychosocial factors (Behrens et al., 2023; McCormick et al., 2019; St Clair Gibson et al., 2017). However, models are conflicted on *which* sensory signals undergo neuronal processing and are therefore central to the generation of effort (Pageaux, 2016).

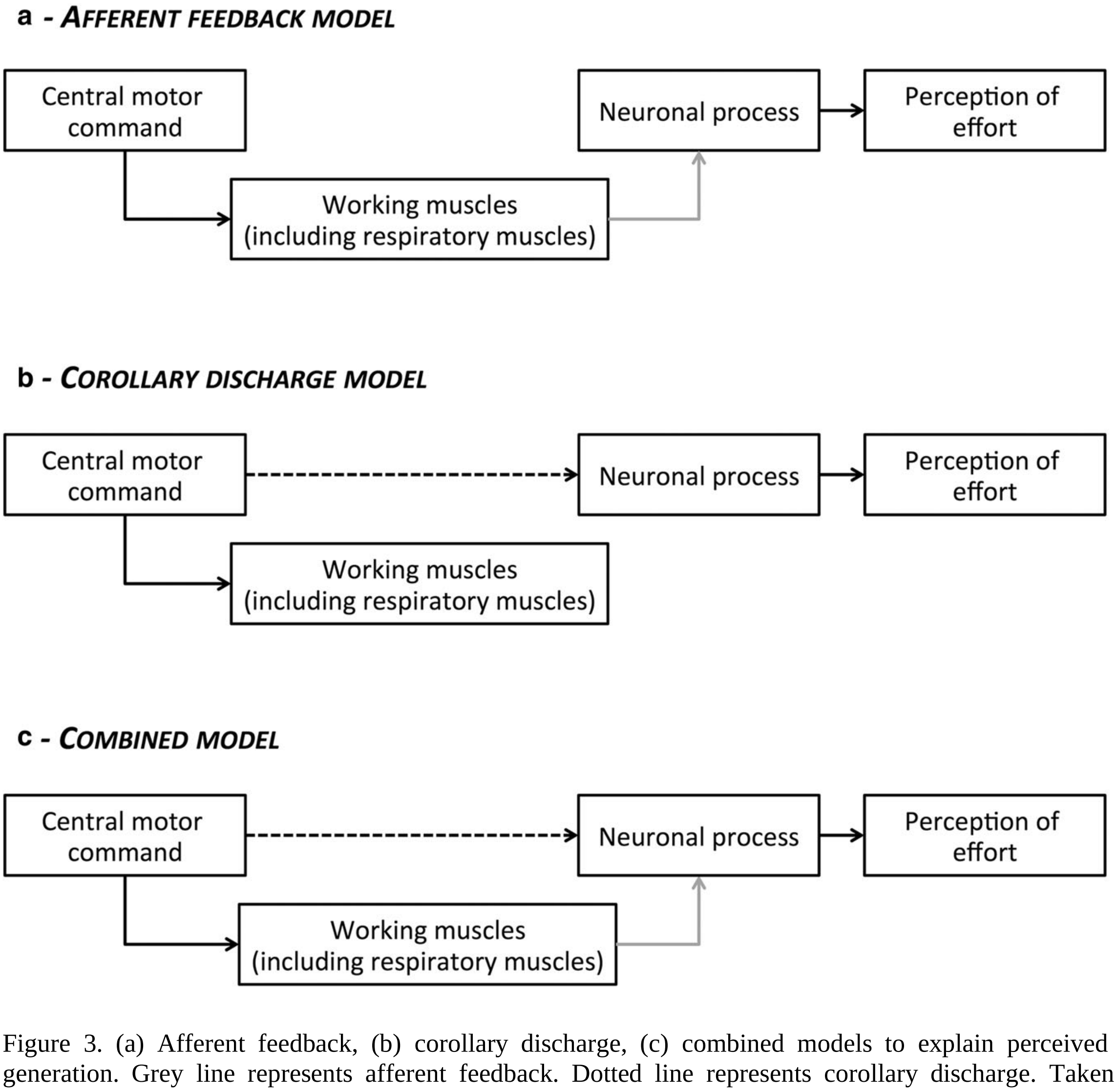


Figure 3. (a) Afferent feedback, (b) corollary discharge, (c) combined models to explain perceived effort generation. Grey line represents afferent feedback. Dotted line represents corollary discharge. Taken from Pageaux (2016)

3.1.1. AFFERENT FEEDBACK MODEL

Firstly, the classic model of effort generation is founded on the neuronal processing of afferent feedback which originates from the working muscles (Gandevia, et al., 1996; Noble & Robertson, 1996). Primarily, the afferent feedback model posits that stimuli which arise due to engagement in a physical (or mental) task, activates molecular receptors located on thinly myelinated (group III mainly mechanosensitive) and unmyelinated (group IV mainly metabosensitive) afferent nerve fibres (Amann et al., 2020, 2022; Taylor et al., 2016). Afferents that are activated by chemical, mechanical, and thermal sensory stimuli subsequently project sensory signals through the central nervous system at various spinal and supraspinal sites including the sensory cortex (Amann et al., 2020).

Therefore, group III and IV afferents relay signals detecting perturbations in current physiological state from resting homeostatic levels back into cerebral centres in the somatosensory areas (Amann et al., 2009, 2010; Amann & Secher, 2010; St Clair Gibson et al., 2018). A greater deviation from resting homeostatic state causes more intense and regular firing of afferents to be relayed back to the central nervous system (St Clair Gibson et al., 2018; Venhorst et al., 2018b). Therefore, a greater neuronal processing of these signals causes an increased perception of effort and its rating (Amann et al., 2010; Hureau, Romer, et al., 2018). As a result, during exercise tasks, the central nervous system can automatically initiate cardiorespiratory responses/reflexes to regulate exercise intensity based on the intensity of sensory signals that are received (Amann & Dempsey, 2008; Amann et al., 2009, 2010, 2015; Dempsey, 2012; Taylor, 2010) in aim of maintaining performance (Amann et al., 2009; Amann & Secher, 2010). Hence, proponents of this model highlight perceived effort as a secondary consequence of exercise (Amann & Secher, 2010) after the autonomic and subconscious regulation of underlying psychophysiological states (Amann, 2011; Taylor et al., 2016).

In relation to exclusively mental tasks, certain models contend that cerebral resources such as cerebral oxygenation and glucose must be delivered to the relevant brain centres depending on the task (Baumeister et al., 1998; Gaillot & Baumeister, 2007). Use of these resources precipitates changes in partial pressures of carbon dioxide and oxygen that are detected by afferent fibres (Amann et al., 2006; Secher et al., 1985). Subsequently, afferents signal these changes towards the same sensory regions of the brain where the perception of effort is generated (Amann & Secher, 2010). As a result, this model provides a plausible explanation as to how a solely mental task elicits perceived effort. Although, it must be acknowledged that this remains unexplored within the exercise science domain. To add to this speculation, studies in the field of psychology and neuroscience indicate that changes in cognitive performance with the absence of physical exertion could be explained by alterations in motivational fatigue (Müller & Apps, 2019) and priority shifting (Inzlicht & Schmeichel, 2016; Inzlicht et al., 2014; Vogel et al., 2020).

Advocates of the afferent feedback model have largely based their arguments on correlative data between metabolic by-products like hydrogen and potassium ions, substance P, serotonin, adenosine, and perceived effort ratings (Noble & Robertson, 1996; Taylor et al., 2016). Moreover, numerous studies have related that RPE differs in conditions where afferent feedback is available or blocked through epidural anaesthesia (Amann et al., 2009, 2011; Amann & Secher, 2010; Blain et al., 2016; Broxterman et al., 2018; Gagnon et al., 2012). In a renowned, yet contentious series of studies, Amann et al. (2009, 2010) injected a spinal infusion of intrathecal fentanyl or lidocaine versus a sham saline or a control (no injection) into participants prior to the onset of an exercise task. Within these studies, researchers observed that performance of five-kilometre cycling time-trials was worse after receiving epidural anaesthesia versus a control and sham (Amann et al., 2009, 2010). Authors ascribed this finding to the combination of an iatrogenic reduction in locomotor muscle strength and the blocking of somatosensory feedback from the working leg muscles being able to inform the body of appropriate cardiorespiratory responses for the exercise (Amann & Secher, 2010; Amann et al., 2009, 2010; Marcora, 2010a). Further studies supported this notion applied to single limb (Broxterman et al., 2018) as well as whole-body exercises (Blain et al., 2016).

However, Marcora (2010a) first argued that whilst the afferent feedback model provides an attractive explanation of subconscious autonomic responses to exercise, it fails to account for the conscious self-regulation of resources (i.e., effort) applied towards a task like a time-trial. Marcora (2010a) validated this counterargument with findings by numerous studies which have highlighted that in the presence of an epidural anaesthetic, perceived effort/exertion has remained unchanged (Fernandes et al., 1990; Friedman et al., 1993; Innes et al., 1992; Kjær et al., 1999). Furthermore, Bergevin et al. (2023) recently exposed that the initial correlational findings between afferent signals and perceived effort are marred by the lack of measurement validity in measuring perceived effort (Bergevin et al., 2023; Halperin & Emanuel, 2020). To illustrate, the studies which utilised afferent nerve blockades (e.g., Amann et al., 2009, 2010; Gagnon et al., 2012) conflated their measurement of perceived effort with other dissociable phenomena such as "*leg fatigue*", "*limb discomfort*", and "*pain perception*". Furthermore, when identifying with studies that have appropriately used perceived effort scales, the link between afferent feedback and perceived effort is *not* clear (Bergevin et al., 2023). Specifically, certain studies have highlighted that a pharmacological blockade during static contractions (Smith et al., 2003) and dynamic exercise (Barbosa et al., 2016) did not alter perceived effort.

There are also concerns with the semantics of certain studies. For instance, Pollak et al. (2014), infused a metabolic milieu into hand muscles and observed increases in ratings of pain and fatigue from rest to validate that afferent fibres were innervated by the infusion of metabolites even in the absence of movement. However, ratings of effort on the category-ratio 10 scale were reported at *0 – no effort* during this investigation indicating that processing of sensory signals from afferents are not contributors to the perception of effort (Smirmaul, 2014; Pageaux, 2016). Whilst authors of this study argue that participants were not asked to contract their hand or enact any voluntary movement (Amann & Light, 2014), this argument appears self-defeating as it highlights that perceived effort is not predicated on afferent sensory signals alone as the model suggests (Pageaux, 2016; Smirmaul, 2014) but instead from other central factors like central drive (Marcora, 2010a). Thus, some would surmise that afferent feedback is not a consistent and valid psychobiological sensory signal for the generation of perceived effort (Marcora, 2010; Monjo et al., 2018; Pageaux, 2014; Proske & Allen, 2019). Instead, some others (e.g., Bergevin et al., 2023; de Morree et al., 2012; Pageaux et al., 2016; Smirmaul, 2012) ascribe to an alternative model that perceived effort is underpinned by the processing of corollaries associated with central drive, termed the corollary discharge model.

3.1.2. COROLLARY DISCHARGE MODEL

In light of some of the shortcomings of the afferent feedback model, alternatively, many researchers champion the corollary discharge model (de Morree et al., 2012, 2014; Marcora, 2008; Pageaux, 2016; Smirmaul, 2012; Staiano et al., 2018; Williamson, 2006; Williamson et al., 2001, 2002; Zénon et al., 2015) which points to the neuronal processing of corollary discharge as *the* contributor to the perception of effort, as first proposed by McCloskey et al. (1974). Further, this model argues that sensory afferent feedback is still relevant but as an *influencer* of the corollary discharge production and processing during an activity (Pageaux, 2016).

In more depth, according to the corollary discharge model, perceived effort is closely related to the central motor command changes that occur during any physical activity (de Morree et al., 2012; Proske & Allen, 2019). Specifically, central motor commands that originate within the premotor cortex, motor cortex, and presupplementary motor areas of the brain (de Morree et al., 2012) are relayed towards muscles to innervate them to contract (Gandevia, 2001). When these central commands are projected to the periphery, an efferent copy (corollary discharge) is processed within several cerebral centres such as the anterior cingulate cortex, dorsal anterior cingulate cortex, middle cingulate cortex, and regions of the insula (Behrens et al., 2023; Williamson, 2006; Williamson et al., 2002; Zénon et al., 2015). Hereat the perception of effort is generated.

Consequently, should an individual need to exert more force (e.g., cycle at a higher power output or run at a higher velocity), their perceived effort is likely to increase compared to instances of lower force production (Proske & Allen, 2019). Naturally, this is thought to occur because higher physical workload demands and increased central drive and therefore, a greater corollary discharge production to be processed. Alternatively, if an individual can relay less central motor commands for a given power output/velocity, this may manifest as a lower perceived effort and benefit exercise performance (Abbiss et al., 2015). Therefore, those that support the corollary discharge model indicate that perceived effort is central in origin as it is largely dictated by the central motor command that is required by the task (Pageaux, 2016). However, a crucial argument of proponents of this model is that whilst physiological signals (e.g., afferent feedback) are not directly involved with the generation of perceived effort, instead physiological and psychological factors are believed to *influence* the neuronal processing of effort-related signals and subsequent effort perceptions and its rating (Hettinga et al., 2017; McCormick et al., 2019; Pageaux, 2016).

For instance, several physiological sensations naturally arise during endurance-based activity such as fatigue and nociception/pain which stimulate changes to corticomotoneuronal pathways (Amann et al., 2022; Behrens et al., 2023; Enoka & Duchateau, 2016). In relation to fatigue, Amann et al. (2022) highlight that physical, endurance-based tasks precipitate naturally occurring decrements in muscle contractile function due to changes in calcium coupling and progressive damage to the muscular tissues; i.e., peripheral fatigue. On top of this, numerous studies have also highlighted that the relaying of central motor commands becomes harder during prolonged exercise engagement due to reduced corticospinal excitability (Aboodarda et al., 2020; Azevedo de Almeida et al., 2022; Chowdhury et al., 2022; Sanderson et al., 2021) and increased corticospinal inhibition (Azevedo de Almeida et al., 2022; Del Santo et al. 2007; Sanderson et al., 2021); i.e., central fatigue. Thus, should an individual wish to maintain a given force/velocity/power in the presence of fatigue – or sensory signals associated with fatigue - more central motor command is required to be sent to the muscle(s) (Amann et al., 2006), instigating a greater production of corollary discharge, and thus, perceived effort (de Morree et al., 2012; Pageaux, 2014b).

On a psychological front, numerous strategies can manipulate the neuronal processing of corollary discharge at somatosensory regions of the brain, and subsequently change perceived effort (Brick et al., 2014; Brick, Campbell, et al., 2016). For example, Terry et al. (2020) indicated that exteroceptive factors such as listening to music during prolonged exercise reduces perceived effort as the overbearing auditory signals from music occupied limited bandwidths within somatosensory regions that preclude - *as much* – corollary discharge being processed. Similarly, Brick et al. (2014) indicates that individuals with a dissociative and external focus causes effort-generating signals to remain unacknowledged and not undergo neuronal processing resulting in decreased perceived effort. Moreover, a study by Williamson et al. (2001) used hypnosis to illustrate that cycling in a perceived easier condition (e.g., downhill versus uphill) caused reductions in perceived effort that were directly linked to a detectable reduction in activity within the anterior regions of the insula via fMRI without changes in cardiorespiratory responses. Beyond these findings, other psychosocial influences such as monetary rewards (Pessiglione et al., 2007) and subliminally positive behaviours by individuals in close proximity to the exercise (Blanchfield et al., 2014b) have also showed ways of reducing perceived effort for a given task/exercise intensity. However, the exact ways in which these final two interventions impact perceived effort and its rating remains unexplored in exercise science.

However, one main discreditations to the corollary discharge model is that several studies have argued that the changes in central motor command are not always proportional to the changes in perceived effort (Amann et al., 2011, 2015, 2022; Proske & Allen, 2019; Taylor et al., 2016). Researcher's favouring the corollary discharge model have often rebuked these arguments by claiming that it is not the direct amount of corollary discharge that dictates the perception of effort, but it is the neuronal processing of that corollary discharge (de Morree et al., 2012; Pageaux, 2016). Therefore, whilst there are several studies which highlight the importance of corollary discharge production on subsequent perceptions of effort and its rating (e.g., de Morree et al., 2012, 2014), the potential that very small subliminal factors can influence the neuronal processing of this perceived effort (Blanchfield et al., 2014b) highlights the degree to which exteroceptive, psychosocial factors can impact perceived effort.

Beyond this argument however, antagonists of this model have also presented findings which suggest that perceived effort increases even without the presence of central motor command (Hureau, Weavil, et al., 2018; Laginestra, Amann, et al., 2022; Laginestra, Cavicchia, et al., 2022). To illustrate, Laginestra, Cavicchia, et al. (2022) informed participants of an upcoming knee extensor exercise, whereby in one condition participants were required to consciously contract their quadriceps muscles (with central motor command) and in another they were subject to an electrically evoked stimulation (no central motor command). Researchers identified that there was an increase in the perceived exertion ratings of participants in both conditions – albeit to a lesser degree in the electrically evoked condition – than compared to a control/rest. Therefore, researchers within this study maintain that perceived effort is not the sole product of central motor command changes but instead, that perceived effort is due to afferent feedback (Amann et al., 2022; Hureau, Romer, et al., 2018; Hureau, Weavil, et al., 2018; Laginestra, Amann et al., 2022; Laginestra, Cavicchia, et al., 2022).

Nevertheless, prior studies in neuroscience had already established that the presence of actual central motor command was not necessary for the activation of key brain regions involved with the processing of corollaries (Williamson et al., 2002), or to increase perceived effort (Jacquet et al., 2021; Marcora et al., 2009; Pageaux, Marcora, et al., 2015). For evidence, Jacquet et al. (2021) noted that electroencephalography traces of non-exercising participants still indexed an increased motor-related cortical potential (a proxy of corollary discharge) when performing imagined contractions. Therefore, in cases where participants are experiencing electrically evoked contractions (e.g., Hureau, Weavil, et al., 2018; Laginestra et al., 2022), participants are still consciously aware of their muscles contracting and are therefore expected to index similar increases in cortical potentials associated with exercise (Williamson et al., 2002). Thus, a perception of effort stemming from corollary discharge is expected.

Furthermore, those who endorse the afferent feedback models have perhaps defined and measured perceived effort inaccurately (Bergevin et al., 2023). In this instance, Laginestra, Cavicchia, et al. (2022) fail to define their measurement of perceived effort. In addition, another study by the same group (Laginestra, Amann, et al., 2022) also failed to define RPE and simply reference Borg (1998) in their use of the category-ratio 10 scale. If this group did indeed use

Borg's (1998) definition, Figure 1 demonstrates that Borg (1998) diverged from his initial conception of perceived effort inferring that RPE *is a tool to estimate effort and exertion, breathlessness, and fatigue*. Once more, a conflation of measurement of perceived effort would be expected as dissociable constructs like force and fatigue are included in the definition. As fatigue is heavily linked to the prolonged stimulation of muscle spindles and Golgi tendon organs (Monjo et al., 2018; Proske & Allen, 2019), it is expected that in the Laginestra, Amann, et al. (2022) study, ratings associated with force and fatigue would increase even if the muscle was not consciously innervated. Most notable is that ratings of electrically evoked contractions still elicited lower RPE responses versus actual contractions (Laginestra, Amann, et al., 2022; Laginestra, Cavicchia, et al., 2022), which further supports this counterpoint. As a result, disputations by the group of Laginestra and colleagues (Laginestra, Amann, et al., 2022; Laginestra, Cavicchia, et al., 2022) are likely confounded by a mismeasurement of perceived effort involving other phenomena like fatigue.

Accordingly, it appears that the corollary discharge model may better explain the perception of effort than the afferent feedback model. Yet, it is worth noting that numerous studies provide interesting data that potentially refute their model's claims to the true neurophysiological underpinning of the perception of effort. Consequently, some have proposed that a combined model may be the most pragmatic and accurate reflection of the underlying neurophysiology of effort perceptions (Amman et al., 2010; Bergstrom et al., 2015). Though there are some studies in recent years (e.g., Monjo et al., 2018; Proske & Allen, 2023) which have provided narratives and objective testing of the combined model, it still remains a relatively unexplored area (Pageaux, 2016).

3.1.3. COMBINED MODEL

Finally, a combined model of perceived effort generation also exists. In which, proponents rationalise that both corollary discharge (central) and afferent sensory signals (peripheral) are neuronally processed to contribute towards the perception of effort (Gandevia & McCloskey, 1976; Lafargue et al., 2003; Monjo et al., 2018; Proske & Allen, 2019). Monjo and Allen (2023) indicate that during bilateral arm-lifting tasks, individuals are required to *untangle* the central (central motor command) and peripheral (sensory afferents) sources of information simultaneously as previous studies showed differences in perceptions of effort experienced between limbs which had varying weights applied to them (Monjo et al., 2018). To add, the participants also provided an overall rating of effort which varied according to the force and heaviness on each arm (Monjo et al., 2018). As a result, these findings hint that during dynamic, multi-limb tasks, sensory signals from the periphery alone are insufficient at explaining accurate representations of perceived effort (Tsay et al., 2016). Therefore, some argue that whole-body tasks involve a mediation between corollaries and periphery signals (Faisal et al., 2008; Harris & Wolpert, 1998; Monjo et al., 2018; Proske & Allen, 2019; Tsay et al., 2016). Alternatively, during single limb activity, some data suggests that individuals prioritise the dominant signals from the muscle spindles at the periphery causing a more accurate sense of force (Monjo et al., 2018; Proske & Allen, 2019). Therefore, surmising that perceived effort is task dependent (McCloskey et al., 1974; Monjo et al., 2018; Proske & Allen, 2019).

However, though a combined model which conciliates the afferent feedback "*peripheralists*" and corollary discharge "*centralists*" seems attractive, there are lingering issues. First, to reiterate, numerous studies have observed that perceived effort is not reduced in the absence of some forms of afferent feedback during single limb, static (Smith et al., 2003), and whole-body, dynamic exercise (Barbosa et al., 2016; Kjær et al., 1999). As a result, arguing that perceived effort is reliant on afferent feedback in any capacity despite that being systematically falsified (Bergevin et al., 2023) is troublesome. Second, a prior explanation about the dissociation between effort and force perceptions has been provided (see section 2.1.1). Regularly, force and effort perceptions are mentioned as similar constructs in studies that are explaining/promoting the combined model. As noted previously, conflating perceptions of effort and force ratings is problematic as they are not the same construct although a close relationship does exist between the two (Pageaux, 2016). Thus, fully accepting the combined model is difficult at present. Nevertheless, as direct testing of the combined model has featured rarely in the exercise science literature, future research may wish to examine this model further before fully excluding it.

3.1.4. SUMMARY OF PERCEIVED EFFORT GENERATION

To summarise, perceived effort is the product of the neuronal processing of sensory signals (Pageaux, 2016). An afferent feedback model is centred on the sensory signals originating from the periphery (Amann et al., 2006, 2015; Amann & Secher, 2010). Meanwhile, a corollary discharge model reinforces that perceived effort is centrally derived and is the product of neuronal processing of corollaries from central motor command (de Morree et al., 2012; Pageaux, 2016; Williamson et al., 2002; Zénon et al., 2015). Beyond these two primary models, there is also a suggestion of a combined model which marries the two models, championing the idea that perceived effort is a product of neuronal processing of *both* the corollaries *and* sensory signals from the periphery (McCloskey et al., 1974; Proske & Allen, 2019). However, findings in support of the afferent feedback model – and in turn the combined model - involving epidural anaesthesia and other afferent nerve blockades have recently been discredited as numerous studies show afferent feedback to be misaligned with perceived effort changes (Barbosa et al., 2016; Bergevin et al., 2023; Kjær et al., 1999; Pageaux, 2016; Smith et al., 2003). In contrast, a convincing body of evidence that falsifies the corollary discharge model is lacking.

Therefore, understanding the generation of perceived effort in relation to the corollary discharge model appears to be more viable at present (Pageaux, 2016). Though one must be conscious that some models and researchers remain averse to the corollary discharge model (e.g., Amann et al., 2020; Monjo et al., 2018), the reason for this decision is based on three major factors. First, alternative models (e.g., afferent feedback) have compelling evidence presented against the model such as those that have found no differences in effort perceptions during instance of normal or blocked afferent feedback (Barbosa et al., 2016; Kjær et al., 1991; Smith et al., 2003), or that correlations between perceived effort and afferent feedback is blurred by a potential lack of measurement validity (Bergevin et al., 2023; Halperin et al., 2020). Second, although some studies provide interesting findings refuting the central principles of the corollary discharge model (e.g., Laginestra, Cavicchia, et al., 2022) this lack of measurement validity appears to undercut their arguments (Bergevin et al., 2023). Third, whilst a conciliatory, combined model is attractive (Amann et al., 2010; Bergstrom et al., 2015), it unfortunately lacks a thorough body of supporting evidence at present (Pageaux, 2016). Furthermore, as this combined model is predicated on both afferent feedback and corollary discharge models being valid (Proske & Allen, 2023), the existence of counterevidence against the afferent feedback model currently makes the validity of a combine model unlikely (Pageaux, 2016).

Therefore, if the remainder of this thesis is to identify with the corollary discharge model it is important to reiterate that the model does not entirely discredit afferent signals. In fact, afferent feedback is highlighted as a regular *influence* on the required central command and subsequent corollary discharge that is produced as part of an exercise. Thus, neurophysiological, psychological, and social factors can influence the neuronal processing of corollary discharge to manipulate the perceptions of effort (Noble & Robertson, 1996; Pageaux, 2016) with potential impacts on decision-making and subsequent behaviour during self-regulated exercise. Subsequently, it is important to review the existing models that explain exercise-related decision-making and behaviour that provide different explanation of how the perception of effort features in this process.

3.2. MODELS OF EXERCISE REGULATION AND PERCEIVED EFFORT

Exercise can be conducted in many forms. As such, there are numerous types of tasks that researchers have subjected participants to (McCormick et al., 2019). Common tasks include time-trials which require individuals to exercise at a maximal capacity but ensure that resources/effort can be regulated freely over the course of the exercise to reach terminal effort at the appropriate time (i.e., at the endpoint of an event) (Marcora, 2019). Consequently, researchers can identify with the pace of the individual as a proxy to their allocation of resources/effort towards the task (Foster et al., 2004). Simultaneously, perceived effort can also be measured to investigate what the trajectories (Abbiss & Laursen, 2008) or possible oscillations (St Clair Gibson et al., 2018) in the perception mean in relation to exercise-based decision-making and its regulation (Boya et al., 2017).

Another well-featured task in the literature is a time-to-exhaustion or time-to-task failure exercise. The nature of this task is to prescribe a set intensity (e.g., a percentage of a maximum capacity) and record the changes in perceived effort and time taken to reach a terminal effort. Using these methods, researchers can monitor the progressive changes in psychophysiological state or other related markers to delineate their relationship between perceived effort and exercise performance outcomes (McCormick et al., 2019).

However, a key characteristic of normal activities of daily living is that they are conducted at submaximal levels throughout (Eston et al., 2005; Marcora & Staiano, 2010; Mauger & Sculthorpe, 2012). Yet, the aforementioned modes of testing result in participants reaching maximal effort at exercise endpoint despite many everyday tasks not being conducted in this manner (Eston et al., 2005; Mauger & Sculthorpe, 2012). Furthermore, perceived effort changes will naturally occur throughout exercises – particularly during freely regulated time-trial events (Faulkner et al., 2008). Yet, a hallmark of exercise performance – even in a controlled laboratory setting – is that numerous unforeseen phenomena can arise which impacts either, central motor command or neural processing of corollary discharge, and therefore, perceived effort (Marcora, 2010a). Subsequently, these previously unforeseen factors can subsequently affect exercise behaviour (Marcora, 2008; Pageaux, 2016; Smirmaul, 2012) without being accounted for in the experimental methodology.

In response, to fully acknowledge the role of perceived effort during endurance-based exercise, researchers may implement a method that invites individuals to exercise at a constant perceived effort. Before delving into the nature of the fixed perceived effort task, it is important to clarify the semantics of the methodology that is used. A fixed *perceived effort* trial involves maintaining a constant RPE response throughout the given task. In relation to section 2.3 and Figure 2, there is a difference between the *perception* of effort and *actual* effort invested towards a task. As a result, the idea of a *fixed effort* task is completely different to a *fixed perceived effort* task as this would alternatively involve maintaining a constant output (e.g., a given power output) Therefore, it becomes clear how time-to-exhaustion trials at set intensities represent *fixed effort* trials as resource application remains constant throughout. Hereon, this thesis will ensure that it uses the phrase *fixed perceived effort* throughout.

Utilising fixed perceived effort exercise, researchers can examine the associated behavioural consequences such as power output or velocity (Cochrane et al., 2015a, b; O'Malley et al., 2023). In addition, researchers can track changes in the psychophysiological states associated with perceived effort which include heart rate, absolute ($\dot{V}O_2$) and relative oxygen consumption ($\dot{V}O_2.kg^{-1}$), minute ventilation ($\dot{V}_E$), breathing frequency, blood lactate, and electromyographic responses (Cochrane et al., 2015a, b; Cochrane-Snyman et al., 2016; Mauger et al., 2013; O'Malley et al., 2023). Equally, psychological characteristics such as affective valence and the perceived ability to execute the task (self-efficacy) can also be monitored alongside to understand the relationship between different cognitive and affective states involved with a set perceived effort (Halperin & Emanuel, 2020).

Although a fixed perceived effort task is not commonplace amongst the exercise science literature, some studies have adopted it to provide a useful perspective of the psychophysiological characteristics of perceived effort and other exercise-related phenomena (e.g., Astokorki & Mauger, 2017a, b; Eston & Williams, 1988; Eston et al., 2007; Faulkner et al., 2008; O'Grady et al., 2021; Parfitt, Alrumh, et al., 2012; Parfitt, Evans, et al., 2012). For instance, Astokorki & Mauger (2017a) utilised a fixed perceived effort task to identify that perceived pain accounted for 7.5% variability in cycling performance when at a constant perceived effort. Alternatively, an intervening measure can be incorporated as a controlled variable before or during the fixed perceived effort trial to assertively judge its impact on perceived effort and subsequent behaviour/exercise output. To illustrate, Swart et al. (2009) randomly provided participants with amphetamine or a placebo-control capsule prior to conducting a fixed perceived effort trial. Successively, this study observed that participants cycled for 32% longer before reaching 70% of their starting exercise intensity after receiving the amphetamine than a placebo-control. Interestingly at this 70% cut off point, participants across conditions demonstrated no difference in electromyographic activity (a marker of central motor command reaching the muscle). Thus, this method can help provide more confident conclusions concerning the changes to the central nervous system and the impact on perceived effort and endurance exercise performance. Whereas correlative analysis from time-trials and time-to-exhaustion tests may mean researchers can be less assured in their conclusions.

Regardless of the type of exercise task that is used, most studies that are referred to throughout this thesis are ultimately concerned with how exercise behaviour is regulated or affected by a given factor. In association with this overarching question, several models exist within the literature which provide their own explanation of how exercise behaviour and subsequent performance are regulated/determined. Of the existing models, each feature the perception of effort in some capacity. As will be evidenced, some implicate that the perception of effort plays a more central role (Marcora, 2008) whilst others indicate perceived effort occupies a more secondary role compared to other psychophysiological factors (Amann & Calbet, 2008). Consequently, this review aims to portray the main arguments of each of these models and the (ir)relevance of the perception of effort on exercise behaviour.

3.2.1. AFFERENT FEEDBACK MODEL

Initial investigations of the psychophysiological changes that occur during exercise identified a consistent pattern of cardiorespiratory (Hill, 1927; Amann, 2011; Amann & Calbet, 2008; Amann et al., 2011; Burnley & Jones, 2007, 2018; Gaesser & Poole, 1996) and later neuromuscular (Burnley et al., 2012; Taylor et al., 2016; Thomas et al., 2015) changes as exercise intensity increased or as time elapsed. Consequently, earlier conceptions about how exercise behaviour is regulated centred on an afferent feedback model (Figure 4 and 9a) whereby the sensory information from singular or collective anatomical systems that detected chemical, thermal, and proprioceptive changes across the exercising body. initiate an automatic, subconscious response to the relative cardiovascular, respiratory, neuromuscular systems (Amann & Secher, 2010). Therefore, this model maintains that bioenergetic, cardiorespiratory, neuromuscular changes are the primary responses that affect exercise behaviour whereas perceptions such as effort are a secondary consequence (Amann et al., 2022).

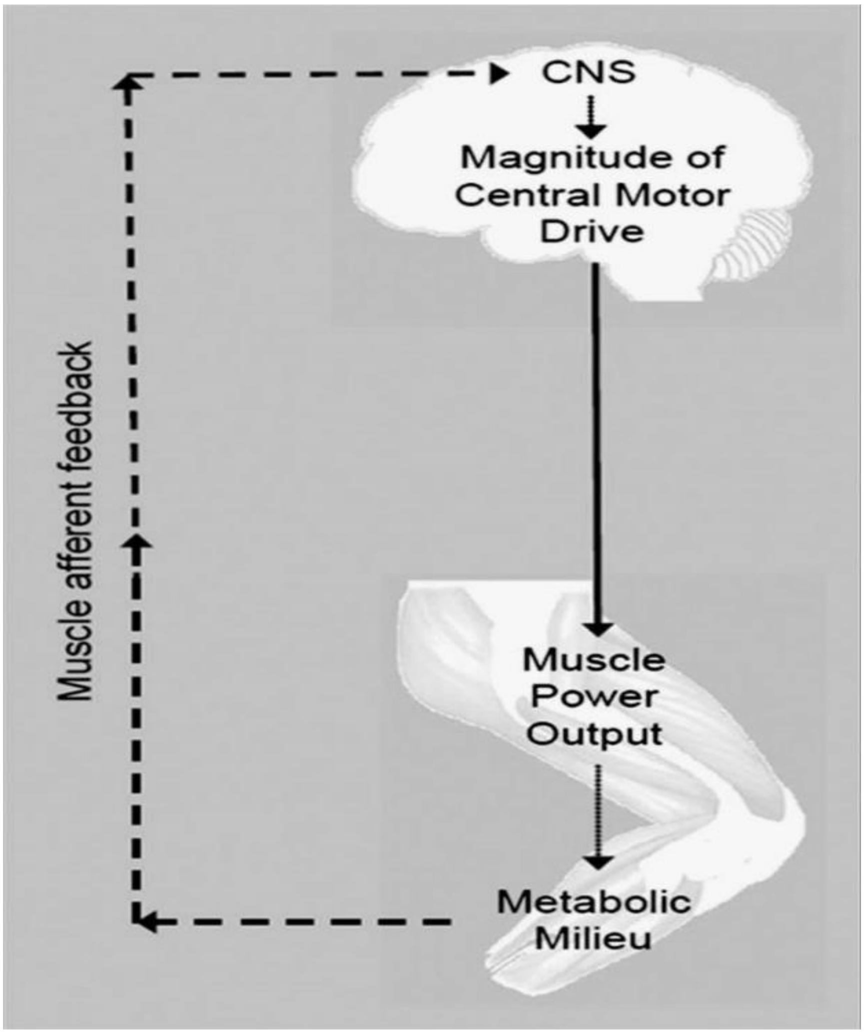


Figure 4. Schematic illustration of the inhibitory feedback model. The solid black line represents efferent nerve activity (central motor drive), the dashed line represents afferent nerve activity. Extracted from Amann and Dempsey (2016).

Many of the main findings around afferent feedback models originate in literature that has investigated the topic of "fatigue" (highlighted in section 3.1.2) which does have a close relation with the perception of effort (Behrens et al., 2023). To recap, fatigue relates to general concept that an individual is subject to a progressive decrease in the ability to produce an original output (Gandevia, 2001) known more specifically as performance fatigability (Enoka & Duchateau, 2016) and an associated sensation/perception of this phenomenon known as perceived fatigability (Enoka & Duchateau, 2016). Importantly, fatigue can be central or peripheral in origin (Enoka & Stuart, 1992) whereby an exercise output can be curtailed by the inability to maintain neural drive to cause muscles to contract at a set rate/force to maintain a given workload (central fatigue) or when skeletal muscle has impaired cross-bridge formation and cycling, action potential failure, and excitation-contraction coupling failure despite maintained or compensatory neural drive because of intramuscular metabolite accumulation (Amann et al., 2005, 2011; Taylor et al., 2000, 2016). Ultimately, as fatigue progresses, the individual must rely more on anaerobic energy sources which perpetuate intramuscular metabolic disturbances, thermal changes, and energy depletion at the respiring site (Noakes et al., 2005). In practice afferent feedback models argue that exercise *termination* is a representation of system(s) failure due to inadequate oxygen supply, energy depletion, thermoregulatory failure at the respiring sites causing "catastrophic" homeostatic failure (Amann, 2011; Amann & Calbet, 2006; Amann & Dempsey, 2008; Amann et al., 2015, 2022; Noakes, 2004, 2008; Noakes et al., 2005; St Clair Gibson & Noakes, 2004). For instance, the peripheral fatigue concept exhibits that even increased/compensatory neural drive cannot always be translated into functional work to maintain exercise outputs (Amann & Secher, 2010). At the working musculature, despite increased muscle activation an individual can reach a veridical point of maximal muscle recruitment (Gandevia, 1992; Taylor et al., 2016). Likewise, at central organs such as the heart, increased sympathetic nervous stimulation cannot cause an increased distribution of blood/oxygen to the working muscles to combat the metabolite accumulation when the heart is already at a maximal capacity (Amann et al., 2010). Therefore, afferent feedback models predict that exercise intensity and its maximum capacity (e.g., endpoint) is dependent on direct sensory inputs (e.g., chemical, thermal, proprioceptive) into the central nervous system (Amann & Secher, 2010). These inputs initiate automatic responses across numerous neuro-physiological systems which dictate exercise behaviour (Amann, 2011). In this manner, any perceptions like effort are a "sensory copy" (St Clair Gibson & Noakes, 2004) of the neuro-physiological changes that occur during exercise.

Therefore, perceived effort has a passive role compared to the innate, subconscious regulatory systems that are the main actors as part of the afferent feedback loops (Marcora, 2010a, 2019).

However, earlier researchers (e.g., Noakes, 2004; Noakes et al., 2005; St Clair Gibson & Noakes, 2004) indicated several concerns of the models. In which, some of those concerns have persisted in more recent literature (Bergevin et al., 2023; Marcora, 2019; Pageaux, 2016). Noakes et al. (2005) noted that catastrophe models involving afferent feedback were unable to explain freely regulated exercise paradigms. Namely, that individuals can appropriately decide how to invest their resources towards a task to complete it at their maximum (Preston & Wegner, 2009). In addition. the afferent feedback models have been labelled as "brainless" with potent psychological sensations/perceptions like effort seemingly holding no purpose (Marcora, 2010a; St Clair Gibson et al., 2003). Thus questioning, why do these perceptions exist if they are irrelevant to the integrity of the exerciser (Behrens et al., 2023) and the regulation of exercise (Marcora, 2008; Noakes, 2004).

3.2.2. CENTRAL GOVERNOR MODEL

In light of the prior concerns with afferent-centred models, Noakes and colleagues (Noakes, 2000, 2004, 2012; St Clair Gibson & Noakes, 2004; St Clair Gibson et al., 2003, 2006; Tucker & Noakes, 2009) ushered in a new wave of thinking as they were the first to comprehensively conceptualise that the brain is principle in the regulator of exercise behaviour (Figure 5). Deriving from a prior model of teleoanticipation (Ulmer, 1996), the central governor model posits that a combination of feedforward control such as the prior expectations of the task and various feedback information streams such as energetic needs, current psychological state, and physiological sensations ensure that the preplanned activity is completed without excessive (i.e., dangerous) cellular homeostatic disruption (Noakes et al., 2005). In short, depending on the various afferent signal inputs, a person "teleoanticipates" – that is compares their prior notion with current psychophysiological state – the way in which an exercise task can be performed to its maximum without threatening their whole-body homeostasis (St Clair Gibson & Noakes, 2004; St Clair Gibson et al., 2003, 2006). Specifically, a subconscious "governor" thought to be located in the brain (Noakes, 2004) is the integrative centre at which an individual tightly regulates muscle recruitment and work-rate (Noakes, 2012; Noakes et al., 2005) to balance between completing a task to its maximum whilst simultaneously maintaining a homeostatic reserve (St Clair Gibson & Noakes, 2004). Thus, resulting an oscillation of pace or application of resources to a task (Noakes, 2004; St Clair Gibson et al., 2006, 2018) preventing any catastrophic physiological failure (Noakes, 2012).

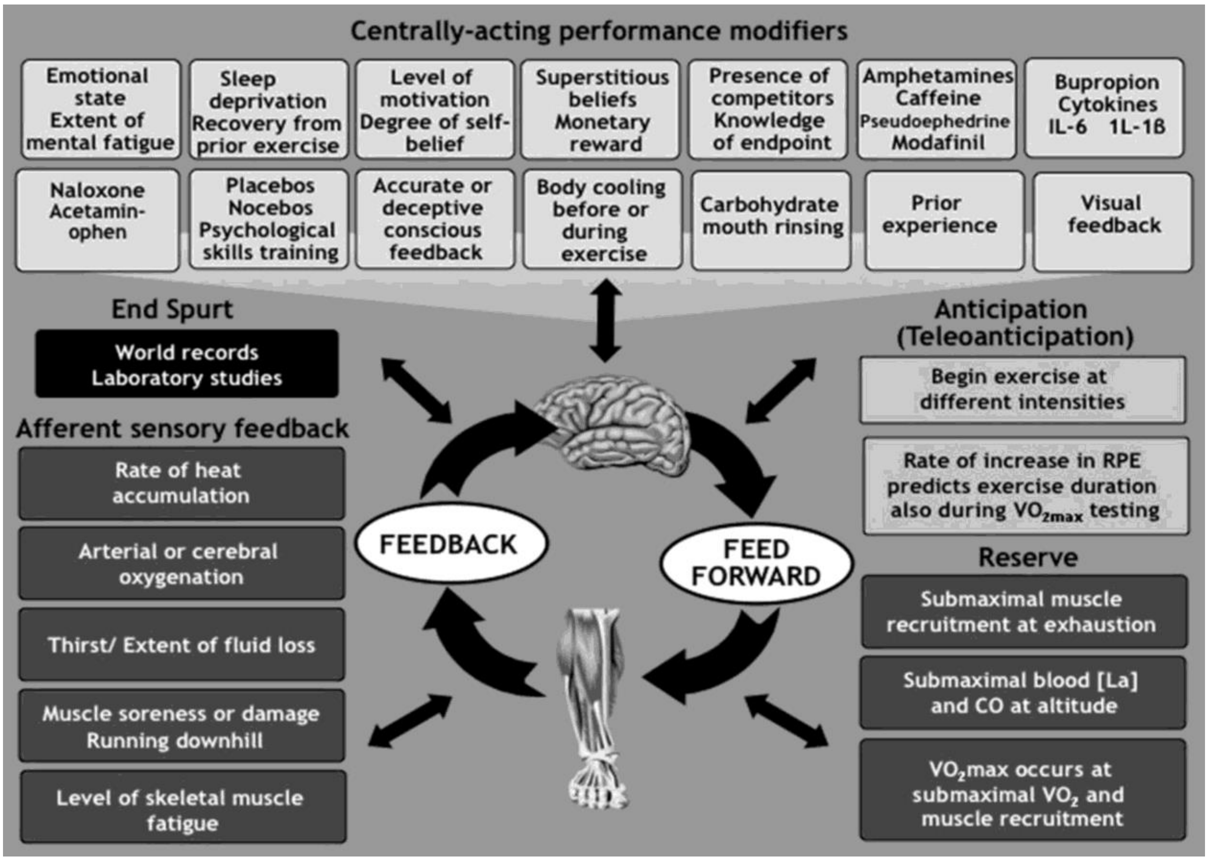


Figure 5. Schematic representation of the most recent iteration of the central governor model. Extracted from Noakes (2012).

As such, the initial iteration of the central governor model made certain assumptions about the exercise phenomenon and how the central governor operates to regulate exercise behaviour. First, the model predicts that all exercise activity is submaximal as exercise terminates when homeostasis is maintained (Noakes et al., 2005). To evidence several studies at the time indicating a physiological reserve at exhaustion (Crewe et al., 2008; St Clair Gibson et al., 2001) or even after a submaximal fixed perceived effort bout which was cut off when the participant dropped below 70% of their original exercise output (Swart et al., 2009).

Next, the central governor model argued that individuals naturally pace themselves by choosing to apply resources at a competitive, yet conservative rate to avoid catastrophic homeostatic failure (Noakes et al., 2005). St Clair Gibson et al. (2006) portrayed this process as an algorithm wherein the central governor has a preconceived of the exercise based on memory of previous experience, anticipation of expected changes to internal bodily state, and knowledge/prediction of the task demands and external conditions. For time-trial events, this seems rational as an individual calculates the optimal strategy for applying resources to reach the endpoint at the best time possible (St Clair Gibson et al., 2006). Successively, numerous studies also found that as an individual became more acquainted/expert at a task, the better they could perform the task without any significant changes in psychophysiological state throughout the exercise (Mauger et al., 2009b; Micklewright et al., 2010; Wittekind et al., 2009). Similarly, for submaximal tasks like fixed perceived effort tasks, this idea also holds true as an individual can anticipate how to apply their resources with the only difference to time-trial tasks being that instead of acceding to maximal performance, the individual is concerned with completing the task whilst always maintain a fixed perception (Swart et al., 2009).

Lastly – and most relevant to the present thesis – Noakes and colleagues were the first idealised that perceptions which reflected the psychophysiological state of the individual (e.g., effort, pain, fatigue) were not a residual effect of all-guiding physiological sensory signals but instead active components in the regulation of exercise behaviour (St Clair Gibson et al., 2006, 2018). In particular, a derivative of the central governor model termed the anticipatory-regulation model (Tucker, 2009; Tucker & Noakes, 2009) highlighted the vital role of RPE (Figure 6). Again, this off-shoot of the original model drew upon the existing literature to provide evidence for how the central governor explains both fixed workload and freely regulated exercise performance. For example, during fixed workload tasks, as exercise intensity progresses, RPE increases linearly (Noakes, 2004; Tucker & Noakes, 2009). Meanwhile, during freely regulated tasks like a fixed perceived effort trial, Tucker et al. (2006) observed that exercise in conditions with increased afferent feedback (e.g., hot versus temperate) resulted in an earlier and steeper decline in workload to maintain RPE but without any differences in core temperature and heart rate markers. Later studies by Swart et al. (2009) found when afferent feedback (e.g., pain) was altered by opioid administration this caused a later and slower decline in workload compared to control/placebo conditions. Once more, without any significant differences in physiological markers of load such as heart rate between conditions. To add, following research also indicated that exteroceptive influences such as an opponent (e.g., Williams et al., 2015a, b; Massey et al., 2020) or various information streams of task-related performance (e.g., Boya et al., 2017; Mauger et al., 2009a) also effected a similar change to fixed workload and freely regulated exercise performance. Moreover, the effects of the exteroceptive cues on performance could vary based on how practiced the athlete was and therefore how intuitive their teleoanticipatory system operated (Boya et al., 2017; Micklewright et al., 2010).

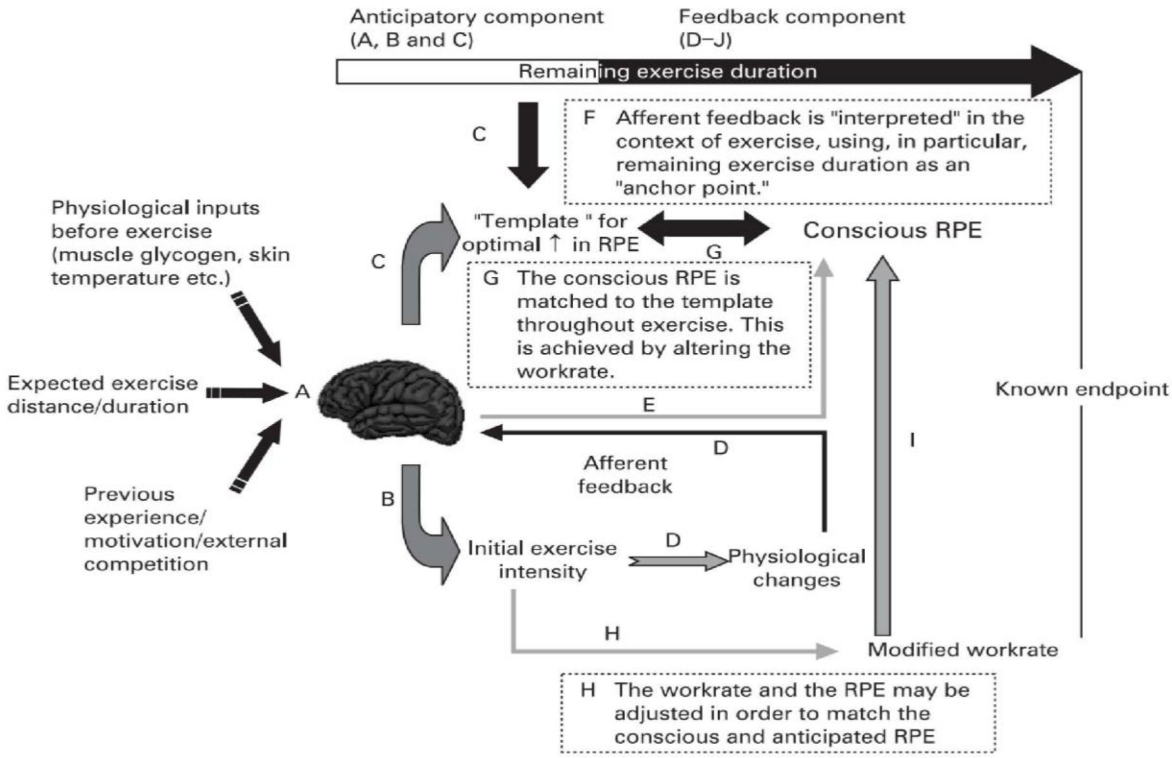


Figure 6. Schematic representation of the anticipatory-RPE feedback model of endurance performance during closed-loop exercise (e.g. time trial). Extracted from Tucker (2009).

Hence, the authors concluded that exercise duration is predetermined (teleoanticipated) before/at the start of the trial (Ulmer, 1996) to ensure RPE reaches a maximal value before any harmful perturbations from resting homeostatic state (Tucker, 2009; Tucker & Noakes, 2009; Tucker et al., 2006). During any task, RPE then acts as an integrator of afferent feedback (Tucker, 2009) and other exteroceptive cues (Noakes, 2012) to monitor psychophysiological state during a task and use this information to achieve exercise-based goals (Tucker & Noakes, 2009) without threatening whole-body homeostasis (St Clair Gibson & Noakes, 2004). Therefore, the purpose of a high perceived effort as one nears exercise endpoint/exhaustion is to deter the conscious brain from overriding the subconsciously calculated teleoanticipatory strategy, and thus endangering the individual from potentially catastrophic homeostatic failure (St Clair Gibson & Noakes, 2004; St Clair Gibson et al., 2003, 2018).

Overall, the central governor model (Noakes, 2004, 2012; St Clair Gibson et al., 2003, 2006) - and its derivatives such as the anticipatory-regulation (Tucker, 2009; Tucker & Noakes,

2009) and integrative governor models (St Clair Gibson et al., 2018) – were a significant shift in thought about how exercise behaviour is regulated. Compared to the long-standing afferent feedback models, the central governor provided compelling evidence that exercise regulation depended heavily on perceptions such as effort (Tucker & Noakes, 2009) to preplan and recalibrate exercise behaviour according to how afferent feedback and other task-related variables affected these perceptions (Tucker, 2009).

However, whilst the central governor posed a considerable body of supporting evidence, many studies/researchers were reticent to accept some of the central assumptions of the model (e.g., Marcora, 2008). Arguing that the data related by Noakes and colleagues (Noakes, 2000, 2004; Noakes et al., 2005; St Clair Gibson & Noakes, 2004; St Clair Gibson et al., 2003, 2006, 2018; Tucker, 2009; Tucker & Noakes, 2009) were not validation of a subconscious, central governor, but actually a falsification of it (Marcora, 2008; Marcora & Inzlicht, 2016). Further, Marcora (2008) commented that the central governor model was "internally inconsistent, unnecessarily complex, and biologically implausible".

The first of Marcora's (2008) objections considered that if the subconscious central governor did in fact operate direct control over maximal neural recruitment and deterred any conscious override that may endanger the individual, similar to the afferent feedback model, the perception is effort is ephemeral (Blanchfield et al., 2014b; Marcora, 2008, 2010a, 2019). Indeed, Marcora (2008) points out that Noakes' (2000) initial conception of the central governor model omitted the perception of effort and only later iterations (e.g., Noakes, 2004; St Clair Gibson & Noakes, 2004) included it.

Another point of contention espoused by Marcora (2008) was that although the central governor is posited as deeply ingrained system that has evolved to protect the individual from catastrophic consequences (Noakes, 2000, 2004), it seems inconsistent that mild incentives and other conscious psychological strategies can override such an important preserver of homeostatic control (Blanchfield et al., 2014a, b; McCormick et al., 2015, 2019). Relatedly, Noakes et al. (2005) had also previously stated that conscious override is undesirable because it would lead to maintained/increased exercise intensity and possible homeostatic threats. However, as a body of evidence has found that psychological strategies can improve exercise performance (Barwood et al., 2008, 2015; Blanchfield et al., 2014a, b). Or even that methods of imposing inhibitive, conscious, psychological states like mental fatigue, can also negatively impact exercise performance during time-trial (Pageaux et al., 2014), time-to-exhaustion

(Marcora et al., 2009), and fixed RPE (Brownsberger et al., 2013) tasks. Therefore, it seems implausible that the subconscious, central governor cannot be overridden by conscious as proposed by Noakes and colleagues (Noakes, 2004; Noakes et al., 2005; St Clair Gibson & Noakes, 2004; St Clair Gibson et al., 2003, 2006).

Accordingly, Noakes (2012) and St Clair Gibson et al. (2018) provided later updates and revisions to the original model (Noakes, 2004). The initial assumption of the listed above by Noakes and colleagues (Noakes, 2000, 2004; Noakes et al., 2005) provided a series of testable hypotheses to judge whether the model was true. However, later iterations (e.g., Noakes, 2012) of the model provided unfalsifiable statements such as "potentially everything… can potentially affect athletic performance". Popper (2005) denoted that to determine the quality of a scientific theory/model, the model must first be falsifiable in principle, then placed under scrutiny and tested whether it can be disconfirmed. Should the model remain inscrutable after testing and aims at falsification, the model can be deemed a quality one (Marcora & Inzlicht, 2016; Popper, 2005). Unfortunately, the updates provided by Noakes (2012) which indicated that everything could impact athletic behaviour and performance tells researchers relatively little about how the perception of effort features in the regulation of exercise, and above all, it violated basic scientific principles (Marcora & Inzlicht, 2016).

Thus, with lingering questions over both the afferent feedback and central governor models, researchers posited an alternative model of exercise regulation and behavioural control that abridged established psychological theory (e.g., motivational intensity theory, Brehm & Self, 1989; Wright, 1996) and exercise physiology. This model was termed the psychobiological model (Marcora, 2008, 2010a, 2019).

3.2.3. PSYCHOBIOLOGICAL MODEL

The psychobiological model which is an effort-based decision-making model (Marcora, 2008; Pageaux, 2014b, 2016). Whilst the content of this thesis does not necessarily relate to performance as the task involves a submaximal fixed perceived effort trial, the psychobiological model still pertains to the regulation of exercise intensity and decision-making during physical tasks. At the centre of the psychobiological model of endurance performance are two key cognitive/motivational factors, perception of effort and potential motivation (Brehm & Self, 1989; Marcora, 2008, 2010a, 2019; Wright, 1996). Though some other factors have been argued to play a role in the effort-based decision-making process, like knowledge of distance/time elapsed or remaining, as well as previous experience of effort, these factors are considered to directly impact the perception of effort or potential motivation of an individual (Pageaux, 2014b).

Perceived effort is the principal component of the psychobiological model (Marcora, 2008). Tantamount to the psychobiological model is that it maintains perceived effort as being a centrally derived phenomenon (Pageaux, 2016) whereby perceived effort has neurophysiological underpinnings which reflect the neuronal processing of corollary discharge signals within brain areas upstream of the motor cortex (de Morree et al., 2012; Williamson et al., 2001, 2002; Zénon et al., 2015). As central motor command relates to the resources applied towards a task and in turn corollary discharge is directly linked to the central motor command (as an efferent copy) that is relayed to the muscles, perceived effort is conceived as a direct, conscious representation of the resources that have been invested in aim of attaining a predesignated goal (Brehm & Self, 1989; Marcora, 2010b; Preston & Wegner, 2009). To reiterate, in an exercise context, Marcora (2010b) defined this as the *conscious sensation of how hard, heavy, and strenuous a physical task feels*.

However, perceived effort is liable to change as any factor that can alter projections of central motor command and therefore corollary discharge production or can influence the neuronal processing of corollary discharge can manipulate effort perceptions (Pageaux, 2016). Nevertheless, the central tenet of the psychobiological model is that if any additional factor is to effect change on exercise behaviour, this occurs *via* changes in perceived effort (Smirmaul, 2012). Irrespective of study design (e.g., time-trial or time-to-task exhaustion), practically all studies demonstrate that perceived effort reaches maximal levels at the point of exhaustion (Aboodarda et al., 2020; Amann & Dempsey, 2008; Amann et al., 2006, 2009; Azevedo de Almeida et al., 2022; de Morree et al., 2012, 2014; Marcora, 2009; Marcora et al., 2009; Noakes, 2004; Norbury et al., 2022a, b). Meanwhile, several studies have demonstrated that other exercise-related sensations/perceptions rarely reach maximal levels upon termination of an exercise such as pain and fatigue (Staiano et al., 2018). Therefore, cementing the notion that perceived effort is central to task performance (Smirmaul, 2012; Staiano et al., 2018).

In connection with the perception of effort, Brehm and Self's (1989) motivational intensity theory from which the psychobiological model is based off, declares that for effort to be mobilised, an individual must be motivated towards the task (Richter, 2013; Wright, 1996). Accordingly, the actual effort which is exerted by the individual represents the current *motivational intensity* of the individual (Richter et al., 2016) and is tailored according to the perceived task difficulty (Richter et al., 2008). Relatedly, individuals also formulate ideas of a maximal conceived intensity of effort they are willing to exert towards the current task; known as *potential motivation* (Pageaux, 2014b; Wright, 1996). As a result, potential motivation represents the uppermost boundary of what the individual deems to be possible for a given task (Marcora, 2010a; Smirmaul, 2012). Thus, if success is viewed as possible and worthwhile, a conscious decision to apply effort is expected (Marcora, 2008, 2010a; Pageaux, 2014b; Richter, 2013).

Motivational intensity is formulated according to numerous subfactors. First, is the *strength* of the individual's motives which is predicated on the individual's needs concerning that task (Clancy et al., 2016). For instance, an individual may consider their needs as more internally (e.g., self-gratification/achievement) or externally disposed (e.g., financial rewards) (Bueno et al., 2008). In combination, the second subfactor relates to the *potential outcomes* of goal attainment. Here, an individual becomes aware of the incentives, rewards, and caveats associated with a task (Chong et al., 2017). For instance, an endurance athlete at the Olympics is likely to understand the rewards of Olympic glory comes at the cost of expected pain and discomfort during the race. Then finally, the individual also acknowledges the *likelihood* of these outcomes as to whether the task goal is attainable or not (Manohar et al., 2015).

Numerous studies have revealed that upregulating an individual's motivation prior to (Chong et al., 2017; Hagger et al., 2006; Le Heron et al., 2018) and during (Apps et al., 2015; Barwood et al., 2008; Blanchfield et al., 2014a, b; Müller & Apps, 2019) tasks has a positive impact on overall task performance. Specifically, Chong et al. (2017) identified that providing a high reward situation even in spite of a high effort requirement naturally increased the motivational intensity of participants. Furthermore, an increased mobilisation of physical resources (Richter et al., 2008, 2016) and neural activity of the anterior cingulate cortex and anterior insula (Chong et al., 2017; Le Heron et al., 2018; Müller & Apps, 2019) is also evident when motivational beliefs are higher. Consequently, it is suggested that the combination of perceived effort and motivational intensity is the *determinant* of task performance (Marcora, 2008; Pageaux, 2014b; Wright, 1996).

Currently, most existing literature around the psychobiological model explains task performance in relation to maximal capacities/exhaustion such as time-trials or time-to-exhaustion tests (e.g., de Morree et al., 2012, 2014; Marcora & Staiano, 2010; Marcora et al., 2008; Pageaux, Angius, et al., 2015; Pageaux, Marcora, et al., 2015). As shown in Figure 7, different trajectories of *effort* responses according to a person's potential motivation are displayed to explain when the point of exhaustion is going to occur. Logically, effort (the investment of physical and mental resources) projects in a linear fashion as task demands increase (Marcora, 2008, 2019). However, *perceived effort* responses may not evidence as linear relationship towards task demands. To elaborate, deviations in perceived effort responses from the linear trajectory arise because individuals can manipulate the neuronal processing of corollaries that generate perceptions of effort (de Morree et al., 2012; Marcora, 2008, 2019; Pageaux, 2014b, 2016). Second, individuals can also alter their motivational beliefs (Wright, 1996) which can alter the given effort for a set perception of effort (Figure 2).

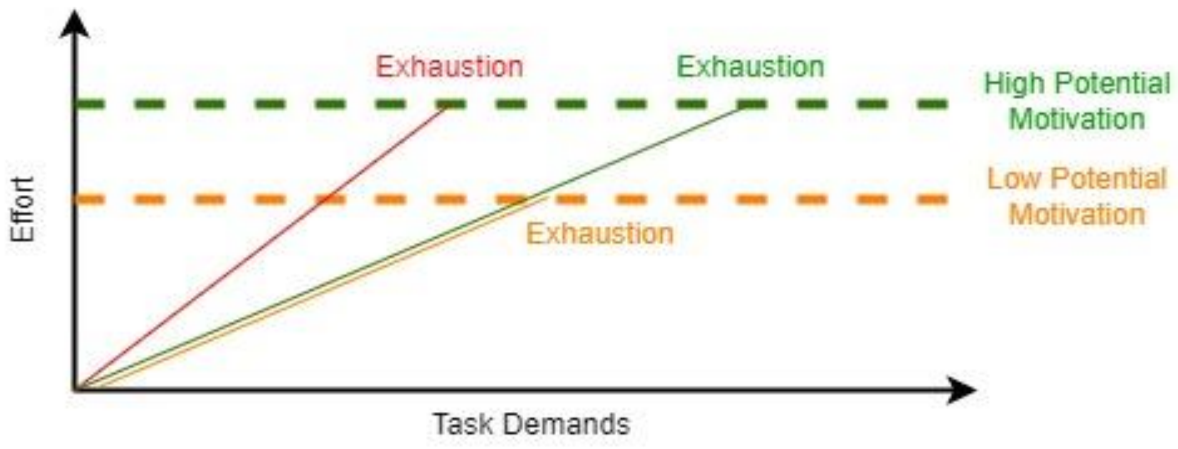


Figure 7. The psychobiological model approach to exhaustion during endurance-based exercise. Dotted lines represent potential motivation. Separate coloured lines represent trajectories of effort responses according to task demands and potential motivation. Figure is based off content from Marcora (2008) and illustrations by Pageaux (2014a).

In relation to the psychophysiology of perceived effort, a close relationship exists between the different linear trajectories of perceived effort and the exercise intensity domains that exercise operates within (Burnley & Jones, 2007; Iannetta et al., 2022). For instance, exercise within the moderate intensity domain which has the gaseous exchange threshold (GET) as its uppermost boundary will elicit a *steady state* in cardiorespiratory response like heart rate, $\dot{V}O_2$, $\dot{V}_E$, breathing frequency, and blood lactate (Brownstein et al., 2022; Burnley &

Jones, 2018; Iannetta et al., 2022). However, there is expected to be a natural occurrence of fatigue, nociception, and changes in other psychological states like pain, affective valence, or self-efficacy (Azevedo de Almeida et al., 2022; Behrens et al., 2023; Iannetta et al., 2022; O'Malley et al., 2023). If theoretically, potential motivation was to be at a high level and remain constant, the natural onset of fatigue and experience of nociception would inherently increase the required central motor command to maintain the task output, and subsequent increases corollary discharge (Aboodarda et al., 2020; Azevedo de Almeida et al., 2022; Brownstein et al., 2022; Iannetta et al., 2022). Furthermore, reductions in affective valence and self-efficacy would also likely impact the neuronal processing of the corollary discharge resulting in a net increase in perceived effort (Ekkekakis et al., 2011; Zenko et al., 2016). Thus, one would expect a progressive increase in perceived effort and RPE responses. Alongside which, exercise may then also progress into higher intensity domains until reaching a maximal capacity (Figure 7 – green line).

Alternatively, the heavy intensity domain represents an exercise intensity between the GET and respiratory compensation point (RCP) (Gaesser & Poole, 1996). Cycling exercise within the heavy intensity domain is expected to elicit a similar set of psychophysiological responses to the moderate domain (Burnley & Jones, 2018). For example, cardiorespiratory variables would be expected to exhibit an elevated *steady state* after 10 - 20 minutes (Burnley & Jones, 2018) as the $\dot{V}O_2$ slow component takes effect (Gaesser & Poole, 1996) thus increasing the oxygen cost of the exercise. However, other research has also shown that there may be a cardiovascular drift – particularly in inexperienced athletes – due to plateaus/reductions in stroke volume causing a compensatory increase in heart rate to maintain cardiac output (Coyle & González-Alonso, 2001). Again, if potential motivation were to theoretically remain constant and at a high level, there would be a similar onset of fatigue and nociception. However, the severity of this fatigue and nociceptive stimulation would likely be greater than when exercising in the moderate intensity domain (Azevedo de Almeida et al., 2022; Brownstein et al., 2022; Iannetta et al., 2022). As a result, a greater compensatory increase in central motor command and subsequent corollary discharge production would be anticipated to overcome the increased corticospinal inhibition (Aboodarda et al., 2020; Azevedo de Almeida et al., 2022; Norbury et al., 2022a, b) and decreased corticospinal excitability (Aboodarda et al., 2020; Brownstein et al., 2022; Norbury et al., 2022a, b) associated with fatigue and nociception during prolonged activity. Furthermore, the greater severity of fatigue and nociception would also be expected to elicit more intensely negative psychological responses such as pain (Mauger, 2013), reduced affective valence (Ekkekakis, 2003), and lower self-efficacy (McCormick et al., 2015). Therefore, exercise within the heavy intensity domain symbolises a situation where task demands are imposed on individuals at a faster rate, causing the responsive application of effort to also increase at faster rate (Figure 7 – red line).

However, there may be other instances where the task demands remain constant between two exercise bouts (e.g., two cycling trials starting within the moderate intensity domain) but the onset point of exhaustion is different. This could stem from differences in the potential motivation between the two task bouts (Figure 7 – orange line). In this example, as potential motivation is at a lower constant level in one situation, the point at which the individual deems the task to be futile and that they cannot exert the required effort to continue will occur earlier than when potential motivation is higher (Marcora, 2008; Inzlicht et al., 2018). However, it is important to note that certain psychophysiological responses (e.g., heart rate, $\dot{V}O_2$) would be expected to track in the same manner as instances with high potential motivation (Aboodarda et al., 2020; Burnley & Jones, 2018; Richter & Gendolla, 2009; Richter et al., 2008, 2016).

To evidence, numerous studies have observed that a prior mental fatigue task reduces time-to-exhaustion in a subsequent exercise performance (Boat & Taylor, 2017; Marcora et al., 2009; Pageaux, Marcora, et al., 2015; Pageaux et al., 2013). During which, although the onset of exhaustion occurred at significantly different time points, the differences in neurophysiological state and function at exhaustion have been negligible (Marcora et al., 2009; Pageaux, Marcora, et al., 2015; Pageaux et al., 2013). Initially, it was viewed that a prior mental task imposed added mental demands before the exercise so that perceptions of effort at the onset of the exercise were higher than when no mentally fatiguing task was completed (Boat & Taylor, 2017; Marcora & Staiano, 2010; Marcora et al., 2009). However, more recent studies in psychology indicate that a prior mental task invokes a motivational fatiguing effect (Müller & Apps, 2019), thus lowering potential motivation for a subsequent task and inclining individuals to discontinue the task earlier due a lower perceived value of exerting more effort (Inzlicht & Marcora, 2016; Inzlicht et al., 2018). As a result, this explanation neatly describes the last instance within Figure 7 (orange line).

Much of the same principles of the psychobiological model that have been discussed for maximal exercise capacity are also thought to apply toward submaximal exercise tasks

(Marcora, 2008; Pageaux, 2014; Smirmaul, 2012). However, less regard has been made to apply the psychobiological model to exercise that is entirely submaximal with no point of exhaustion. A hallmark difference between maximal testing protocols like time-to-exhaustion tasks and submaximal testing methods is that the imposed task demands can vary (McCormick et al., 2019). As such, the application of effort on both a conscious and subconscious level oscillates according to the perceived task difficulty (Apps et al., 2015; Chong et al., 2017, 2018; Faulkner et al., 2008; Frömer et al., 2021; Manohar et al., 2015; Richter et al., 2008, 2016).

The subjective valuations that underpin the motivational beliefs strongly dictate what responses the individual displays on a conscious (Apps et al., 2015; Chong et al., 2017, 2018; Frömer et al., 2015; Manohar et al., 2015) and subconscious (Richter & Gendolla, 2009; Richter et al., 2008, 2016) level. Consciously, should an individual deem their current effort to be equal to or superior to the task demands and motivational intensity, then the task will be continued at least at its current intensity (Figure 8). Alternatively, when task demands exceed their current effort or the "*amount*" of effort they are willing to invest, this will immediately override the individuals' other behaviours (Pageaux, 2014). Resultantly, as the individual views the task as futile, they will either reduce their exercise/task intensity or totally retract from the task (Inzlicht & Marcora, 2016; Manohar et al., 2015; Marcora, 2008; Müller & Apps, 2019; Westbrook & Beaver, 2015). Subconsciously, Richter et al. (2008) demonstrated that cardiac function indexed a corresponding change according to task difficulty until the task was deemed impossible. Interestingly, if the task was considered impossible, autonomic function adapted accordingly wherein cardiovascular responses exhibited a lower reactivity than if the task was deemed easy (Richter & Gendolla, 2009; Richter et al., 2008). Apps and colleagues also found a similar trend between motivation and the activation of cerebral regions associated with executive function and decision-making (Apps et al., 2015; Le Heron et al., 2018; Manohar et al., 2015).

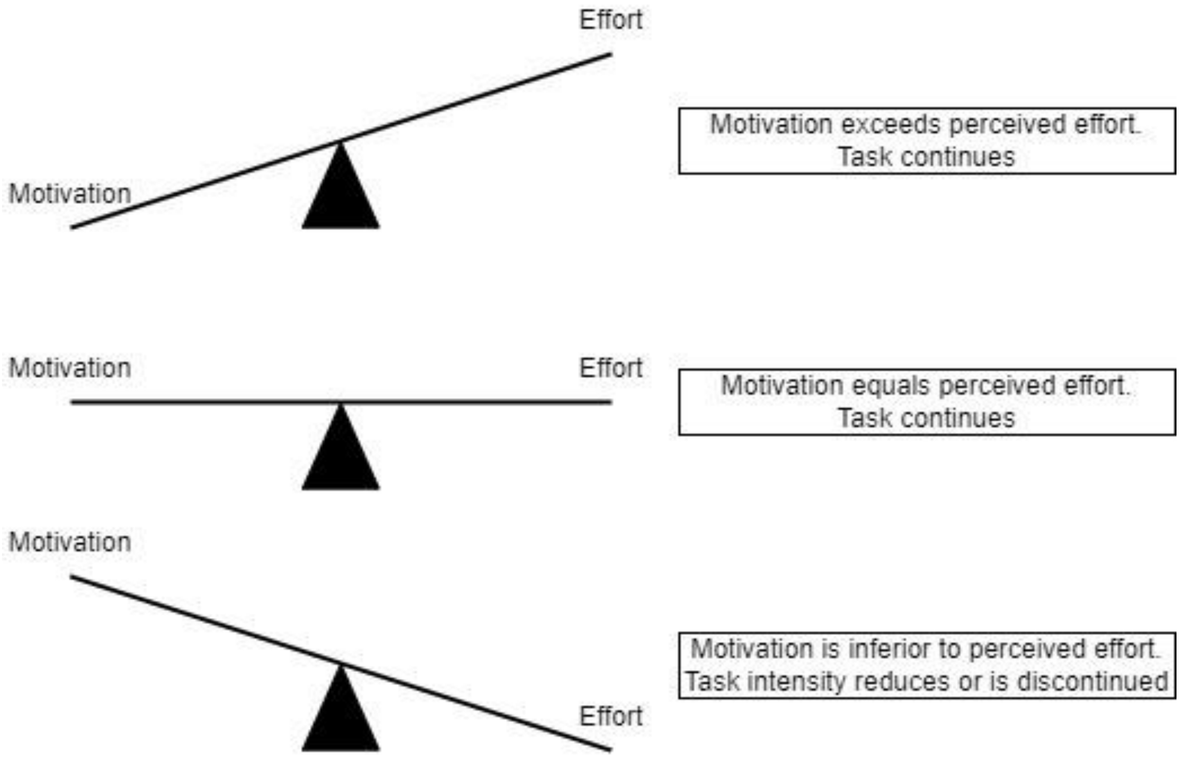


Figure 8. “Balancing act” of subjective valuations to represent the psychobiological model’s effort-based decision-making in action during submaximal exercise.

However, as has been related in section 2.3, linking the trend in perceived effort responses compared to effort responses between maximal exercise testing like time-to-exhaustion trials and submaximal exercise whereby the task demands vary is not entirely accurate. Namely, one issue is that potential motivation is *changeable* (Brehm & Self, 1989; Richter et al., 2016; Wright, 1996). As a result, the linear trajectory of perceived effort and its rating towards potential motivation becomes skewed if potential motivation changes during an event (Figure 2).

To illustrate, an individual may enter an event with a moderate potential motivation where after prolonged engagement in the event, the individual reaches an intensity of RPE *17 – very hard* (Figure 2, Bar C). However, at this point, an added variant could instantly change their potential motivation (Wright, 1996). For example, a sudden onset of unexpected pain/injury could result in an immediately higher perceived effort response despite the same resources (effort) being applied to the task (Figure 2, Bar E). Therefore, a reduction in intensity or discontinuation of the exercise could occur as the potential motivation is likely to decrease and perceived willingness to apply effort to continue does not match the required demands (Müller & Apps, 2019). Alternatively, an introduction of a previously unknown reward like money or engagement in motivational self-talk could enhance potential motivation to a higher level (Figure 2, Bar D) (Apps et al., 2015; Barwood et al., 2008, 2015; Manohar et al., 2015; Pessiglione et al., 2007). Consequently, the individual could then apply more effort resources towards the task for the same RPE response than when their potential motivation was lower. Although the exact nature of this response is not fully tested within exercise science, there are numerous studies (e.g., Barwood et al., 2008, 2015; Blanchfield et al., 2014a) which support its premise as they have shown a higher task output for a given RPE.

First, Blanchfield et al. (2014a) conducted a study whereby participants completed a fixed power output task to exhaustion whilst either engaging in motivational self-talk or no self-talk. It was discerned that participants were able forestall their point of exhaustion when using motivational self-talk than without self-talk without any differences in RPE throughout. Thereby suggesting that for a given intensity of task demand (i.e., the set power output), participants were able to apply more effort when using self-talk than without self-talk due to motivational self-talk (Blanchfield et al., 2014a). Further, Barwood et al. (2015) established that during time-trial events, individuals who engaged in motivational self-talk compared to neutral self-talk were able to exert more power output during a time-trial for a given RPE response. Thus, solidifying the findings from Blanchfield et al. (2014a) and transferring the same premise to a freely regulated task where task demands could change. Therefore, in short, it is conceivable that motivational self-talk enhanced potential motivation to cause RPE responses to be lower for a set intensity of actual effort.

Another study to articulate this point is Malleron et al. (2023). Granted this study intended to espouse the importance of researcher’s instructions that are given to participants to obtain valid RPE responses. However, it also provided some added context for this argument. Revisiting the Malleron et al. (2023) article, when conducting a series of back squat repetitions, the cohort rated their perceived effort on average as near maximal (~9.7 out of 10) when instructions included an *imposed* anchor (e.g., opening a jar of honey). On the other hand, RPE responses when instructions included a *self-imposed* anchor (e.g., a previous experience of the most effortful exercise ever done by that individual) were submaximal with a mean around 6.9 on the category-ratio 10 scale (Malleron et al., 2023). Conclusively, this study exemplifies how a RPE response denotes a numerical representation of a person’s perceived effort (Borg, 1962; Halperin & Emanuel, 2020), yet this numerical representation seems to be modelled according to an individual’s perceived maximum (Malleron et al., 2023). Thus, should either boundary on the RPE scale be changed via anchors or explanation, this alters the perception of effort and not the actual effort applied to a task (Halperin & Emanuel, 2020). To summarise, this argument has not been fully explored with no studies having objectively tested these assertions. Moreover, very few have even scrupulously looked at what perceived effort truly is and how it is being measured (e.g., Halperin & Emanuel, 2020; Pageaux, 2016). Therefore, although the main purpose of this thesis was not to directly test the psychobiological model, some findings from the studies within the current thesis may have some relevance to this argument.

However, as was noted, an understanding of perceived effort, its application, and continual self-regulation during submaximal tasks is unclear (McCormick et al., 2019; O'Malley et al., 2023; Richter et al., 2016). Considering perceived effort has been championed as a central factor in determining task performance it is odd that less is known about the potential effort-based decision-making processes that are undertaken throughout submaximal tasks. Especially so when submaximal tasks form the majority of tasks that humans undertake on a daily basis. Therefore, in the present thesis, researchers flipped the task paradigm and instead of using a task where resource demand would change (e.g., time-trial), instead they implemented a unique fixed perceived effort cycling task lasting 30 minutes. In which, the ultimate purpose is that perceived effort remains constant (O'Malley et al., 2023). Using this approach, any enactment of physical or cognitive strategies would help understand how effort-based decision-making is governed.

Although the psychobiological model provides a comprehensive and yet unfalsified account of how endurance-based exercise is regulated, certain researchers have provided some compelling evidence (Hureau, Romer, et al., 2018; Hureau, Weavil, et al., 2018; Amann et al., 2022) to dispute the validity of some of the psychobiological model's propositions. Primary amongst these antagonists are proponents of renewed afferent feedback-centred models such as the sensory tolerance limit (Hureau, Romer, et al., 2018). Maintaining that afferent feedback is central to the regulation of exercise behaviours (Amann, 2011; Amann & Secher, 2010; Amann et al., 2015; Hureau, Romer, et al., 2018; Hureau, Weavil, et al., 2018), recent models like the sensory tolerance limit (Figure 9b) assume that the sum of all feed-forward (e.g., corollary discharge/effort) and feedback (e.g., metabo and/or nociceptive afferents, respiratory afferents) signals regulate endurance performance (Amann et al., 2020; Hureau, Romer, et al., 2018). In this manner, the sensory tolerance limit has a similar premise to the psychobiological model in that the closer an individual is to the reaching of their "*sensory limit*", the more likely exercise will be discontinued, or its intensity will be reduced (Amann et al., 2020, 2022; Hureau, Romer, et al., 2018). Yet, the main difference is that perceived effort is considered as *only one* of the numerous factors (e.g., pain/nociception, other afferent feedback) involved with regulating endurance exercise behaviour in the sensory tolerance limit (Amann et al., 2020; Hureau, Romer, et al. 2018). Whereas the psychobiological model infers that perceived effort and its relation to the willingness to invest effort (motivational intensity) is the *only* factor determining endurance exercise performance (Marcora, 2008; Pageaux, 2014).

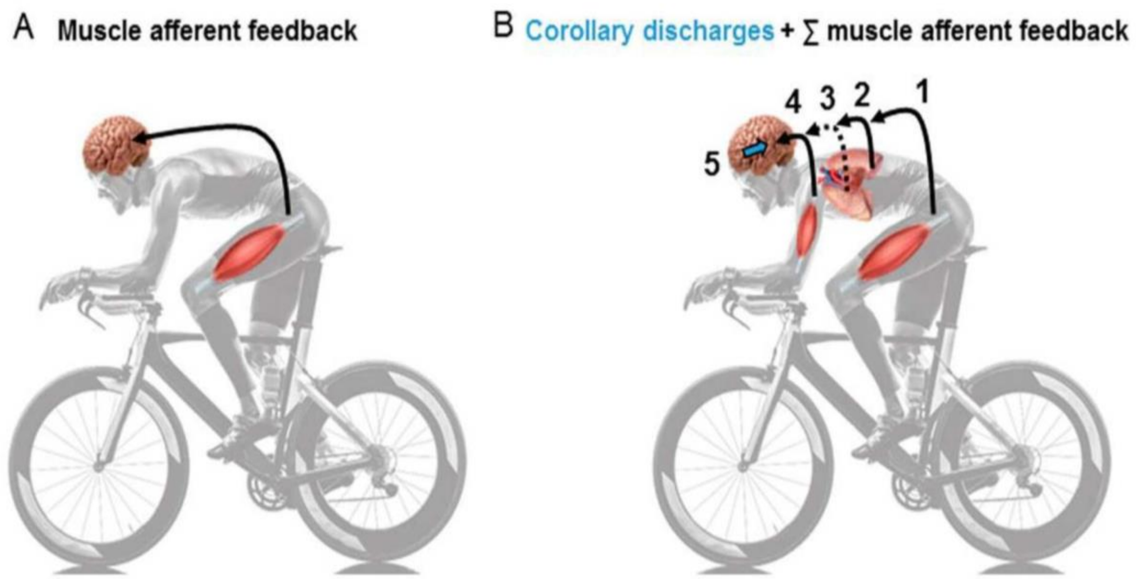


Figure 9. Schematic illustration summarising the hypothetical "exercise-pressor reflex" involving afferent feedback loops such as from Amann & Secher (2010) (A) and the "sensory tolerance limit" (B). Extracted from Hureau, Romer, et al. (2018).

Notably, the sensory tolerance limit does provide some feasible arguments in place of the psychobiological model, particularly when the exercise causes individuals to maintain a maximal force output or culminates with a terminal effort (Norbury et al., 2022a; Smith et al., 2020). For instance, Burnley and Jones (2018) indicate that there must be a veridical point at which it becomes impossible for the central nervous system to continue compensating for the fatigue-induced changes across the metabolic and cellular levels of neuromuscular and cardiorespiratory systems, no matter how much an individual wants to persist on a task. Thus, indicating that task failure within severe exercise intensity domains is "purely physical" (Burnley & Jones, 2018). Furthermore, several researchers have challenged that a singular model is likely to be insufficient at explaining the multifaceted nature of exercise regulation (Abbiss & Peiffer, 2010; Burnley & Jones, 2017; Hettinga, 2010). Instead, some have advocated that an integrative approach is necessary (Hettinga, 2010; Micklewright, Kegerreis, et al., 2017; Smits et al., 2014).

Yet, initial attempts (e.g., Hureau, Romer, et al., 2018; St Clair Gibson et al., 2018) of this have been problematic for numerous reasons. One, attempts at integrative models remain at conflict with Popper's (2005) basic scientific principle of falsifiability. To illustrate, Hureau and colleagues (2018) argue that exercise capacity occurs when an individual reaches their "sensory tolerance limit" but provide no explanation how to appropriately define this limit (Aboodarda et al., 2020). Thus, it seems that current integrative models are insufficient at providing reasonable disputation of existing models like the psychobiological model. Two, models like the sensory tolerance limit fail to explain how prolonged, submaximal contractions (Marcora, 2019) are regulated which is a hallmark of endurance-based exercise (McCormick et al., 2015). And third, the psychobiological model *is* an integrative model (Marcora, 2019). Crucially, the model accounts that psychological elements (perceived effort) of the model involve underlying neurobiological processes, hence terming it the psychobiological model (Marcora, 2010a). Neurobiological processes which encompass physiological processes like afferent feedback can impact the perception of effort and/or potential motivation (Pageaux, 2016) However, the crucial aspect of the psychobiological model is that it is neurobiological processes impact exercise behaviour via changes in psychological phenomena and not directly (Brehm & Self, 1989; Marcora, 2010a, 2019; Pageaux, 2016; Richter et al., 2016; Smirmaul, 2012; Wright, 1996).

Therefore, based on all that has been related according to main models that have surfaced in the literature over the last 30 years, the psychobiological model may offer the most reasonable explanation of endurance-based exercise and its self-regulation via effort-based decisions (Marcora, 2019; McCormick et al., 2019). Yet, readers must be cognisant that the psychobiological model is still relatively new and ought to undergo continued testing to assess whether it is a quality model to explain exercise regulation (Marcora & Inzlicht, 2016). However, the psychobiological model at present, appears to be a thorough and unfalsified model. Crucially, its central component is the perception of effort (Marcora, 2010a). Namely, perceived effort is considered an enduring factor of endurance-based activity (Pageaux, 2016)which factors into the decision-making processes and self-regulation of submaximal exercise (Pageaux, 2014). Thus, how someone self-regulates their perceived effort and subsequent behaviour towards a task is thought to be central to maximising the likelihood of goal attainment (McCormick et al., 2019). In turn, this review will turn towards literature surrounding the topic of self-regulation.

3.3. SELF-REGULATION

Perceived effort has in equal parts been posited as the limit to (Staiano et al., 2018) as well as the determining factor (Marcora, 2019) towards endurance-based exercise performance. In exercise contexts, the product of any task such as power output or velocity represents the effort that was applied (Preston & Wegner, 2009). Closely linked to this effort is the perception of effort which involves a perceptual awareness of the resources being applied to the task. Therefore, it is of particular interest for researchers to understand how individuals decide to regulate their perceived effort during an exercise (Marcora, 2019; McCormick et al., 2019). As such, an emergent strategy within the literature relating to the management of perceived effort is self-regulation (McCormick et al., 2019).

Zimmerman's (2000) social-cognitive perspective of self-regulation posits that human function is a constant state of adapting the self in relation to current behaviour, events, and the environment; known as triadic reciprocal determinism (Bandura, 1997). In consequence, self-regulation encapsulates the continual control over an individual's cognitions and behaviours in reference to the demands of the current situation (Carver & Scheier, 2000) and the attainment of a desired goal (Zimmerman, 2000). Centrally, the control of self-regulation is moderated through self-oriented, feedback loops (Carver & Scheier, 1982; Zimmerman, 2000) which often require individuals to enact self-control over their predominant, automatic tendencies in favour of a more reasonable alternative that serves the individual better for their overarching goal (Inzlicht et al., 2014). Thus, for humans to engage in the self-regulation of perceived effort properly, individuals must be cognisant of their own psychophysiological state relative to a current task (Brick et al., 2014) as well as understanding of their sense of agency to adapt in accord with desired goals (Anstiss et al., 2018; Brick, MacIntyre, et al., 2016).

Importantly, the regulation of perceived effort is individualised. Therefore, whether a certain cognition, emotion, or behaviour related to the effort invested is up- or down-regulated, can be dependent on the individual perception of its utility towards the current goal (Zimmerman, 2000; McCormick et al., 2019). In addition, though pre-set standards and goals relating to a task are often consciously derived (Carver & Scheier, 2000; McCormick et al., 2019), responses to regulate the self can act on either conscious or subconscious levels, or even a blend of the two (Carver & Scheier, 1982; Micklewright, Kegerreis, et al., 2017). Consequently, self-regulation is viewed as an overarching process which enlists the recruitment of multiple lower order strategies to deal with current demands imposed by internal and external sources (Brick, MacIntyre, et al., 2016; McCormick et al., 2019).

Self-regulation can be subcategorised into three distinct stages (Figure 10a): forethought; performance; and reflection (Zimmerman, 2000). These stages can operate across an entire exercise bout (e.g., one race/time-trial/activity) or multiple loops may occur within a singular event (e.g., one loop during the swim, cycle, run of a triathlon). Moreover, within each phase, several lower order strategies are relevant and can be utilised by the individual to adjust their perceived effort for subsequent endurance-based exercise performance (McCormick et al., 2019).

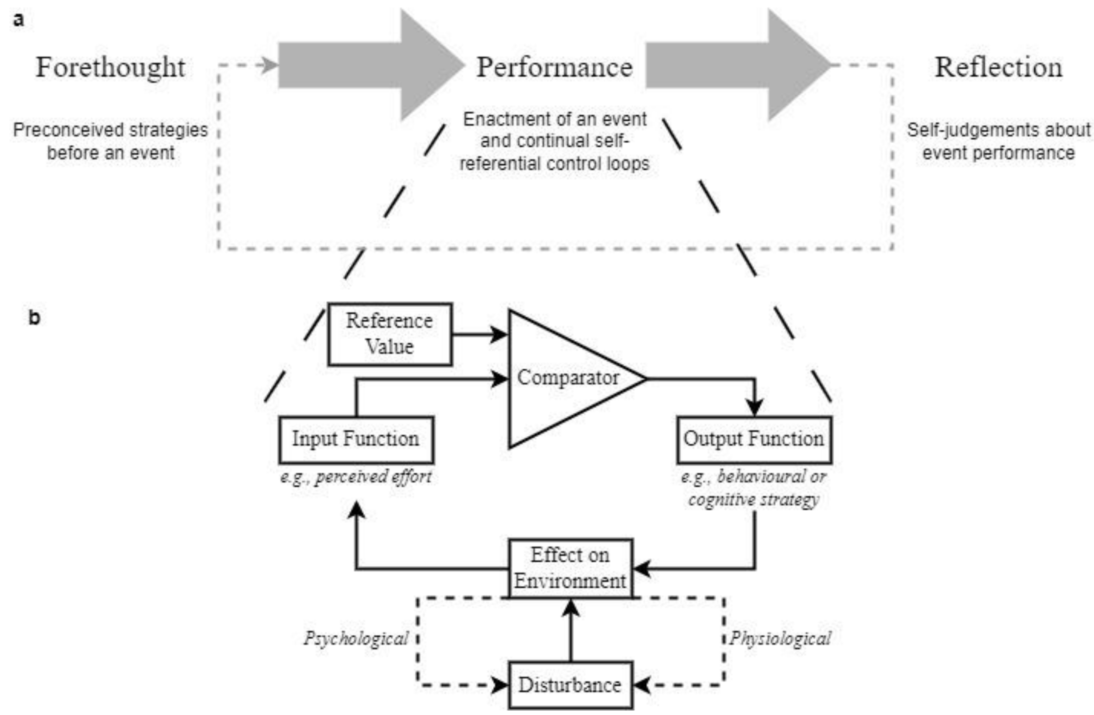


Figure 10a/b. (a) Depiction of the self-regulatory process during an event. (b) Adapted cybernetics control theory (Carver & Scheier, 1982) according to self-referential control loops that operate during the performance phase of self-regulation.

Although each stage of the self-regulatory process is important, the present thesis largely revolves around the measurement of psychophysiological responses associated with perceived effort and the subsequent self-regulation of perceived effort *during* an exercise activity. Consequently, this literature review will target the performance phase of self-regulation and the underpinning theories that explain how individuals regulate the self during an event. Thus, content concerning the forethought and reflective phases will be less in depth, yet the reader is pointed towards several other studies (see Elferink-Gemser & Hettinga, 2017; McCormick et al., 2019) which expand on the central points that this review makes.

3.3.1. PHASES OF SELF-REGULATION

3.3.1.1. FORETHOUGHT

Forethought lies at the start of the self-regulatory process and encapsulates the active planning and preparation that is made before the upcoming event (McCormick et al., 2019). To begin with, individuals must initially select a given task to engage with (Zimmerman, 2000). In tandem, relevant goals must be identified, fitting to an individual's motivational intensity (Marcora, 2010b) and orientation (Gross, 2002), self-efficacy beliefs (Anstiss et al., 2018), and cognitive appraisals (Smith & Lazarus, 1993). Depending on the task selection and subsequent goals, individuals can then begin to formulate plans revolving around how they will execute the task (Elferink-Gemser & Hettinga, 2017). In the context of self-regulating perceived effort, this would involve a template to how one expects to exert their effort over the course of an exercise (Abbiss & Laursen, 2008; Elferink-Gemser & Hettinga, 2017; McCormick et al., 2019).

In reference to motivational dispositions, the psychobiological model explicitly states that anything which enhances an individual's potential motivation will improve performance whilst reductions to potential motivation will undermine performance (Marcora, 2008; McCormick et al., 2019; Pageaux, 2014). In review, motivation is characterised as the continual series of cost-benefit evaluations relating to a present task (Chong et al., 2017; Westbrook & Beaver, 2015). Therefore, individuals with enhanced perceptions of benefit (e.g., likelihood of attainment, value of goal attainment, and strength of the motive) will theoretically demonstrate superior motivational intensity (Chong et al., 2017, 2018) and subsequent performance (Marcora, 2008; Pageaux, 2014; McCormick et al., 2015). In doing so, individuals may trend towards the belief that it is worth expending effort towards obtaining rewards (Chong et al., 2017; Renfree et al., 2014). For evidence, Chong et al. (2018) utilised a computational model to identify that trained/experienced individuals index a higher intensity of motivation and therefore are more willing to exert greater amounts of physical effort for an ensuing exercise task.

In addition, other research indicates that experienced individuals demonstrate more intrinsic motivational tendencies on approach to a task compared to inexperienced counterparts (Clancy et al., 2016). Supposedly, internally motivated individuals deem their effort as a crucial determinant of exercise performance whereas extrinsically motivated individuals place more of an onus on external factors such as competitors and luck (Deci & Ryan, 2000; Hagger & Chatzisarantis, 2007). As a result, experienced individuals are more likely to persist with their effort compared to inexperienced individuals who are predominantly extrinsically motivated (McCormick et al., 2015; Inzlicht & Marcora, 2016).

Therefore, in short, if an individual approaches an exercise task with higher motivational intensity, individuals will likely demonstrate greater effort input during the task and subsequently self-regulate their psychophysiological state to maintain effort in the face of adversity in aim of aspiring towards their motivational beliefs (McCormick et al., 2019; Venhorst et al., 2018b). Furthermore, if the individual's motivation is intrinsically oriented, the individual may also be more likely to avoid regulation of behaviour (e.g., reducing exercise intensity) in response to adversity, instead, opting for the regulation of cognitions and emotions associated with the exercise to maintain physical effort outputs (Carver & Scheier, 2000; Gross, 2013; Lasnier & Durand-Bush, 2022).

Next, social-cognitive perspectives of self-regulation identify that self-efficacy beliefs are central to how an individual plans and subsequently regulates a task (Zimmerman, 2000). Drawing upon Bandura's self-efficacy theory (1997), individuals possess a complex set of schema and inner beliefs based upon their previous experiences from similar tasks. In turn, these beliefs shape how an individual envisages an upcoming task and the planning of how effort will be applied throughout (Elferink-Gemser & Hettinga, 2017; Mauger et al., 2009; Micklewright et al., 2012). It is interesting to note that after individuals are exposed to a particular exercise activity (e.g., time-trial), there is an alteration in the pacing (i.e., allocation of effort) based on previous experience in subsequent trials (Mauger et al., 2009). Likewise, Micklewright et al. (2012) indicated that younger individuals, lacking in previous experience demonstrate erratic and unplanned resource distribution during athletic events, further validating the role of previous experience and the self-efficacy beliefs they form to plan appropriate effort-based decisions in subsequent exercise tasks (Elferink-Gemser & Hettinga, 2017).

In addition, during freely regulated tasks, studies also show that individuals who index greater self-efficacy ratings tend to set more challenging goals (Bueno et al., 2008), as well as demonstrating an increased likelihood to sustain higher levels of effort to attain said goals (Hutchinson et al., 2008). Anstiss et al. (2018) attributes this relationship to individuals believing more in their ability to bring their behaviour in accord with their goals through the investment of effort. Furthermore, self-efficacy would also be closely linked to the individual's notions of their likelihood to attain their goals which is known to be a significant contributor to an individual's potential motivation (Marcora, 2008, 2019). Therefore, providing a mechanistic link as to how higher self-efficacy beliefs lead to improved effort persistence and performance as the individual is likely to demonstrate a greater willingness to apply effort in aim of achieving their goals (McCormick et al., 2019)

Finally, cognitive appraisals have also been identified as an indicator of performance in subsequent exercise tasks (Jones et al., 2009). Specifically, appraisals are subjective interpretations of a present situation which accounts for the relevant stimuli in the current environment (Lazarus, 1991). Whilst appraisals operate throughout an entire activity and can be subject to change (Martinent & Ferrand, 2015), studies do also indicate that the initial cognitive appraisals that are made towards an exercise event are stable and endure over long periods of time (Arthur et al., 2019; Blascovich et al., 2004; Hase et al., 2019; Tomaka et al., 1997).

An original and revised version of the theory of challenge and threat states in athletes (see Jones et al., 2009 and Meijen et al., 2020) provide comprehensive overviews of the psychophysiological antecedents to cognitive appraisals, an insight into the typical psychophysiological responses throughout an exercise task, the impact on perceived effort, and the subsequent performance outcomes of these appraisals. In short, higher motivational intensity, intrinsic motivational disposition, and higher perceptions of control stemming from higher self-efficacy beliefs are the main antecedents of challenge appraisal (Jones et al., 2009; Meijen et al., 2020). Alternatively, the absence of these same psychological properties is characteristic of threat appraisal formation (Jones et al., 2009; Meijen et al., 2020; Tomaka et al., 1997). Subsequently, challenge appraisal is associated with a functional autonomic response whereas threat appraisal is aligned with a dysfunctional autonomic response (Blascovich & Tomaka, 1996; Blascovich et al., 2004; Jones et al., 2009; Meijen et al., 2020; Tomaka et al., 1997). Due to the differences in psychophysiological priming, challenge appraisal is linked to superior performance outcomes than threat appraisal across numerous cognitive and physical endurance-based tasks (Arthur et al., 2019; Giles et al., 2018; Hase et al., 2019).

Collectively, it becomes apparent how an individual's approach to a task is influential for the subsequent requirement to self-regulate effort for desired outcomes. Namely, if an individual is willing to invest more effort (i.e., a higher motivational intensity), the task will be continued at a certain intensity almost indefinitely until the individual no longer feels motivated and efficacious at doing so (Marcora, 2008, 2010a; Anstiss et al., 2018). Linked to these motivational and self-efficacy beliefs, individuals' appraisals of a task may also differ and cause them to experience differences in the priming of their psychophysiological state (Blascovich et al., 2004; Jones et al., 2009; Meijen et al., 2020) which may dispose them to superior performance – particularly for endurance-based tasks (Arthur et al., 2019).

3.3.1.2. PERFORMANCE

Upon commencing an exercise, an individual will enter the performance phase wherein athletes begin to execute their preconceived plans during the athletic event (McCormick et al., 2019). The metacognitive underpinnings of self-regulation are most evident within this phase as athletes must be cognisant of the potential changes to their cognitions, psychophysiological state, and behaviours due to the exercise (Brick et al., 2014; McCormick et al., 2019). Moreover, several environmental and social aspects can further exacerbate the intensity of some of the internal changes that the individual experiences (e.g., heat on thermal sensation, hypoxia on breathlessness). Therefore, it is useful to consider the psychobiological and corollary discharge models in explaining how self-regulatory strategies operate to effect changes on perceived effort and/or motivational intensity. Namely, self-regulatory strategies can either up- (improve performance) or down-regulate (reduce performance) motivational intensity (McCormick et al., 2018; Pageaux, 2014). Or self-regulatory strategies can impact perceived effort via alterations in central motor command that is projected to the muscles or the neuronal processing of the corollary discharge that surfaces in proportion to the central drive (Marcora, 2019; Pageaux, 2014).

For clarity, these self-regulatory strategies must be considered in the context of this thesis which involves 30-minute fixed perceived effort cycling. Foremostly, this task involves the participant maintaining a constant RPE throughout the trial therefore the participant enacts self-regulatory strategies to ensure that perceived effort intensity is maintained. Thus, if a participant is to maintain an RPE *15 – hard*, this person may resort to two main themes of regulating their RPE. On the one hand, they may enact behavioural changes (e.g., increase/decrease power output) to stimulate changes in central drive and psychophysiological states to change perceived effort (Carver & Scheier, 1982, 2000). On the other hand, the participant may entertain cognitive strategies that alter the neuronal processing of effort-driving signals (Marcora, 2019; McCormick et al., 2019) so that power output remains constant (or potentially increases). As discussed previously, there may also be a route to enact cognitive strategies which upregulate motivation to manipulate the relational value of perceived effort to a preconceived maximum capacity (Figure 2).

According to these possible changes, there are several ‘lower order’ strategies that function as part of the self-regulatory process during the performance phase such as attention to specific psychophysiological and psychosocial phenomena (Brick et al., 2014) as well as self-control over cognitive or behavioural responses (Carver & Scheier, 2000). Both attentional and self-control models will be explored to understand how they impact the self-regulatory processes during an endurance-based exercise task.

3.3.1.2.1. ATTENTIONAL FOCUS

Research has highlighted that a myriad of psychophysiological phenomena such as fatigue (Behrens et al., 2023) nociception/pain (Mauger, 2013), and other psychosocial indices can manifest during endurance-based tasks (McCormick et al., 2015). Thus, a large scope of factors can effect change on perceived effort or motivational intensity (Marcora, 2008; Pageaux, 2014). Consequently, what information an individual attends towards has a highly influential role on how perceived effort is regulated during exercise (Brick et al., 2014).

Brick et al. (2014) proposed a metacognitive framework that alludes to existing attentional models which rationalise what individual’s focus on during exercise. Importantly, attentional focus during exercise factors heavily into the subsequent decisions to self-regulate (Smits et al., 2014) as this allows the individual to identify what element of the self needs to be brought into accord with a pre-set standard – like a specific RPE (Carver & Scheier, 2000).

First, Morgan and Pollock (1977) identified attentional focus as having two dimensions which an individual can shift between. One dimension relates to focus being internal, consisting of interoceptive sensory cues that originate within the body, or external, consisting of information that originates outside the body (Morgan & Pollock, 1977). As highlighted, during prolonged exercise internal sensory signals include – but are not limited to – fatigue (Behrens et al., 2023; Enoka & Duchateau, 2016), nociception/pain (Mauger, 2013), and breathing/dyspnea (Bigliassi, 2015; Dempsey et al., 2006). Meanwhile, depending on the type of exercise task being completed, external cues may include the surrounding environment, other's behaviour, and time elapsed/remaining on task (Chinnasamy et al., 2013; Skorski & Abbiss, 2017).

Second, in addition to the locality of attentional focus, individual's focus can be associative, with a purposeful direction towards the present task, or dissociative, with a purposeful distraction away from the present task (Morgan & Pollock, 1977). In this manner, individuals can have four categories of attentional focus to shift between during an endurance exercise: internal associative (e.g., breathing rate); internal dissociative (e.g., daydreaming about a past memory); external associative (e.g., opponent's pacing); and external dissociative (e.g., looking at the scenery) (Brick et al., 2014; Morgan & Pollock, 1977).

Crucially, attentional focus is task-dependent *and* individualised (Ekkekakis et al., 2011; Lind et al., 2009). In relation to the task, exercising at varying perceptions of effort has been evidenced to correlate with different patterns of attentional focus (Ekkekakis, 2009c). To illustrate, endurance exercise at a harder perception of effort usually corresponds to a higher physiological intensity (Tucker, 2009). Consequently, this type of exercise is predisposed to an experience of greater perceived fatigability (Azevedo de Almeida et al., 2022; Behrens et al., 2023; Iannetta et al., 2022), nociception (Cook et al., 1997; Mauger, 2014), and other psychological consequences of these phenomena (Venhorst et al., 2018b). As a result, attention is more likely to be internally oriented compared to exercise at a lower perception of effort due to the salience of interoceptive cues (Ekkekakis, 2003, 2009a, c). Likewise, as exercise intensity increases, the attention of the individual may become narrower as the volume and intensity of sensory signals reaching the central nervous system override other signals (Brick et al., 2014; Ekkekakis, 2009a). In response, as the individual is aware of the natural vicissitudes of exercise, this may impact their motivational intensity depending on how they are appraised (Smith & Lazarus, 1993; Venhorst et al., 2018b). Or phenomena like perceived fatigability and pain can impact the central drive of the athletes (Aboodarda et al., 2020) which can impact the neuronal processing of signals to generate elevated perceptions of effort (Pageaux, 2014b).

Nevertheless, lower intensity exercise also involves some perturbation from a resting state with resources being applied to the task, but to a less intense degree (Burnley & Jones, 2018). Meaning, that just because an exercise is not in the heavy or severe intensity domain, does not mean that it will not cause individuals to have an internal focus (Brick et al., 2014). However, other cues that are external can be acknowledged *more* in comparison to higher intensity exercise (Masters & Ogles, 1998). Instead, the overarching message is that higher intensity exercise *disposes* individuals to have a predominantly internal focus than at lower intensity exercise because of the more intense rate of sensory signals informing the body of homeostatic disruption (Brick et al., 2014; Morgan & Pollock, 1977).

Yet, beyond the intensity of exercise, time-based factors could also impact the individual's attentional focus (Pageaux, 2014b; Renfree et al., 2014). In review, Pageaux (2014b) highlights that the time or distance elapsed/remaining constitutes two important sub-factors of the psychobiological model. Endurance-based exercise can range from 75 seconds to hours or even days on end. Studies that have used time-trial events have found that individuals demonstrate a predominantly internal focus at the earlier stages of an exercise and transition to an external focus at the closing stages of the time-trial (Brick, MacIntrye, et al., 2016; Robinson et al., 2021; Whitehead et al., 2018, 2019). In these studies, participants displayed a typical "*J-shaped*" pacing profile which indicates exercise intensity is higher at the start and end phase of the exercise (Foster et al., 2004). Hence, the association between internal and external focus is not entirely determined by exercise intensity but also by time.

Further to the task-related differences, attentional focus also has an individualised aspect (Brick et al., 2014). Recently, Whitehead et al. (2018) demonstrated that trained cyclists would demonstrate a more internal focus at the start of an exercise compared to inexperienced counterparts. In addition, as the exercise progressed, experienced athletes shift their focus to an equal share of internal and external sensory monitoring (Whitehead et al., 2018; Williams et al., 2015b). Alternatively, inexperienced cyclists consistently display an external focus throughout a prolonged exercise bout (Whitehead et al., 2018). In addition, other studies have also elucidated that experienced individuals typically attend to more task-relevant/associative cues throughout an exercise compared to inexperienced counterparts who typically focus on more task-irrelevant/dissociative cues (Hutchinson & Tenenbaum, 2007; Lind et al., 2009; McCormick et al., 2015). In turn, an associative, task-relevant focus helps prompt more targeted and appropriate self-regulatory strategies towards psychophysiological state to negate the need for added effort to attain their goals (Brick et al., 2014; Brick, MacIntyre, et al., 2016;

Hutchinson & Tenenbaum, 2007; Lind et al., 2009; Masters & Ogles, 1998). Meanwhile, inexperienced individuals with an external and task-irrelevant focus will prompt less targeted and discursive self-regulatory strategies which could expediate the requirement of more effort to attain their goals (Lind et al., 2009).

If these summaries are to be applied to a fixed perceived effort trial, this likely means that individuals who are attuned to their psychophysiological state can make more informed decisions about which strategies to use to regulate their perceived effort and behaviour (Elferink-Gemser & Hettinga, 2017). Therefore, they can enact more targeted self-control of their self-regulatory responses to ensure that their behaviour is facilitative towards goal attainment (McCormick et al., 2019). In contrast, those who are less attuned to their underlying psychophysiological state may err in selecting the most effective and appropriate self-regulatory strategies to manage their perceived effort (Elferink-Gemser & Hettinga, 2017). Instead, participants may lack the capacity to fully understand their psychophysiological state and therefore acquiesce towards the use of more natural and impulsive strategies (Hagger et al., 2010). For instance, an individual might opt to lower their exercise intensity (dysfunctional) compared to implementing cognitive strategies that upregulate motivation and/or reduce neuronal processing of effort-driving signals to continue at the same physical output for a given RPE (Inzlicht & Marcora, 2016; Marcora, 2019).

3.3.1.2.2. SELF-CONTROL

It is important to consider attention before delving into the enactment of self-regulatory strategies as the awareness of the present situation – involving current psychophysiological state and psychosocial factors – forms a crucial element of the feedback loops that govern self-regulatory behaviours (Carver & Scheier, 2000). Carver and Scheier (1982) proposed a cybernetics control theory which explains how individuals regulate the self in accordance with preconceived goals (Figure 10b). Importantly, the present situation acts as a comparative factor for the individual to judge whether their current state aligns with the individual’s designs towards the goal via a feedback loop (Carver & Scheier, 2000).

In the case of a 30-minute fixed perceived effort exercise, the goal (or reference value) centres on maintaining a set RPE for the required time. As part of the engagement in prolonged exercise, natural disturbance to physiological (Burnley & Jones, 2018) and psychological

(Venhorst et al., 2018b) state that individuals can have varying degrees of awareness about (Brick et al., 2014). Associated with this awareness, this could potentially cause a change in the central motor commands that are sent, or the neuronal processing of corollaries coupled with central drive (Marcora, 2019). Thus, changes in psychophysiological state could provoke indirect changes onto the perception of effort. As a result, an individual must be cognisant of any changes to perceived effort and the potential causes behind these changes like variations in psychophysiological state. Consciousness of this allows individuals to then effect relevant self-regulatory strategies to assuage disturbance to their psychophysiological state and bring perceived effort into accord with the requirements (reference) of the task goal (Carver & Scheier, 2009; McCormick et al., 2019).

Due to naturally occurring sensations/perceptions during prolonged exercise like fatigue and nociception/pain, it is likely that perceived effort will increase if power output remains constant (Amann et al., 2020; Azevedo de Almeida et al., 2022; Brownstein et al., 2022). When considering the models that explain the generation of perceived effort, anything that can directly affect the central motor commands that are projected to the periphery and/or that can affect the neuronal processing of corollaries of central motor commands will alter perceived effort (de Morree et al., 2012; Pageaux, 2016).

Subsequently, the dominant and natural impulse to reduce central drive to the muscles involves a reduced exercise intensity (Marcora, 2010a) or a cessation of the activity altogether (Inzlicht & Marcora, 2016). If the individual reduces the exercise intensity, this typically entails accompanying changes to the psychological state of the individual that makes the exercise feel less aversive and more pleasurable (Ekkekakis, 2003; Ekkekakis et al., 2011). Thus, improvements in motivation are likely to occur (Behrens et al., 2023; Venhorst et al., 2018b), with further impacts on the neuronal processing of the effort-generating signals (Pageaux, 2014). Therefore, it is clear how reductions in relaying central motor commands to cause a reduction in exercise intensity realigns the perceived effort (input) with the required RPE (reference) in this context.

However, in many situations in life, reduced output towards a task or altogether terminating the task is not conducive to goal attainment (Evans et al., 2016). Particularly, in the sport and exercise domain, compromising exercise intensity in the face of natural vicissitudes of exercise is highly dysfunction (Englert, 2016; Inzlicht & Marcora, 2016). As a result, individuals must opt for alternative ways to regulate their perceived effort during prolonged physical exercise to ensure that goal attainment is not compromised (Evans et al., 2016). Thereby necessitating the use of self-control (Englert, 2016).

Self-control is a component of self-regulation whereby individuals must override natural, dominant impulses and behaviours in favour of more functional alternatives (Englert et al., 2021). If an individual has identified that a certain sensation/perception is disruptive towards goal attainment and is causing perceived effort to increase too quickly, alternative behavioural and cognitive strategies can be implemented to soften the disturbance it is causing to the individual without conceding their exercise intensity (Evans et al., 2016; Hagger et al., 2010). Yet, whilst Carver & Scheier's (1982) cybernetics theory of control provides an appropriate framework to understand how self-control is enacted in-situ, an awareness of the underpinning theories to explain self-control can help explain how appropriate self-regulatory strategies that do not compromise exercise intensity are decided upon (Renfree et al., 2014).

Since the mid 1990's Baumeister and colleagues (Baumeister & Heatherton, 1996; Baumeister & Vohs, 2007; Baumeister et al., 1998, 2007; Muraven & Baumeister, 2000; Vohs et al., 2014) have championed a resource-dependent model of self-control. In which, researchers hypothesise that self-control is dependent on a limited and finite resource (Baumeister et al., 1998; Englert et al., 2021), supposed to be brain glucose (Gaillot & Baumeister, 2007). Subsequently, a prolonged engagement in self-control without appropriate time to replenish resources precipitates a depletion to this resource whereupon there is an eventual exhaustion resulting in self-control failure (Englert et al., 2021). Hereat, decisions concerning the self-regulation of perceived effort become unsuitable towards the task goal (Hagger et al., 2011). Furthermore, as self-control is intrinsically linked to the perception of effort (Kurzban, 2016), self-control can also be viewed as the expenditure of mental resources towards a task, thus, effortful (Boksem & Tops, 2008; Englert et al., 2021).

Baumeister et al. (1994) formulated the strength model of self-control based on the premise that effective engagement in self-control involves the active suppression of a dominant impulse for a more rational, functional alternative. This phenomenon is referred to as *response inhibition* (Mostofsky & Simmonds, 2008) and initiates the occurrence of *ego depletion* (Evans et al., 2016). Marcora et al. (2009) were one of the first to exhibit that a prior enactment of response inhibition (via a Stroop task), elicited poorer subsequent performance in a physical task. Since then, meta-analytic data of numerous studies in exercise science infers that an ego depleting task has moderate effects ($\delta = .34$) on whole-body exercise with even larger effects

($\delta = .71$) on more intricate tasks (Giboin & Wolff, 2019). Moreover, Brown et al. (2020) demonstrated that a cognitive/ego depleting task before an exercise causes higher perceptions of effort at baseline without any differences in physical state, providing a causal link between ego-depletion and effort perceptions.

Although there are data are supportive of the strength model of self-control (Boksem & Tops, 2008; Hagger & Chatzisarantis, 2009; Englert, 2016), others posit that prior bouts of self-control which increase the susceptibility of subsequently self-control failure due to a depletion of resources provide inconclusive data (Friese et al., 2018). Alternatively, some suggest that self-control of responses is not contingent on a limited resource but instead reflects the motivation to apply mental effort as part of the self-control process (Beedie & Lanes, 2012; Brown & Bray 2017; Inzlicht & Schmeichel, 2012; Inzlicht et al., 2014; Kurzban, 2016). Principally, adversaries of the strength model maintain that availability of a certain resource may factor as an input into decisions to self-control (Kurzban et al., 2013), but that finite resources do not act as the overbearing constraint to functional self-control engagement (Beedie & Lane, 2012; Brown & Bray, 2017; Inzlicht & Schmeichel, 2016). Moreover, there are several arguments that these finite resources are hard to identify, locate, and objectively measure (Friese et al., 2018; Inzlicht et al., 2014). Instead, self-control is considered to have a refractory period whereby it is harder to enact functional self-control after an intense bout of prior self-control (Inzlicht et al., 2014). However, this is not because of resource depletion but due to the shifting in opportunity-cost dynamics which reduce motivation (Müller & Apps, 2019) to apply increasingly aversive cognitive work (Inzlicht et al., 2014) or due to the occurrence of other phenomena such as boredom (Biekele et al., 2021).

Another crucial disputation of the strength model resides in how decisions are actually made (Inzlicht & Marcora, 2016). For example, Marcora's (2008) psychobiological model is ultimately a decision-making model that places perceived effort and potential motivation as the central factors for how decisions are made (Pageaux, 2014). Accordingly, it is thought that the way an individual behaves during a task is based on the subjective values they create about a situation (Chong et al., 2017; Westbrook & Beaver, 2015), not the presence a specific resource to keep effort in check (Inzlicht & Marcora, 2016). Specifically, if an individual deems the outcome worthy of effort it requires, one will continue to apply resources until that outcome is achieved or considered no longer worthy of the required resources/effort (Müller & Apps, 2019; Westbrook & Beaver, 2015). Other exercise-based models with similar principles (e.g., Smits et al., 2014) also insist that individuals continually collect evidence through experience (past and present) to determine which course of action to take (Cisek & Kalaska, 2010). Naturally, rewards/costs/risks are thought to influence which course of action is most appealing and suitable (Cisek & Kalaska, 2010; Smits et al., 2014). Furthermore, as an individual becomes more experienced, they may become more adept at selecting the relevant information sources (Boya et al., 2017; Chinnasamy et al., 2013; Massey et al., 2020; Micklewright, Kegerreis, et al., 2017) within the environment and subsequently adopt a more appropriate action to self-regulate effectively and maintain task performance (Boya et al., 2017; Venhorst et al., 2018b). Therefore, contrary to prior strength models (Baumeister et al., 1994) or integrative models that posit a higher-order governor determines human behaviour (Noakes et al., 2005), the self-regulation of effort appears to not depend on a finite resource.

Moreover, Renfree et al. (2014) highlights two other primary decision-making processes which can govern how individuals self-regulate their perceived effort/behaviour/cognitions. One of which is rationality which requires individuals to be aware of all the relevant information and opt towards the most feasible and rational course of action according to this information (Renfree et al., 2014). In this case, an individual would need to be aware of as much of their psychophysiological state to make the most rational decision to regulate perceived effort (Venhorst et al., 2018b). Rational decision-making aligns well with the strength model of control as the choice to override a given impulse in favour of a more appropriate alternative requires individuals to be acutely aware of the benefits of the potential alternative (Inzlicht et al., 2014). Yet, in exercise environments, it is ordinary for key information to be missing (Renfree et al., 2014). Thus, decisions to implement self-regulatory strategies must be made according to other predictions besides rationality (Dougherty et al., 2008). Alternatively, heuristic decision-making theory posits that not all the information is readily available or that some information is actively ignored so that individuals make quicker, predictive decisions (Gigerenzer & Gaissmaier, 2011; Renfree et al., 2014). In doing so, more adaptive ways of self-regulating perceived effort could be possible (Gigerenzer & Gaissmaier, 2011). For instance, participants can choose to have an external focus for a period of an exercise towards other phenomena such as music or the environment (Brick et al., 2014; Terry et al., 2020). In consequence, several studies have found when doing so can reduce the perception of effort as it can affect the neural processing of effort-driving signals to cause a reduced perceived effort (Terry et al., 2020).

Findings of prior self-control to an exercise task at a fixed perceived effort, discerned that a prior cognitive task caused participants to cycle at a lower average power output for a fixed perceived effort considered *11 - light* and *15 - hard* than when no prior cognitive task was completed (Brownsberger et al., 2013). However, Roussey et al. (2018) argued that a prior cognitive task invoked no changes in mental fatigue and subsequent power output for a given RPE value than when no cognitive task was performed. Ostensibly, after a cognitive task, participants in Brownsberger et al. (2013) opted to change their behaviour with a reduced power out (dysfunctional) compared to implementing behavioural/cognitive resources that would increase motivational intensity or reduce neuronal processing of effort-driving signals to maintain power output (functional). As Brownsberger et al. (2013) observed that a prior cognitive task elicits heightened neuronal activity, proponents of a strength model would surmise that this means a greater utilisation of resources (Vohs et al., 2014) which then stimulated greater neuronal processing of perceived effort (Englert et al., 2021; Marcora et al., 2007; Marcora & Staiano, 2010). In contrast, motivational-oriented models would theorise that prior cognitive tasks stimulated a motivational fatiguing effect (Müller & Apps, 2019) which subsequently made further self-control during an ensuing physical task seem less attractive (Chong et al., 2017) and contradictorily, more effortful (Inzlicht et al., 2014; Kurzban, 2016).

In summary, the enactment of self-regulatory strategies during the performance phase is highly individualised and context-dependent (McCormick et al., 2019). Using Carver & Scheier's (1982) cybernetics control theory, it has been related how an individual's attentional focus (Brick et al., 2014) parcels certain psychophysiological indices into the self-oriented, self-control loops to inform individuals of their current state. Hereon, the awareness of psychophysiological disturbances could impact the perception of effort via changes in central motor command or neuronal processing of corollaries. Thereon, the onus is on the individual to enact certain strategies to bring perceived effort back into accord with a preconceived reference point (fixed RPE) via changes in behaviour or cognitions (Carver & Scheier, 2009). In turn, these behavioural and/or cognitive strategies recalibrate the perceptions of effort either via direct changes to the central motor command or neuronal processing of effort-driving signals. Alternatively, these strategies could also possibly act via changes to the underlying psychophysiological state so that individuals are less aware of disturbance to the homeostatic state of the body. Thus, bring perceived state back into accord with the reference value (Carver & Scheier, 2000).

However, the engagement in self-control as part of these self-referential feedback loops may be taxing on finite resources associated with effort (Baumeister et al., 1994; Englert, 2016; Marcora et al., 2007; Vohs et al., 2014). Or self-control could also affect the motivational intensity of an individual (Chong et al., 2017; Inzlicht et al., 2014; Kurzban et al., 2013; Müller & Apps, 2019). Thus, making it harder to implement more targeted and appropriate self-regulatory strategies over time (Englert et al., 2021). Therefore, it is of interest to investigate how self-regulation of perceived effort during fixed perceived effort tasks may occur as this has yet to feature in any exercise science literature.

3.3.1.3. REFLECTION PHASE

Self-regulation concludes with the reflection phase in which an athlete will entertain self-judgements about their overall performance (McCormick et al., 2019). Herein, an individual will identify how their execution of the task (e.g., effort expenditure) matched up with their preconceived plans made in the forethought phase (McCormick et al., 2019). In doing so, an athlete will evaluate their overall performance and begin to formulate attributions as to why certain outcomes prevailed (Zimmerman, 2000). This is individualised as self-regulation is a self-referential system in which the athlete alone is responsible for deciding the perceived outcomes of a specific event (Zimmerman, 2000).

Self-reflection within this phase also has important connotations for future notions of perceived effort (Pageaux, 2014) and self-regulatory activity (Elferink-Gemser & Hettinga, 2017). As highlighted by Pageaux (2014b), a final sub-factor in the psychobiological model concerned the previous experiences of perceived effort in similar events. Notably, memories of prior exercise tasks at a given perceived effort will dictate the self-efficacy beliefs and other preconceptions of the individual for future tasks (Anstiss et al., 2018; Bandura, 1997; McCormick et al., 2015). Consequently, the approach to other future tasks can be affected by the psychophysiological dispositions of the individual (Venhorst et al., 2018b).

As highlighted previously, studies within the exercise science domain have discovered that a prior exercise bout (time-trial) shapes the performance of ensuing exercise bouts (Mauger et al., 2009). Specific to exercising at a fixed perceived effort Mauger et al. (2014) observed that exercising at a fixed RPE could be accurately reproduced based on a prior experience alone (i.e., without any exercise feedback). Furthermore, a recent study also found that power output and cardiorespiratory indices can also be reliably replicated across multiple fixed perceived effort exercises (O'Grady et al., 2021) likely due to a habituation effect (Siddle, 1991). On the other hand, other studies have also exhibited that inexperienced individuals (e.g., novices or children), index a more sporadic reproduction of prior efforts (Micklewright et al., 2012) which may be attributable to their lack of metacognitive abilities or embedded experiences to base subsequent performance off (Elferink-Gemser & Hettinga, 2017). Evidently then, prior engagements in exercise at set perceived effort intensities are stored within the individual's memory in which they utilise the associated psychophysiological experiences with the exercise to calibrate future exertional tasks (Elferink-Gemser & Hettinga, 2017; Mauger et al., 2014; O'Malley et al., 2023; Venhorst et al., 2018b).

Further to the gradual learning associated with perceived effort, individuals also utilise prior experience as a form of practice to develop more appropriate self-regulatory techniques (Elferink-Gemser & Hettinga, 2017). Like trial-and-error, prior practice allows participants to hone their self-regulatory skills to trial which strategies work most effectively to adapt perceptions of effort or regulate motivational intensity (Elferink-Gemser & Hettinga, 2017; McCormick et al., 2019). Furthermore, prior learning has also be postulated to make the self-control process of self-regulation automatic and effortless for future events (Cos, 2017; Siddle, 1991).

In conclusion, the self-regulatory process draws upon numerous lower order strategies to help bring the self into accord with the requirements of the task and the individual's preconceived goals (Carver & Scheier, 2000; McCormick et al., 2019; Zimmerman, 2000). Whilst this review has not divulged deeply into the specific self-regulatory strategies that might operate (e.g., self-talk, reappraisal) during a prolonged exercise bout like a 30-minute fixed perceived effort trial, the cybernetics control theory (Carver & Scheier, 1982) serves as a suitable framework (Figure 10b) to understand how individuals decide upon task-specific and individualised behavioural or cognitive strategies to manipulate perceptions of effort. These strategies can theoretically act to directly change the perception of effort via alterations in central motor command and therefore corollary discharge production or via modifications in the neuronal processing of corollaries (de Morree et al., 2012; Marcora, 2019; McCormick et al., 2019). Alternatively, a rationale has also been provided to suggest that changes in perceived effort could be caused more indirectly, such as changing the psychophysiological state of the individual which then precipitates changes in central drive or neuronal processing (Carver & Scheier, 1982, 2000; Venhorst et al., 2018b). Moreover, there may also be a means of changing perceived effort via changes in potential motivation/motivational intensity as it changes the relational value of current perceived effort to maximum conceived capacity (Figure 2).

3.4. RATIONALE

Working periodically through the content of the literature review, the narrative has followed what perceived effort is by definition (Bergevin et al., 2023; Borg, 1962, 1970; Marcora, 2010b; Pageaux, 2016) and its neurophysiological underpinnings to how perceived effort is generated in reference to the corollary discharge model (de Morree et al., 2012; Marcora, 2008; Pageaux, 2016). Furthermore, an explanation of how task behaviour such as exercise intensity is regulated according to the psychobiological model has also been related (Marcora, 2008, 2010a, 2019). Particularly, an explanation has been provided to how perceived effort and motivational intensity interact during endurance-based tasks to determine task performance. However, although Pageaux (2014b) highlights the psychobiological model as an effort-based decision-making model to explain endurance performance, there is a lack of depth in explanation as to how these decisions are made. Instead, there is only reference to perceived effort levels reaching a point at which the individual no longer feels that the task warrants or that they are motivated enough to invest the required effort anymore (Figure 7 and 8).

Therefore, the psychobiological model alone lacks the capacity to fully rationalise the decision-making processes that operate to regulate purely submaximal exercise. For example, a body of studies have found that exercise at a constant submaximal perceived effort (e.g., RPE *13 – somewhat hard*) results in a change in exercise intensity, usually, a reduction in power output or running velocity over time (Eston & Williams, 1988; Eston et al., 1987; Faulkner et al., 2007; O'Grady et al., 2021; Parfitt, Alrumh, et al., 2012; Parfitt, Evans, et al., 2012). Reviewing some of the fatigue literature (e.g., Aboodarda et al., Iannetta et al., 2022), this review has demonstrated why changes in power output are likely to occur during fixed perceived effort cycling due to the underlying neurophysiological and psychophysiological changes when conducting prolonged exercise. However, a crucial aspect of changing exercise intensity at a fixed perceived effort is that this is a conscious decision that is made by the participant.

Thus, this led the review onto models of self-regulation and its lower-order themes such as attentional strategies and self-control to provide more clarity into how an individual adapts their psychophysiological state and behaviour during fixed perceived effort trials to maintain a given RPE. In which, the self-regulatory processes from Zimmerman's (2000) social-cognitive perspective have explained the three-stage process of regulating effort-based decisions during exercise tasks. Mainly, during the performance phase of self-regulation (i.e., self-regulation during an event), this review has discussed that individuals can vary their attentional strategies to be selectively aware of their own cognitions and sensations (Brick et al., 2014). Next, using Carver and Scheier's (1982) cybernetics control theory (Figure 10b) it has been evidenced how individuals implement self-control to actively quell certain responses in favour of more functional alternatives with the overarching aim to maintain a fixed perceived effort.

In doing so, this literature review has brought together a range of theories and models across the kinesiology, sport science, and psychology domains. From which, this thesis aims to reconcile some of those theories to provide a clearer understanding as to how certain perceived effort intensities are self-regulated and the decision-making processes that underpin that regulation. As noted previously, to provide this clarity, researchers will adopt a psychophysiological approach to identify the underlying physiology (e.g., cardiorespiratory responses) related to behavioural and perceptual phenomena like perceived effort (Cacioppo et al., 2012). Thus, researchers can gather an understanding of the effect self-regulation has on physiological as well as psychological associated with given intensities of perceived effort. Furthermore, a mixed-method approach which employs qualitative data analysis would also glean more information to the underlying decision-making processes associated with regulating perceived effort during the event. this helps inform which self-regulatory strategies may be most appropriate.

3.5. OBJECTIVES

Therefore, the purpose of this thesis is to explore the psychophysiological indices associated with fixed perceived effort exercise during a 30-minute fixed perceived effort cycle. Thereon, differences in psychophysiological responses between different perceived effort intensities will be investigated (Study 1 and Study 2 [Part A]). Moreover, differences between experienced and inexperienced cyclists in the self-regulation of the psychophysiological indices and overall perceived effort during these trials will be explored (Study 2 [Part B]). Finally, a specific intervention of pain will be implemented to explore how psychophysiological indices change and the subsequent self-regulation of perceived effort may differ in the presence of varying afferent feedback (Study 3). All that is related is discussed in a general narration (Chapter 7) before final conclusions, inferences, and future directions of research are made (Chapter 8).

Chapter 4 – TEST-RETEST RELIABILITY OF A 30-MINUTE FIXED PERCEIVED EFFORT CYCLING EXERCISE AND DIFFERENCES BETWEEN FIXED PERCEIVED EFFORT INTENSITIES

This chapter forms a major part of the recent publication by O'Malley et al. (2023) https://doi.org/10.1007/s00421-022-05094-z with some adaptations made for the narrative of this thesis submission.

4.1. ABSTRACT

Using exercise protocols at a fixed rating of perceived effort (RPE) is a useful method for exploring the psychophysiological indices associated with perceived effort in an exercise context. However, studies that have employed this protocol have arbitrarily selected RPE values without demarcating how these values correspond to exercise intensity thresholds and domains. Therefore, aligning RPE intensities with established physiological boundaries seems appropriate, although the reliability of this method has not been assessed. Eight recreationally active cyclists completed two identical ramped incremental trials on a cycle ergometer to identify gas exchange threshold (GET). A linear regression model plotted RPE responses during this test alongside gas parameters to establish an RPE corresponding to GET (RPE_{GET}) and 15% above GET ($RPE_{+15\%GET}$). Participants then completed three trials at each intensity, in which power output, cardiorespiratory data, affective valence and self-efficacy measures were averaged into five-minute time zone (TZ) intervals and 30-minute 'overall' averages. Data were assessed for reliability using intraclass correlation coefficients (ICC) and accompanying standard error measurements, 95% confidence intervals, and coefficient of variations (CoV). Furthermore, linear mixed-model regression analysis assessed the condition, time, and condition × time interactions of all power output and psychophysiological variable data. Power output and ventilatory data showed excellent levels of test-retest reliability (ICCs = > .900) across both intensities. Overall measures of power output and cardiorespiratory data also demonstrated good intra-individual reliability (CoV = < 5%). Linear mixed-model

regression found significant condition interactions for all variables as well as condition × time interactions for power output, $\dot{V}O_2.kg^{-1}$, breathing frequency, blood lactate, and affective valence. To conclude, recreationally active cyclists can reliably produce fixed perceived effort exercise across multiple visits when RPE is aligned to physiological thresholds. Some evidence suggests that exercise at $RPE_{+15\%GET}$ is more reliable than RPE_{GET}. In addition, exercise at different intensities of perceived effort elicits *different* but also *distinct* behavioural and psychophysiological responses.

4.2. INTRODUCTION

Perceived effort is a crucial determinant in the regulation of exercise intensity (Marcora, 2008). In short, perceived effort is characterised as a psychophysiological phenomenon (Borg, 1962) involving a complex interaction between physical stimuli (e.g., power/velocity) and perceptual responses (Geschieder, 1997). Crucially, interpretations of perceived effort consider both subfactors. For instance, a lower perception of effort is deemed functional when an individual can achieve a higher output for a given rating of perceived effort (RPE) value *or* a lower rating of effort for a given velocity/power (Abbiss et al., 2015; McCormick et al., 2018).

Marcora (2009) highlights that perceived effort has two components, locomotor effort (Marcora et al., 2008) and respiratory effort (Dempsey et al., 2008). Locomotor effort encapsulates *how hard, heavy, and strenuous the exercise task feels to drive the working muscles* (Marcora, 2010b). Effort perceptions surrounding locomotor effort are likely derived from corollaries linked to central motor commands that are sent to working muscles (de Morree et al., 2012; Pageaux, 2016). The accumulated corollary discharge undergoes neuronal processing within cerebral centres such as the supplementary and presupplementary motor areas, anterior and middle cingulate cortices, and regions of the insula (de Morree et al., 2012; Williamson, 2006; Williamson et al., 2001; Zénon et al., 2015).

Alternatively, respiratory effort outlines a sub-component of dyspnea which concerns the perception of how hard one is breathing (Laviolette & Laveneziana, 2014). Gigliotti (2010) discerned that respiratory effort originates within the brain's anterior and middle cingulate cortices where the central processing of respiratory-related signals (e.g., changes in the partial pressure of oxygen/carbon dioxide, and neuromuscular work of respiratory muscles) generates the perceived difficulty to breathe (Kearon et al., 1991).

Borg's 15-point RPE scale (Borg, 1970) is widely accepted as the most convenient measure of assessing perceived effort. Initially conceived as a surrogate measure of exercise intensity/load (Borg, 1970), the use of the RPE scale has adapted to also allow contemporary researchers to obtain a singular value that simultaneously considers the neurophysiological integration of central commands in connection with psychosocial influences present in the current situation (Halperin & Emanuel, 2020). In addition, the RPE scale (Borg, 1970) and its derivatives (e.g., category-ratio 10 and 100, [Borg, 1998; Borg & Borg, 2002]) have also been used to prescribe exercise intensity (Faulkner et al. 2007), quantify training load (Seiler & Kjerland, 2006) and assess cardiorespiratory fitness (Faulkner et al., 2007; Mauger et al., 2013).

A novel method that has recently been employed is the use of fixed perceived effort exercise. During which, individuals are required to conduct an exercise in accordance with their perceptions of effort (Astokorki et al., 2017a, b; Cochrane et al., 2015a, b; Cochrane-Snyman et al., 2016, 2019). Such a task is a unique opportunity for individuals to self-regulate their exercise whilst maintaining a fixed perceived intensity. Furthermore, recent studies (Cochrane et al., 2015a, b) have aligned RPE intensities with established physiological boundaries such as GET and RCP. In doing so, researchers can begin to characterise the common psychophysiological response patterns that occur during set intensities of fixed RPE exercise. Furthermore, the procedure also allows researchers to examine the influence of additional psychophysiological phenomena on perceived effort and subsequent self-regulation of perceived effort (Halperin & Emanuel, 2020).

However, before adopting a specific protocol, it must be compared over repeated instances to determine whether it is reliable and that measures are precise. Across numerous laboratories, researchers, and studies, measured values should be accurately reproduced when the same procedure and measurements are repeated (Hopkins, 2000). This concept is known as test-retest reliability and must apply to both inter (between individuals) and intra (within individual) levels. Successively, intraclass correlation coefficient (ICC) calculations can determine whether a test is sufficiently reliable. Additionally, measures such as the standard error measurement (SEM) allow researchers to calculate the precision of these measurements and ascertain whether a substantial difference has occurred within subsequent studies that use the same methodology (Weir, 2005).

Several studies have identified that fixed perceived effort activity is reliable. For instance, O'Grady et al. (2021) discerned that exercise at three separate RPE intensities was considered reliable at both the intra- and inter-individual level. Notably, the more intense the fixed perceived effort exercise was, the more reproducible the findings were (i.e., RPE *17 – very hard* demonstrated better reliability than RPE *9 – very light*). Likewise, Cochrane-Snyman et al. (2016) – who utilised the more novel method of corresponding RPE intensities to know physiological boundaries – found that power output or running velocity and electromyographic responses were consistent during 60-minute fixed perceived effort exercises. However, this study did not measure the cardiorespiratory markers despite the methodological aim to tailor RPE intensity to a known physiological boundary using cardiorespiratory markers. As a result, the study could not determine the exercise intensity and boundaries as well as presenting no results to determine whether the cardiorespiratory responses were reliable.

Therefore, the purpose of this study was to probe the test-retest reliability of three separate 30-minute cycling trials whereby fixed perceived effort intensities were paired with exercises *at* and *above* GET. This study tested two main hypotheses. First, power output, cardiorespiratory (e.g., heart rate, $\dot{V}O_2.kg^{-1}$, $\dot{V}_E$, breathing frequency), and psychological (e.g., affective valence, self-efficacy) variables during both fixed perceived effort intensities would exhibit good levels of reliability. Second, based on findings by previous studies (Cochrane-Snyman et al., 2016; Eston & Williams, 1988; O'Grady et al., 2021), power output, cardiorespiratory (e.g., heart rate, $\dot{V}O_2.kg^{-1}$, $\dot{V}_E$, breathing frequency), and psychological (e.g., affective valence, self-efficacy) variables during a higher intensity fixed effort exercise would indicate higher reliability values compared to lower intensity fixed effort exercise.

4.3. METHODS

4.3.1. PARTICIPANTS

Eight healthy, (seven male; one female) recreationally active cyclists ([M ± SD] age: 24 ± 2.6 years; stature: 1.75 ± 0.1 m; mass: 72 ± 11.5 kg and maximum oxygen uptake [$\dot{V}O_2max$]: 54 ± 5.8 ml.kg^{-1}.min^{-1}) participated in the present study. All participants had at least two years of cycling experience (9 ± 3.4 years) and met nationally recognised guidelines for weekly physical activity (659 ± 386 $min \cdot wk^{-1}$). In addition, all participants were free from underlying cardiorespiratory or other pre-existing medical conditions and injuries. None of the participants were currently taking any medication. Prior to providing written informed consent, participants were informed of the procedures, benefits, and risks of the study. The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the School of Sport and Exercise Sciences Research Ethics Advisory Group (Prop 31_2019_20).

4.3.2. PERCEPTUAL SCALES

4.3.2.1. RATINGS OF PERCEIVED EFFORT SCALE

Both parts of the study used the Borg 15-point RPE scale (Borg, 1970) which denoted *how hard, heavy, and strenuous does the exercise feel to drive the working muscles and your breathing* (Marcora, 2010b). To maximise the measurement validity of the RPE scale, the semantic representation of perceived effort that researchers provided was precise and consistent according to the aforementioned definition (Halperin & Emanuel, 2020). Additionally, the same anchors for the minimum (*6 – like when you are sitting at rest, doing absolutely nothing*) and maximum (*20 – like giving everything you have got at the end of a* $\dot{V}O_2max$ *test*) ratings were provided (Malleron et al., 2023). Moreover, added scales that encapsulated similar psychophysiological phenomena were used in this study.

4.3.2.2. AFFECTIVE VALENCE SCALE

Responses for affective valence were collected via the single-item, 11-point feeling scale (Hardy & Rejeski, 1989) denoting *how are you feeling at the current moment of the exercise*. Responses ranged from *+5 - I feel very good* to *-5 - I feel very bad* with a median of *0 - neutral*.

4.3.2.3. SELF-EFFICACY SCALE

Responses for self-efficacy were collected via an adapted single-item visual analogue scale according to Bandura's social-cognitive framework (1997) denoting *how confident are you that you can tolerate the physical and mental effort associated with the task to maintain your current performance level*. Responses ranged from *10 - extremely confident* to *0 - not at all confident* with a median of *5 - moderately confident*.

4.3.3. PROCEDURES

This study employed a within-participants randomised crossover design, wherein participants were required to visit the laboratory on eight separate occasions (Figure 11). All experimental sessions were conducted a minimum of two days and maximum of seven days apart. Each participant was scheduled at the same time of day (± 2 hours). *Visits 1 and 2* involved identical ramped incremental $\dot{V}O_2max$ tests on a cycle ergometer with an ensuing fixed perceived effort familiarisation cycle. *Visits 3 – 8* consisted of 30-minute fixed perceived effort cycling bouts that matched to one of two intensities (see section 4.3.3.2). Each condition/intensity was completed three times wherein the completion of each intensity was conducted in a randomised, alternating order to prevent any order effects. Randomisations can be seen in Appendix 1. All procedures took place in the same laboratory setting which had a constant temperate environment ([M ± SD] Temperature, 19.3 ± 0.6 °C; Humidity, 40.2 ± 4.3%; Barometric Pressure, 751.5 ± 3.2 mmHg). All research sessions were scheduled at the same time of day (± 2 hours), and participants abstained from food (2 hours), caffeine (4 hours), alcohol (24 hours), intense exercise (48 hours) and were asked to replicate eating habits in the 24 hours leading up to each session. All female participants were eumenorrheic and were scheduled to conduct all procedures during their luteal stage to minimise any confounding effects due to the stage of menses in the study (McNulty et al., 2020).

4.3.3.1. VISITS 1 AND 2 - RAMPED INCREMENTAL $\dot{V}O_2$MAX TESTS AND FAMILIARISATIONS.

Upon arrival to the laboratory, anthropometric data were obtained along with a 20 μL resting blood lactate sample from the right-hand index finger which was lysed and assessed using an automated analyser (Biosen: C-Line, EKF Diagnostics, GmbH, Barleben, Germany). After this, participants were briefed on the protocols of the ramped incremental test, the scales used during the test, and subsequent familiarisation whilst being fitted with a heart rate monitor (Cyclus 2: ANT+, Leipzig, Germany) for measurements on a beat-by-beat basis. Participants were then asked to perform a short self-selected five-minute warm-up on the cycle ergometer (Cyclus 2, Leipzig, Germany) which allowed participants to mount their own bike frame for familiarity. Each participant used the same bike frame throughout all visits.

During the completion of the warm-up, the researcher re-explained the RPE scale which would be administered throughout the test. After completing the warm-up, participants were fitted with a mask that covered the nose and mouth and connected to a flowmeter that was attached to a metabolic cart system (Cortex Metalyser: Model 3B, Leipzig, Germany) which measured gas exchange parameters and pulmonary ventilation (inspired and expired flow rates) on a breath-by-breath basis. The gas analyser was pre-calibrated using a fixed three litre syringe (Hans Rudolph, Kansas, USA) and known gas concentrations. After participants were fitted to the equipment, confirmed an understanding of the perceptual scales, and provided a resting value for the RPE scale, the ramped incremental test began. The affective valence and self-efficacy scales were used exclusively during the familiarisation and experimental trials.

For the ramped incremental tests, males were required to cycle at 80 W for three minutes to allow gas parameters to stabilise before commencing the test. Once elapsed, the incremental ramped test began at 100 W and increased incrementally by 25 $W \cdot min^{-1}$. In contrast, females were required to cycle at 40 W for three minutes to allow gas parameters to stabilise before the commencement of the $\dot{V}O_2$max test at 50 W with identical 25 $W \cdot min^{-1}$ ramped increments. These intensities were selected as pilot testing showed that these starting intensities and progressions every minute resulted in all participants reaching volitional exhaustion within the recommended eight to ten-minute period (Keir et al., 2015). All participants were informed to maintain a cadence above 80 $revolutions \cdot min^{-1}$ which should gradually increase as cycling intensity became harder until they could no longer sustain the exercise. Each minute (including at 50 [females] or 100 [males] W), RPE was recorded. Power output (each second) and cardiorespiratory (beat-by-beat and breath-by-breath) were monitored continuously throughout the test. Participants were expected to perform to their maximum perceived ability. Whereupon the participant: a) believed they had reached volitional exhaustion; or b) cadence dropped below 60 revolutions·min^{-1} for more than five seconds despite strong verbal encouragement, the test was stopped. Additional RPE measures were taken at exhaustion alongside a final blood lactate sample.

After the cessation of the ramped incremental test, participants received 15-minutes passive recovery and then conducted a ten-minute familiarisation (five minutes at RPE *13 – somewhat hard* and *15 - hard* each) to the fixed perceived effort cycling trials. During these familiarisation trials, participants maintained a cadence between 80 - 90 revolutions·min^{-1} which was then used as a reference for the experimental visits. Intensities of RPE *13 – somewhat hard* and *15 - hard* were selected based on previous studies findings as to what experimental fixed perceived effort intensities would correspond to (Cochrane et al. 2015b; Cochrane-Snyman et al. 2016).

4.3.3.2. DETERMINATION OF RPE_{GET} AND $RPE_{+15\%GET}$

Individual's GET was determined by utilising a $\dot{V}$-slope method (Beaver et al., 1986) whereby GET corresponded to the point at which $\dot{V}O_2$ values above and below the breakpoint with expired carbon dioxide ($\dot{V}CO_2$) diverged from the intersection of the two linear regression lines. For validation, $\dot{V}$-slope was used in conjunction with secondary criteria including: ventilatory equivalents; end-tidal volumes and respiratory exchange ratio. A secondary researcher conducted their own GET analysis and corresponded it with the primary researcher's analysis to confirm that GET was assigned at the same place. Any disagreements were discussed and agreed upon between the researchers. Once GET was determined, $\dot{V}O_2$ values that were 15% above GET were also calculated. Using these values, the power output that was exerted over the course of the ramped incremental test was plotted against the $\dot{V}O_2$ and a linear regression equation (y = mx + c) derived the power output that corresponded to GET and 15% above GET. Finally, the ramped incremental power output data were plotted against the obtained RPE values in which an identical linear regression equation was used to identify the RPE corresponding to GET (RPE_{GET}) and 15% above GET ($RPE_{+15\%GET}$). These RPE values were rounded to the nearest whole number. An average of the two values from *Visits 1 and 2* were used as reference RPE points for *Visits 3 – 8*, experimental visits.

4.3.3.3. FIXED EFFORT CYCLING (EXPERIMENTAL SESSIONS)

After participants completed an identical warm-up and baseline measures to *Visits 1 and 2*, participants mounted the ergometer and were asked to cycle at RPE *10 - between very light and light* for two minutes. Once two minutes had elapsed, approximately 30 – 60 seconds was afforded for participants to ramp up to the required RPE intensity based on average times to reach the required RPE in pilot testing (mean time taken = 42 seconds).

The researcher(s) stressed that the task was a fixed perceived effort trial, meaning RPE must remain constant throughout. As a result, power output changes were expected, therefore, participants could change their power output by increasing/decreasing the virtual gears on the ergometer to ensure the appropriate RPE was maintained throughout the entirety of the fixed perceived effort cycles. Virtual gears on the Cyclus2 system were calibrated to the gear ratio that was used by all participants (50 / 13). Any changes to the virtual gears would adjust the magnetic resistance of the ergometer's rear flywheel which the bike frame was attached to. Participants were advised to maintain a cadence between 80 – 90 revolutions$\cdot$min^{-1} throughout and to replicate this cadence (± 2 revolutions$\cdot$min^{-1}) in all subsequent experimental visits.

Throughout the fixed perceived effort trials all data except cadence were screened from the participants to ensure that the task was solely regulated according to perceived effort. Though participants could have potentially counted their number of gear changes alongside a fixed cadence to replicate their outputs, this would have been unlikely. Crucially, the researcher reemphasised the requirement for participants to constantly tailor their outputs according to a fixed perception of effort which the participants reaffirmed to the researcher every two minutes. During fixed perceived effort cycling, power output and cardiorespiratory markers (heart rate, $\dot{V}O_2.kg^{-1}$, $\dot{V}_E$, breathing frequency, $\dot{V}_T$, and respiratory exchange ratio) were extracted continuously (each second) throughout the 30-minute exercise. Every five minutes, including baseline (Minute 0), blood lactate, affective valence and self-efficacy were extracted/recorded.

Figure 11 depicts all testing procedures. After the completion of all visits, participants were fully debriefed before being permitted to leave.

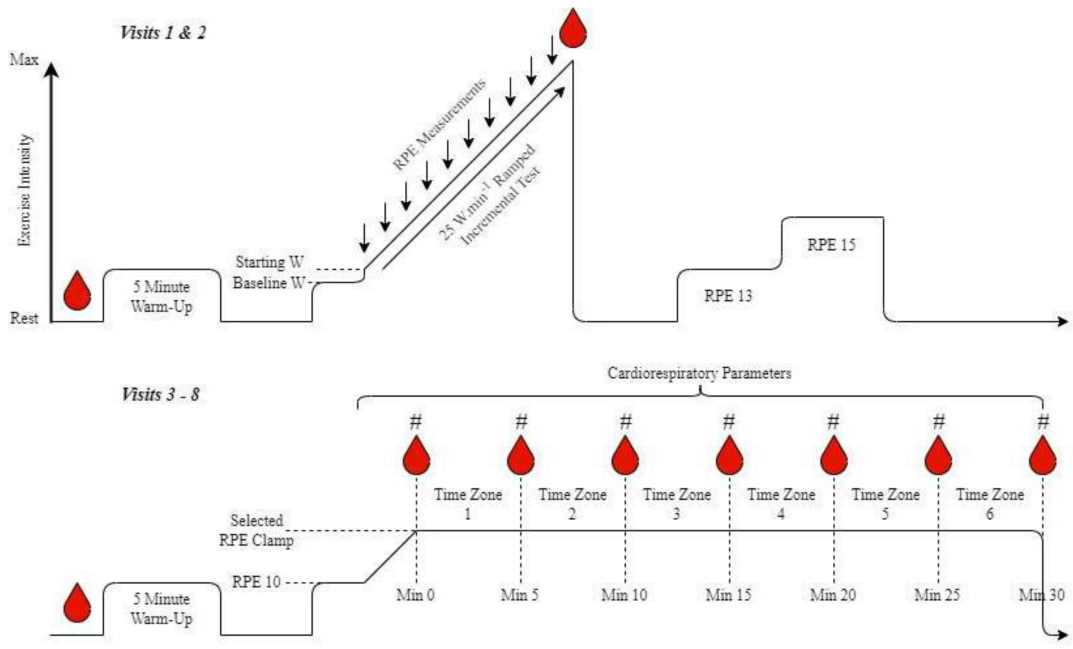


Figure 11. Visual representation of Study 1 protocols. W represents power output. # indicates affective valence and self-efficacy measurements. 🌢 represents blood lactate measurements. ↓ represent rating of perceived effort (RPE) measurements.

4.3.4. ANALYSIS

Continuous data (e.g., power output, cardiorespiratory parameters) from experimental session data were averaged into six discrete five-minute time zones (TZ) (e.g., TZ1 = average from Minute 00:00 – Minute 04:59). Other data (e.g., blood lactate, perceptual measures) were grouped based on when they were extracted, (e.g., minute 0, 5, etc.). Finally, all data were also averaged over the entirety of the exercise as ‘overall’ (average from Minute 0 – Minute 30).

All data were first exported to SPSS (IBM: v.26, New York, USA) where data were assessed for normality and symmetry. Normality was assessed using the Shapiro-Wilk test and visual inspection of Q-Q plots before any subsequent analysis. Power output, cardiorespiratory (e.g., heart rate, $\dot{V}O_2.kg^{-1}$) and RPE responses from the ramped incremental tests were analysed according to 30-second averaged values. For *Visits 1 and 2*, a mean across both visits was calculated for values at peak, GET and 15% above GET. A single-measures, two-way ICC

(3,1) was calculated between both ramped incremental tests for peak, GET, and 15% above GET values with accompanying SEM to assess the test-retest reliability of *Visits 1 and 2*. The ICC values were interpreted as ≥ 0.9 excellent reliability, ≥ 0.8 good reliability, ≥ 0.6 questionable reliability and < 0.6 poor reliability. A Pearson (*r*) correlation coefficient was also conducted to assess the relationship of power output, physiological and RPE values between each ramped incremental test with values ≥ 0.9 indicating very strong, ≥ 0.8 strong, ≥ 0.6 moderate, ≥ 0.4 weak and < 0.4 no association.

Test-retest (inter-individual) reliability for data within *Visits 3 – 8* (experimental sessions) were assessed across TZ averaged and 'overall' (30-minute averaged) data for power output, heart rate, blood lactate gas parameters ($\dot{V}O_2.kg^{-1}$, $\dot{V}_E$, breathing frequency), and psychometric (affective valence and self-efficacy) data. When calculating reliability using a single-measures, two-way, mixed ICC (3,1) and accompanying SEM, data from each visit within each condition were used. The SEM was used to calculate a minimal difference (see equation 1). Subsequent 95% confidence intervals (95%*CI*) for each of these variables were calculated by subtracting and adding the minimal difference to the group mean. A coefficient of variation (CoV) was also used to identify intra-individual variation for 'overall' 30-minute averaged power output, $\dot{V}O_2.kg^{-1}$, heart rate, $\dot{V}_E$, breathing frequency, and blood lactate with measurement errors of ≤ 5% indicative of reliability. As CoV was presented as a percentage the Tate and Klett (1959) method was used to calculate 95%*CI* for measures of intra-individual reliability.

(1) Minimal Difference = SEM × 1.96 × √2 – (Weir, 2005)

After reliability analysis, data were the exported to Jamovi (JAMOVI: v 2.3, Sydney, Australia). A series of random-intercepts linear mixed-effects models (LMM) were conducted to assess the condition and time effects, and condition × time interactions on all dependent variables data. Within LMM, all data from all visits and TZ were included except for overall (30-minute averaged) data. The condition main effect was the intensity of the fixed perceived effort exercise (RPE_{GET} versus $RPE_{+15\%GET}$). The variables of *condition* and *time* were set as fixed effects. Models were fitted according to the group intercept. Results from the LMM were reported as *t* values (RPE_{GET} versus $RPE_{+15\%GET}$) as time was entered as a continuous variable. Another benefit to this method is that reporting of estimated marginal means (β-coefficient) denotes the raw mean differences between the two conditions as an effect size with supplementary an upper and lower *95%CI*. The LMM used each participant as a cluster variable so that the variation across visits 1-3 within each condition was accounted for. Equation 2 shows the clustering variable within the LMM string that was used to assess condition and time effects, and condition × time interactions. A normality test was conducted on the residual values and if they violated normality, a Wilcoxon signed ranks test was reported with a rank biserial correlation (*r*) denoting effect size. However, no residual values for power output, cardiorespiratory, blood lactate, or perceptual measures violated normality. Subsequent presentation of "group mean" data in Table 1 – 2, Figures 12 – 15, and Appendix 2 denotes the 'mean of means' which has been calculated according to the average across all three visits within each condition. Thereon, the average value from the three visits in each condition has then also been averaged across the entire group.

(2) (Dependent Variable) = Condition + Time Zone + Condition:Time Zone + (1|Participant)

4.4. RESULTS

4.4.1. VISITS 1 & 2 (RAMPED INCREMENTAL TESTS)

4.4.1.1. CORRELATION COEFFICIENT BETWEEN VISITS

Mean group data demonstrated a peak power output of 349 ± 36 W which showed strong test-retest reliability and strong correlations between ramped incremental visits (ICC = .962, SEM = 6.97, r = .962). Mean peak $\dot{V}O_2.kg^{-1}$ was 52 ± 7 $mL.kg^{-1}.min^{-1}$ and demonstrated a questionable test-retest reliability but strong correlations between ramped incremental trials (ICC = .792, SEM = 3.05, r = .925). Finally, mean peak heart rate was 194 ± 6 $b.min^{-1}$ and demonstrated strong test-retest reliability and correlations between ramped incremental trials (ICC = .916, SEM = 1.62, r = .945).

Mean power output corresponding to GET was 201 ± 29 W and demonstrated strong test-retest reliability and correlations between ramped incremental tests (ICC = .957, SEM = 6.01, r = .968). Mean $\dot{V}O_2.kg^{-1}$ at GET was 33 ± 4 $mL.kg^{-1}.min^{-1}$ and demonstrated strong test-retest reliability and correlations (ICC = .929, SEM = 1.12, r = .960). Finally, mean heart rate at GET was 158 ± 7 $b.min^{-1}$ and demonstrated questionable test-retest reliability and correlations between ramped incremental visits (ICC = .668, SEM = 4.14, *r* = .629).

Mean power output corresponding to 15% above GET was 236 ± 34 W and demonstrated strong test-retest reliability and correlations between ramped incremental trials (ICC = .955, SEM = 7.31, *r* = .963). Mean $\dot{V}O_2.kg^{-1}$ at 15% above GET was 38 ± 5 $mL.kg^{-1}.min^{-1}$ and demonstrated strong test-retest reliability and correlations between ramped incremental trials (ICC = .910, SEM = 1.49, *r* = .962). Finally, mean heart rate at 15% above GET was 168 ± 8 $b.min^{-1}$ and demonstrated questionable test-retest reliability and correlations between ramped incremental trials (ICC = .664, SEM = 4.36, *r* = .677).

Mean RPE at GET was 13.0 (*13 – somewhat hard*). Mean RPE at 15% above GET was 14.7 (*15 – hard*). Participant reference values for RPE_{GET} ranged from 12 to 14 (1n = RPE 12, 6n = RPE 13, 1n – RPE 14), whilst reference values for $RPE_{+15\%GET}$ ranged from 14 to 16 (1n = RPE 14, 6n = RPE15, 1n = RPE 16).

4.4.2. VISITS 3 – 8 (EXPERIMENTAL SESSIONS)

4.4.2.1. TEST-RETEST RELIABILITY

Single measure test-retest reliability measures indicated that overall (30-minute averaged) measures of power output and $\dot{V}O_2.kg^{-1}$ demonstrated an excellent degree of reliability within the RPE_{GET} condition (Table 1). Overall heart rate, blood lactate, $\dot{V}_E$ (ICC = .839, SEM = 5.08), and self-efficacy (ICC = .807, SEM = 0.45) measures showed a good degree of reliability whilst overall breathing frequency (ICC = .728, SEM = 1.66) and affective valence (ICC = .749, SEM = 0.48) showed a questionable reliability within the RPE_{GET} condition Within the $RPE_{+15\%GET}$ condition, overall measures of power output, $\dot{V}O2.kg^{-1}$, blood lactate (Table 2), $\dot{V}_E$ (ICC = .963, SEM = 3.26), and breathing frequency (ICC = .969, SEM = 0.96) demonstrated an excellent degree of reliability, whilst heart rate showed a good degree of reliability, and affective valence (ICC = .770, SEM = 0.65) and self-efficacy (ICC = .711, SEM

= 0.65) demonstrated questionable reliability. Main group mean overall and TZ results can be seen in Table 1 and 2).

Table 1. Group mean RPE_{GET} inter- and intra-individual results for each time zone and overall.

Variable	TZ	Mean	SD	ICC (3,1)	SEM	95%*CI*	*CoV*
Power Output	1	184	8.1	.903	2.5	177 – 192	*4.4*
	2	182	8.0	.919	2.3	176 – 188	
	3	179	7.3	.924	2.0	174 – 185	
	4	176	8.4	.906	2.6	169 – 184	
	5	176	9.7	.884	3.3	166 – 184	
	6	175	9.8	.887	3.3	166 - 184	
	Overall	179	8.0	.915	2.3	172 – 185	
Heart rate	1	144	8.8	.566	5.8	128 – 160	*3.1*
	2	153	12.4	.882	4.2	142 – 165	
	3	155	13.2	.884	4.5	143 – 168	
	4	156	12.6	.806	5.5	141 – 171	
	5	157	12.7	.778	6.0	141 – 174	
	6	158	13.0	.805	5.8	142 – 174	
	Overall	154	11.9	.825	5.0	140 – 168	
$\dot{V}O_2.kg^{-1}$	1	33	5.5	.915	1.6	29 – 38	*4.2*
	2	35	6.7	.950	1.5	31 – 39	
	3	35	6.9	.943	1.7	30 – 40	
	4	35	7.1	.921	2.0	29 – 40	
	5	35	7.3	.928	2.0	29 – 40	
	6	35	7.6	.910	2.3	29 – 41	
	Overall	35	6.8	.932	1.8	30 - 40	
Blood Lactate	Min 0	2.46	0.6	.735	0.3	1.55 – 3.37	*12.7*
	Min 5	3.63	1.3	.837	0.5	2.21 – 5.04	
	Min 10	4.04	1.9	.820	0.8	1.85 – 6.23	
	Min 15	4.24	2.2	.881	0.8	2.10 – 6.37	
	Min 20	4.10	2.1	.823	0.9	1.61 – 6.60	
	Min 25	4.05	2.3	.835	0.9	1.51 – 6.59	
	Min 30	4.20	2.6	.831	1.1	1.26 – 7.14	
	Overall	3.34	1.6	.849	0.6	1.67 – 5.01	

Note: Group mean data refers to the mean of means wherein each value denotes the mean across all three visits within each condition which has then been averaged across the entire cohort.

Table 2. Group mean $RPE_{+15\%GET}$ inter- and intra-individual results for each time zone and overall.

Variable	TZ	Mean	SD	ICC (3,1)	SEM	95%*CI*	*CoV*
Power Output	1	219	10.9	.896	3.52	209 – 229	*2.2*
	2	208	5.0	.941	1.22	205 – 212	
	3	201	7.0	.928	1.89	195 - 206	
	4	199	4.7	.945	1.11	196 – 202	
	5	195	4.8	.960	0.95	193 – 198	
	6	193	5.5	.943	1.32	190 - 197	
	Overall	203	4.3	.962	0.84	201 – 206	
Heart rate	1	159	9.0	.807	3.97	148 – 170	*1.6*
	2	167	10.5	.849	4.10	156 – 179	
	3	168	11.1	.853	4.24	156 – 180	
	4	169	10.4	.874	3.70	159 – 179	
	5	170	11.0	.853	4.22	158 – 182	

	6	171	11.9	.868	4.31	159 – 183	
	Overall	167	10.5	.876	3.69	157 - 178	
$\dot{V}O_2.kg^{-1}$	1	39	5.5	.902	1.73	34 – 44	*2.7*
	2	40	6.1	.947	1.40	37 – 44	
	3	39	6.1	.931	1.59	35 – 44	
	4	39	6.0	.939	1.47	35 – 43	
	5	39	6.4	.937	1.62	35 – 43	
	6	39	6.5	.936	1.64	34 – 43	
	Overall	39	6.0	.951	1.34	36 - 43	
Blood Lactate	Min 0	3.36	0.9	.813	0.4	2.28 – 4.44	*9.2*
	Min 5	6.25	2.2	.819	0.9	3.68 – 8.82	
	Min 10	6.95	2.9	.871	1.0	4.07 – 9.84	
	Min 15	6.76	3.2	.948	0.7	4.74 – 8.79	
	Min 20	6.86	3.5	.941	0.8	4.51 – 9.20	
	Min 25	6.85	3.8	.953	0.8	4.58 – 9.11	
	Min 30	6.70	3.8	.917	1.1	3.69 – 9.72	
	Overall	5.47	2.4	.939	0.6	3.80 – 7.13	

Note: Group mean data refers to the mean of means wherein each value denotes the mean across all three visits within each condition which has then been averaged across the entire cohort.

When assessing five-minute TZ data, power output reliability within the RPE_{GET} condition was excellent from TZ1 – 4 whilst TZ5 – 6 were considered good. Within the $RPE_{+15\%GET}$ condition, all time zones except TZ1 indexed an excellent degree of reliability.

During the RPE_{GET} and $RPE_{+15\%GET}$ condition, all $\dot{V}O2.kg^{-1}$ values demonstrated an excellent degree of reliability across all time zones. During the RPE_{GET} condition, heart rate values showed a good degree of reliability within TZ2, 3, 4, and 6, whilst TZ5 showed questionable reliability and TZ1 showed poor reliability. Alternately, within the $RPE_{+15\%GET}$ condition, all heart rate TZ data showed a good degree of reliability.

During the RPE_{GET} condition, $\dot{V}_E$ showed good reliability across all time zones except TZ5 which showed questionable reliability. During the $RPE_{+15\%GET}$ condition, excellent reliability across all time zones was observed except at TZ1 which showed good reliability. During the RPE_{GET} condition, breathing frequency showed questionable validity across all time zones, whereas the $RPE_{+15\%GET}$ condition showed excellent reliability across all time zones except TZ1 which showed good reliability.

During the RPE_{GET} condition, blood lactate demonstrated good reliability at every timepoint except minute 0 (questionable), whereas the $RPE_{+15\%GET}$ condition demonstrated excellent reliability of measures taken at minute 15 – 30 and good reliability at measures taken from minute 0 – 10.

During the RPE_{GET} condition, affective valence demonstrated good reliability at minute 0 – 5, questionable reliability at minute 10, 15, and 25, and poor reliability at minute 20 and

30. During the $RPE_{+15\%GET}$ condition affective valence demonstrated questionable reliability from minute 0 – 15 and minute 30, and poor reliability at minute 20 -25.

Self-efficacy data during the RPE_{GET} condition demonstrated good reliability at minute 0, 5, and 30, questionable reliability at minute 10 - 20, and poor reliability at minute 25. Self-efficacy data during the $RPE_{+15\%GET}$ condition demonstrated a good reliability at minute 0 and 5, questionable reliability at minute 10, and poor reliability at minute 15 - 30.

4.4.2.2. INTRA-INDIVIDUAL RELIABILITY

Measures of intra-individual reliability demonstrated that overall power output varied by a mean ± SD of 4.4 ± 1.5% (95%*CI* 2.9 – 8.9%) within the RPE_{GET} condition, whereas the $RPE_{+15\%GET}$ condition varied by 2.2 ± 1.1% (95%*CI* 1.5 – 4.5%) on average.

Overall $\dot{V}O2.kg^{-1}$ was 4.2 ± 1.5% (95%*CI* 2.8 – 8.5%) during the RPE_{GET} condition and 2.7 ± 1.3% (95%*CI* 1.8 – 5.5%) during the $RPE_{+15\%GET}$ condition. Variability in Overall heart rate was 3.1 ± 1.1% (95%*CI* 2.0 – 6.2%) in the RPE_{GET} condition and 1.6 ± 1.2% (95%*CI* 1.1 – 3.3%) in the $RPE_{+15\%GET}$ condition.

Mean ± SD overall $\dot{V}_E$ variability was 6.2 ± 1.2% (95%*CI* 3.2 – 9.3) during the RPE_{GET} condition and 2.8 ± 1.1% (95%*CI* 1.0 – 4.6) during the $RPE_{+15\%GET}$ condition. Overall breathing frequency variability was 4.0 ± 2.0% (95%*CI* 3.1 – 5.0) during the RPE_{GET} condition and 2.6 ± 1.1% (95%*CI* 1.9 – 3.3) during the $RPE_{+15\%GET}$ condition. Mean ± SD overall blood lactate variability was 12.7 ± 9.6% (95%*CI* 12.4 – 13.0) during the RPE_{GET} condition and 9.2 ± 7.3% (95%*CI* 8.9 – 9.4) during the $RPE_{+15\%GET}$ condition.

4.4.2.3. DIFFERENCES BETWEEN RPE_{GET} AND $RPE_{+15\%GET}$ CONDITIONS

Power output demonstrated a significant condition effect as it was found to be significantly higher in the $RPE_{+15\%GET}$ than the RPE_{GET} condition $(t_{277} = 18.48, p = .001, \beta = 23.90\ [21.36,26.43])$. Power output also showed significant changes over time

($t_{277} = -9.08, p = .001, \beta = -3.44\ [-4.18, -2.69]$). Finally, changes in power output also varied between RPE intensities as a condition × time interaction was also observed ($t_{277} = -3.64, p = .001, \beta = -2.75\ [-4.24, -1.27]$) suggesting power output declined more in the $RPE_{+15\%GET}$ than the RPE_{GET} condition (Figure 12).

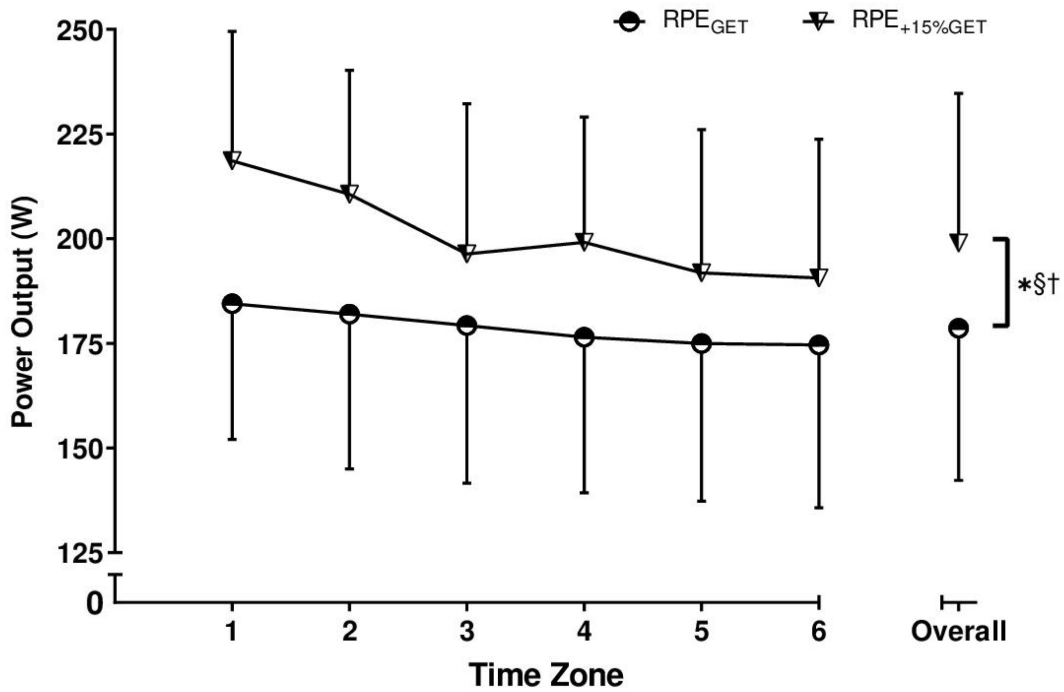


Figure 12. Group mean power output responses during fixed perceived effort cycling. Significant condition (∗), time (§), and condition × time (†) effects illustrated. Note: Group mean data refers to the mean of means wherein each value denotes the mean across all three visits within each condition which has then been averaged across the entire cohort.

Heart rate also exhibited condition ($t_{268} = 18.09, p = .001, \beta = 13.73\ [12.24, 15.22]$) and time ($t_{268} = 10.04, p = .001, \beta = 2.24\ [1.80, 2.67]$) main effects. However, there was not condition × time interaction to suggest heart rate changes were similar between RPE intensities (Figure 13a). Alternatively, $\dot{V}O_2.kg^{-1}$ showed a condition ($t_{277} = 20.21, p = .001, \beta = 4.83\ [4.36, 5.29]$) but no time main effect to suggest that $\dot{V}O_2.kg^{-1}$ remained stable across both conditions but there was a significant difference between the two. In addition, $\dot{V}O_2.kg^{-1}$ demonstrated a condition × time interaction ($t_{277} = -3.02, p =$

$.003, \beta = -0.42\ [-0.70, -0.15]$) suggesting a difference in how $\dot{V}O_2$.kg^{-1} responses changed over time based on the intensity of fixed effort exercise being conducted (Figure 13b).

Other cardiorespiratory variables like $\dot{V}_E$ demonstrated condition ($t_{277} = 24.06, p = .001, \beta = 21.88$ [20.1,23.66]) and time ($t_{277} = 3.97, p = .001, \beta = 1.06$ [0.54,1.58]) main effects. However, a condition × time interaction was not observed to suggest though values were different between conditions and changed over time, the trajectory of these changes were similar (Figure 13c). Breathing frequency also showed condition ($t_{277} = 21.16, p = .001, \beta = 6.71$ [6.09,7.33]) and time ($t_{277} = 11.95, p = .001, \beta = 1.11$ [0.93,1.29]) main effects. Also, a condition × time interaction was found for breathing frequency ($t_{277} = 2.77, p = .006, \beta = 0.51$ [0.15,0.88]) suggesting that breathing frequency differed between conditions, changed significantly over time and that these changes were significantly difference in trajectory between conditions (Figure 13d).

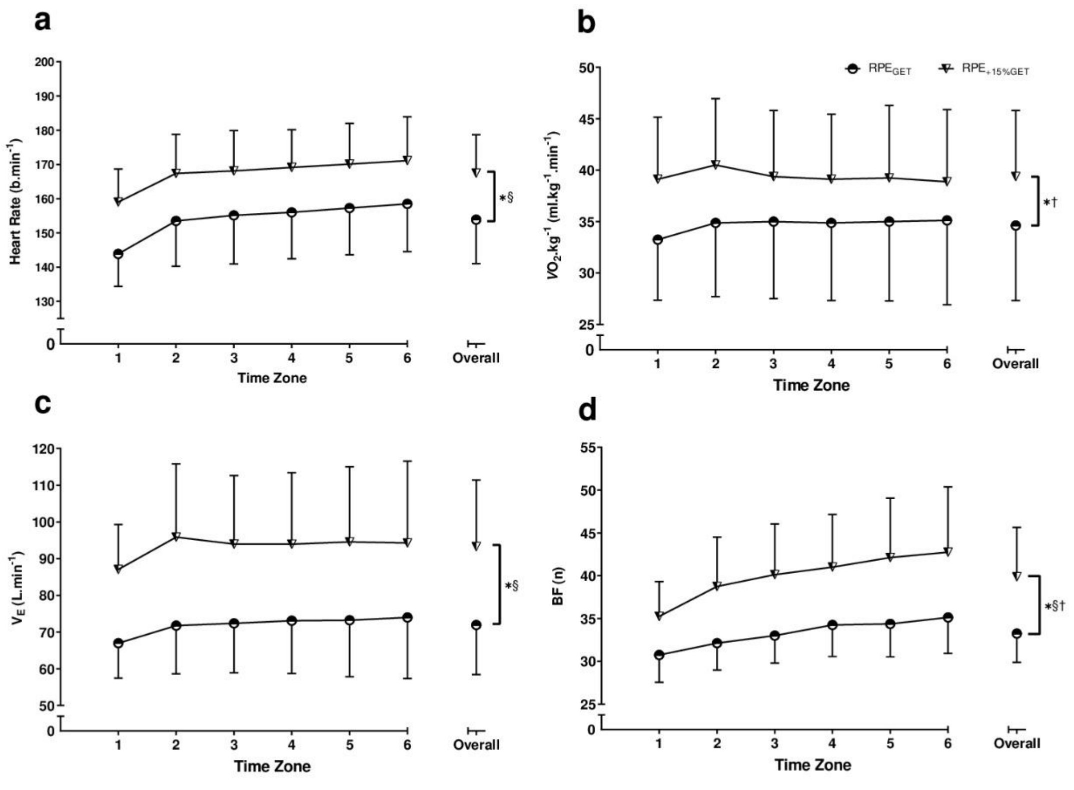


Figure 13. Group mean (a) heart rate, (b) relative oxygen uptake ($\dot{V}O_2$.kg^{-1}), (c) minute ventilation ($\dot{V}_E$), (d) breathing frequency (BF) responses during fixed perceived effort trials. Significant condition (∗), time (§), and condition × time (†) effects illustrated. Note: Group mean data refers to the mean of means wherein each value denotes the mean across all three visits within each condition which has then been averaged across the entire cohort.

For blood lactate, a condition ($t_{325} = 13.59, p = .001, \beta = 2.43$ [2.08,2.78]) and time ($t_{325} = 6.90, p = .001, \beta = 0.31$ [0.22,0.40]) main effect was observed. Furthermore, a condition × time interaction ($t_{325} = 2.00, p = .047, \beta = 0.18$ [0.00,0.35]) exhibited a significant difference showing that blood lactate responses differed between RPE intensities (Figure 14).

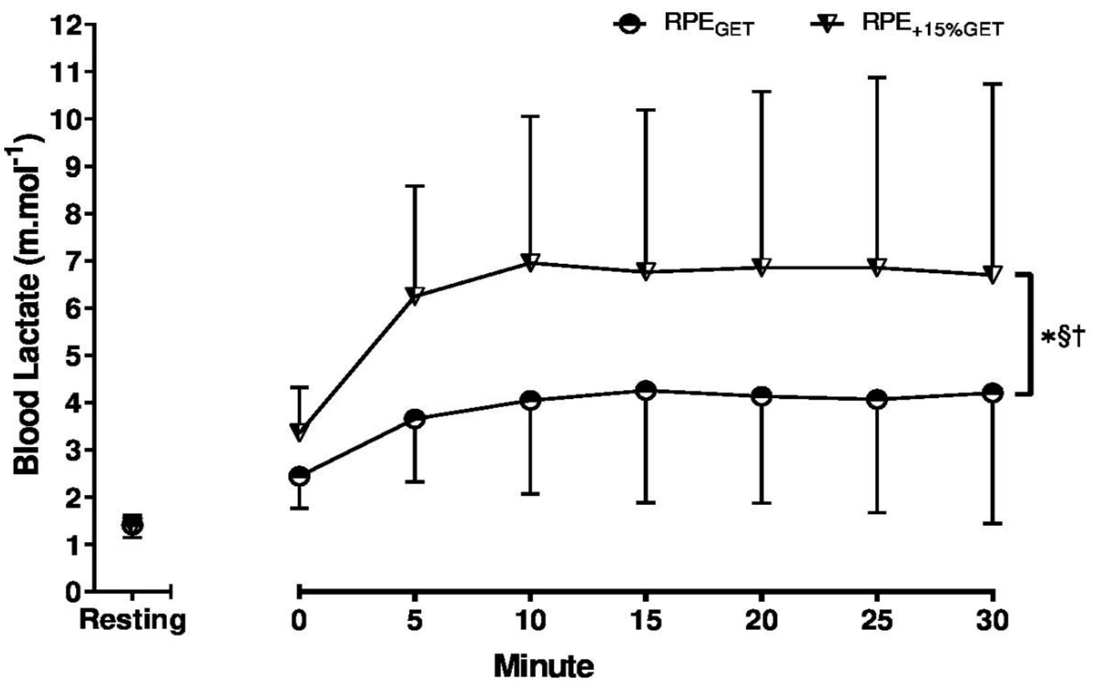


Figure 14. Group mean blood lactate responses during fixed effort trials. Significant condition (∗), time (§), and condition × time (†) effects illustrated. Note: Group mean data refers to the mean of means wherein each value denotes the mean across all three visits within each condition which has then been averaged across the entire cohort.

Perceptual markers like affective valence demonstrated significant condition ($t_{325} = -16.39, p = .001, \beta = -1.90$ $[-2.13, -1.67]$) and time ($t_{325} = -11.65, p = .001, \beta = -0.34$ $[-0.40, -0.28]$) main effects showing affective valence became more negative in both conditions but was more negative in the $RPE_{+15\%GET}$ condition. There was also a condition × time interaction for affective valence responses ($t_{325} = -5.04, p = .001, \beta = -0.29$ $[-0.41, -0.18]$) inferring that affective valence declined more rapidly in the $RPE_{+15\%GET}$ than RPE_{GET} condition (Figure 15a). Self-efficacy responses also demonstrated condition ($t_{325} = -11.13, p = .001, \beta = -15.39$ $[-18.10, -12.68]$) and time ($t_{325} = 5.74, p = .001, \beta = 1.98$ [0.35,2.66]) main effects. No condition × time interaction was found for self-efficacy suggesting similar types of response throughout both conditions although main effects suggest that self-efficacy did differ significantly between conditions and increased over time (Figure 15b).

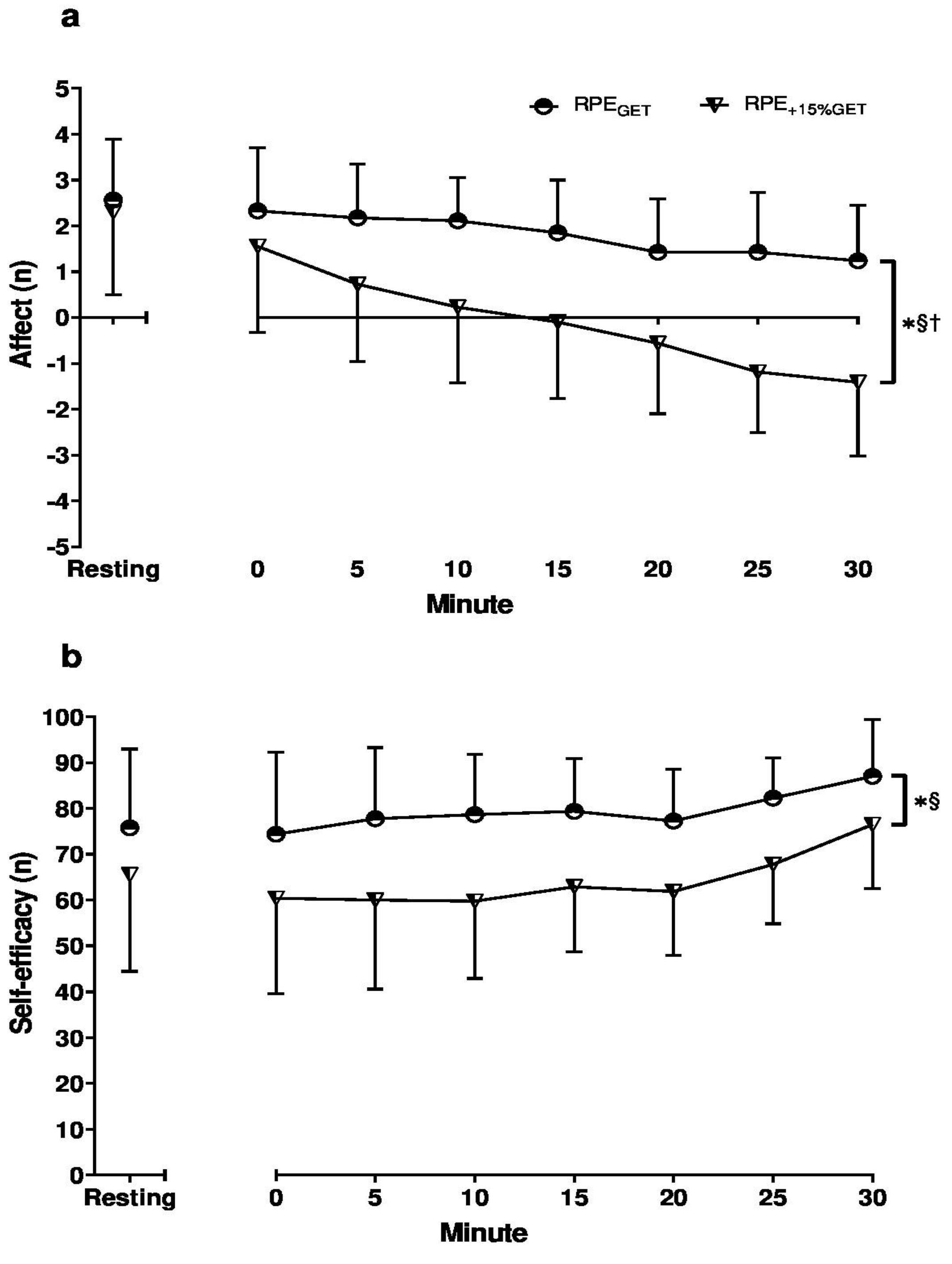


Figure 15. Group mean (a) affective valence, (b) self-efficacy responses during fixed perceived effort trials. Significant condition (∗), time (§), and condition × time (†) effects illustrated. Note: Group mean data refers to the mean of means wherein each value denotes the mean across all three visits within each condition which has then been averaged across the entire cohort.

Further analysis on $\dot{V}_T$ and respiratory exchange ratios during fixed effort trails have also been conducted and are provided within Appendix 2 as they factor into the narrative of the general discussion (Chapter 7).

4.5. DISCUSSION

The present study aimed to assess the test-retest reliability of 30-minute fixed perceived effort cycling trials which used a linear regression model to fix RPE intensity according to physiological thresholds. Foremostly, results showed that 30-minute fixed perceived effort cycling demonstrated good test-retest and intra-individual reliability within a cohort of recreationally active cyclists. This was supported by ICC values which evidenced that overall power output demonstrated an excellent degree of reliability (> .900) between visits in both conditions. In addition, overall cardiorespiratory variables such as $\dot{V}O_2.kg^{-1}$, $\dot{V}_E$, breathing frequency, and blood lactate also demonstrated an excellent degree of reliability (> .900) in the $RPE_{+15\%GET}$ condition. Test-retest reliability for heart rate demonstrated good reliability (> .800) across both conditions.

Other research has also exhibited that perception of effort remains consistent over different exercise tasks such as time-to-exhaustion (Okuno et al., 2015) and time-trials (Borg et al., 2018). Furthermore, irrespective of exercise modality, previous studies have identified that fixed perceived effort exercise can be reliably replicated across visits (Cochrane et al., 2015a, b; Eston & Williams, 1988). Such findings agree with those observed in this study as measures of power output and certain psychophysiological indices (e.g., $\dot{V}O_2.kg^{-1}$, $\dot{V}_E$, breathing frequency, blood lactate) showed excellent measures of test-retest reliability (ICC = > .900 with small < 6% SEM from the group mean) (Weir, 2005). Therefore, it appears that recreationally active individuals can consistently reproduce physical outputs that are regulated by perception of effort alone. This may be beneficial for practitioners and coaches alike in future who lack the resources to measure intricate psychophysiological markers that relate to specific workloads and physiological thresholds. Instead, RPE can be used as a surrogate measure during physical activity.

In addition, the present study also assessed intra-individual reliability measures, in which, participants demonstrated low CoV values (≤ 5%) and narrow 95%*CI*s for overall power output and certain psychophysiological variables (e.g., $\dot{V}O_2.kg^{-1}$, heart rate, $\dot{V}_E$, and breathing frequency). However, it was notable that blood lactate varied significantly (12.7% in RPE_{GET} and 9.2% in $RPE_{+15\%GET}$). This finding may discredit the use of blood lactate as a reliable indicator of exercise intensity if variations between individuals exist so prominently. For instance, the use of maximal lactate steady state has come under increased scrutiny in recent years as opposed to other mathematical models to determine maximal aerobic capacity (Iannetta et al., 2020; Inglis et al., 2019). As such, arguments may be further validated by this study's findings.

As noted, only two studies to date (Cochrane et al., 2015a, b; Cochrane-Snyman et al., 2016) have explored the reliability of performance and physiological parameters during a fixed perceived effort exercise in which RPE has been tailored to known physiological thresholds/domains. However, these studies only utilised correlation coefficients and ICCs to assess the reliability of repeated fixed perceived effort performance, despite research advocating that a 95%*CI* is a more robust alternative (Hopkins, 2000). At the intra-individual level, participants of this study were able to replicate the physical output and associated cardiorespiratory responses at a fixed perceived effort consistently between visits in both the RPE_{GET} and $RPE_{+15\%GET}$ condition. Moreover, the 95%*CI* for most participants remained below 5% to further substantiate this conviction. Paton and Hopkins (2001) identified that self-paced cycling trials usually produce variances of 2 - 3%. The findings of this study – particularly data in the $RPE_{+15\%GET}$ condition - remain close to this range of variances as power output, $\dot{V}O_2.kg^{-1}$, and heart rate demonstrated CoVs between 3.1 – 4.4% in the RPE_{GET} condition, and 1.6 – 2.7% in the $RPE_{+15\%GET}$ condition.

Many have ascribed this consistency in performance to the athlete's familiarity (i.e., experience level, practice) to the exercise tasks. With this in mind, several factors can help rationalise why this study showed the degree of reliability it did, and subsequently inform future research studies to obtain similarly reliable and comparable data. Firstly, the participants that were recruited within this study were all healthy and recreationally active cyclists. In doing so, this likely led to a more homogenous sample which has consequences for the reliability measures that are calculated (Hopkins, 2000). All participants demonstrated very good to excellent physiological results (e.g., $\dot{V}O_2max$, $\%\dot{V}O_2max$ at GET) during the ramped incremental trials (de Pauw et al., 2013). Therefore, having a collection of participants with a narrower distribution of physical capabilities compared to other studies (e.g., Cochrane et al., 2015a; Bergstrom et al., 2015) could explain the low CoV values and 95%*CI* observed in this study.

In addition, as all participants were trained, albeit recreationally, it may be assumed that participants of this study were more attuned to the underlying psychophysiological signals during the fixed perceived effort trials (Venhorst et al., 2018b) compared to previous studies that have used less trained cohorts (e.g., Cochrane et al., 2015a). Notably, this study involved fixed perceived effort exercise which was aligned to known physiological thresholds, such as GET. Thus, a cohort of currently active individuals who are aware of the typical psychophysiological sensations and perceptions associated with these thresholds could mean that it became substantially easier to taper their self-regulatory behaviours (e.g., changing power output) according to the required RPE value (Lamb et al., 1999).

Moreover, another critical factor to the reliability of this study could have been the employment of multiple familiarisation trials. Conducting exercise at a fixed RPE is a relatively artificial exercise task, therefore, the opportunity for participants to familiarise themselves twice before the experimental trials could be a key factor. Extant literature has evidenced that the inclusion of familiarisation trials significantly improves the validity and reproducibility of performance indices during self-regulated RPE-based exercise (Lim et al., 2016). Furthermore, Mauger et al. (2014) determined that a cohort of active males could replicate fixed perceived effort exercises without reference to the scale, and solely based off internal prior experience of a fixed perceived effort task.

Another notable finding of this study was that $RPE_{+15\%GET}$ results demonstrated better test-retest reliability and much lower variability compared to the RPE_{GET} condition. A previous study by O'Grady et al. (2021) determined that fixed perceived effort exercise at higher RPE values rendered lower between- and within- individual variances in power output and cardiorespiratory parameters compared to fixed perceived effort exercise at lower RPE values. In addition, other studies appear to share similar ideas based on their results (Cochrane-Snyman et al., 2016; Eston & Williams, 1988). However, no study has aimed to explain *why* harder intensity fixed effort exercise appears to be better replicated than lower intensity fixed perceived effort exercise.

One possible suggestion is that during harder intensity exercise, participants experience more salient interoceptive cues than lower intensity exercise that inform the individual of the psychophysiological changes that have occurred (Ekkekakis, 2003; Ekkekakis et al., 2011). To illustrate, when exercising at $RPE_{+15\%GET}$, participants began exercising within the heavy intensity domain (Cochrane et al., 2015a, b; Cochrane-Snyman et al., 2016). Whilst in this domain, athletes experience a more intense presence of metabolites (e.g., hydrogen ions), subsequent nociceptive stimulation (Mauger, 2013), and other forms of afferent feedback (Amann et al., 2009). As a result, Renfree et al. (2014) suggests that this may engender athletes to adopt more heuristic decision-making processes. This is because the overbearing discomfort and negatively-oriented sensations/perceptions – as seen in this study (Figure 15a) - that arise due to harder intensity exercise cause athletes to make decisions based on more select pieces of information. Therefore, responses become more 'primal' and 'instinctive,' meaning that they may be more easily replicated as they are based on stable trait-like factors (Gigerenzer & Gaissmaier, 2011).

On the other hand, exercise at RPE_{GET} is expected to occur entirely within the moderate intensity domain whereby metabolite production equals metabolite clearance (Gaesser & Poole, 1996). Therefore, the athlete experiences fewer negative sensations and perceptions such as pain and discomfort (Venhorst et al., 2018b). Consequently, Renfree et al. (2014) suggests that this would endear the athlete to employ more rational-based decision-making. As a result, more situational factors are considered when regulating exercise intensity, which could translate into more variances in behaviour overall (Renfree et al., 2014). However, as this study did not monitor the underlying decision-making processes during the fixed perceived effort exercise, firmer conclusions cannot be drawn. Nonetheless, recent studies have employed the use of a novel *think aloud* protocols which allows researchers to understand the underlying cognitions and decision-making processes that are articulated during an endurance event (Whitehead et al., 2018). In line with this, future research may wish to consider the use of *think aloud* approaches to begin to discern how perceived effort is consciously regulated and the concomitant changes to psychophysiological indices as a result.

It is also interesting to note the differences in the power output and psychophysiological responses between conditions during this study. Although the study aims primarily focused on the reliability measures associated with novel fixed perceived effort cycling trials, some discussion can also be generated around the potential mechanisms that underpin the self-regulation of power output and psychophysiological indices that were measured in this study. To begin with the changes over time in both conditions, all variables except $\dot{V}O_2.kg^{-1}$ indexed a time-based main effect inferring that only $\dot{V}O_2.kg^{-1}$ remained stable as perceived effort remained constant. This may be somewhat surprising as prior research would indicate that breathing frequency is the closest correlate to perceived effort due to its inherent links with the respiratory effort components of perceived effort (Nicolò et al., 2016). Therefore, breathing frequency was be expected to show a plateau during fixed perceived effort exercise, not $\dot{V}O_2.kg^{-1}$ (Nicolò et al., 2016). In contrast, breathing frequency within this study exhibited a progressive increase throughout both conditions. Nevertheless, upon further review of the data (see Appendix 2), it appears that as breathing frequency increased, $\dot{V}_T$ indexed a mirrored decrease (Figure 13d, Appendix 2). Thus, although $\dot{V}_E$ responses appeared to show a time-based effect, closer inspection of the data does show that $\dot{V}_E$ was relatively constant over the course of the exercises – particularly the $RPE_{+15\%GET}$ condition (Figure 13c). As a result, the air hunger that drives respiratory effort (O'Donnell et al., 2009) would have remained relatively stable. The only difference being that in this study breathing frequency and $\dot{V}_T$ showed a mirrored response to keep $\dot{V}_E$ consistent whereas other studies have shown a plateaued breathing frequency response with only minor changes in $\dot{V}_T$ to maintain $\dot{V}_E$ (Nicolò et al., 2016).

In succession, every variable showed a significant condition main effect between RPE intensities. Furthermore, power output, $\dot{V}O_2.kg^{-1}$, breathing frequency, blood lactate, and affective valence responses evidenced significant condition × time interactions suggesting a difference in trajectories of responses between RPE_{GET} and $RPE_{+15\%GET}$ conditions. Therefore, not only do fixed perceived effort intensities corresponding to either GET or +15% above GET have significantly *different* power output and psychophysiological responses but also *distinct* self-regulatory strategies are employed to adapt the behavioural and psychophysiological responses associated with them.

To elaborate, power output showed a steeper decline in the $RPE_{+15\%GET}$ versus RPE_{GET} condition. Using Carver and Scheier's (1982) cybernetics control theory as a basis (Figure 10b) reductions in power output are likely a means to self-regulate perceived effort to ensure that perceived effort was maintained at a constant intensity. As noted previously, the link between self-regulation of perceived effort via changes in power output (or potential cognitive strategies which could not be detected in this study) may be *in part* due to the psychophysiological changes that occurred as part of the prolonged fixed perceived effort cycle. To illustrate, due to engagement in prolonged exercise, a natural onset in fatigue and other aversive psychophysiological phenomena like pain are likely to occur (Behrens et al., 2023; Enoka & Duchateau, 2016; Enoka & Stuart, 1992; Mauger, 2013). Furthermore, the demands at higher perceived effort are more likely intense than lower perceived effort tasks (Marcora, 2019).

Thus, causing a potentially greater intensity of these aversive psychophysiological phenomena (Pageaux, 2016; Venhorst et al., 2018b). Consequently, a greater perturbation in psychophysiological state(s) such as cardiorespiratory or perceptual marker like those in this study would expect to be different as was observed.

Furthermore, disturbances in psychophysiological state may impact the production of corollary discharge due to increased central motor drive or an altered neuronal processing of corollary discharge signals (Pageaux, 2016). Addressing changes in central motor command, the changes in power output is the closest reflection of motor command in this study. As power output exhibited a steeper decline in the $RPE_{+15\%GET}$ condition, this intimates that individuals opted to self-regulate their behaviour by downregulating central motor command projections (and therefore corollary discharge production) more when exercising at a higher than lower perceived effort.

As for neuronal processing, affective valence is an indicator of the hedonic and motivational state of an individual (Berridge, 2019). Parfitt and colleagues have demonstrated that exercising at a constant positive (i.e., hedonically satisfying) versus negative (i.e., hedonically aversive) affective valence does not mean exercising at a lower intensity but may be manifest due to differences in the neuronal processing of effort-driving signals (Parfitt, Alrumh, et al., 2012; Parfitt, Evans, et al., 2012; Zenko et al., 2016). Within the present study a steeper decline towards a negative affective state throughout the $RPE_{+15\%GET}$ condition compared to a gradual decrease from positive to less positive/neutral affective state in the RPE_{GET} condition was observed (Figure 15a). Linked to Parfitt and colleagues' findings, as higher perceived effort exercise involved a more negative affective state which could have perpetuated increases in neuronal processing of corollaries (Brand & Ekkekakis, 2019; Ekkekakis et al., 2011; Parfitt, Alrumh, et al., 2012; Parfitt, Evans, et al., 2012; Zenko et al., 2016). Subsequently, instigating more likely increases in perceived effort (Pageaux, 2016). Therefore, to prevent any increases in perceived effort to maintain the task goal (maintain a constant perceived effort), participants were impelled to opt for further declines in power output (Figure 12).

However, as noted, this is one possible interpretation of the data to explain why the self-regulation of physical outputs like power output (indexed by differences in trajectories between perceived effort conditions) were different. Furthermore, this study did not account the potential cognitive self-regulatory strategies that could have been at play to change potential motivation during cycling bouts, therefore, a further investigation into how perceived effort is self-regulated according to both behavioural and cognitive strategies is warranted.

Finally, it must also be acknowledged that there are some statistical limitations to this study[1]. Assessment of differences between the conditions is likely underpowered and therefore certain statistical differences between cardiorespiratory and perceptual variables may exist but have remained undetected. As a result, the conclusions drawn from the linear mixed model regression analysis should be taken with caution and future studies as part of this thesis ought to validate these findings.

4.6. CONCLUSION

Overall, this study demonstrated that recreationally active cyclists can reliably produce physical outputs and psychophysiological responses during fixed perceived effort cycling which is corresponded to physiological thresholds/domains. It appears that the harder the RPE intensity, the more reliably the exercise can be completed at both inter- and intra-individual levels. However, the underpinning factors for this remain unknown and yet to be fully explored. Some possible avenues for exploration may be the underlying decision-making processes that influence exercise behaviours during fixed perceived effort cycling. Finally, this study also noted a significant difference in power output and psychophysiological indices between conditions. Notably, condition × time interactions were also observed for power output, $\dot{V}O_2.kg^{-1}$, breathing frequency, blood lactate, and affective valence affect suggesting a *different* but also *distinct* self-regulatory responses to adapt behavioural and psychophysiological indices associated with each perceived effort intensity. A potential understanding behind the distinct self-regulatory responses may lie in which behavioural and cognitive strategies are activated. Thus, further probing into the self-regulation of perceived effort is of interest.

[1] This entire thesis (primarily the Study 1, Chapter 4) was affected by the Covid-19 pandemic which was declared 4-6 weeks into the data collection period of this study (March 2020). In-person data collection became unavailable for a prolonged period for a large portion of the author's PhD qualification (2019 – 2022) with multiple, successive lockdowns and halts to data collection taking place. Though this study is likely underpowered, it demonstrates some interesting findings which have been published and these findings are also furthered by the subsequent Study (Chapter 5) which found similar differences in the power output and perceptual markers associated with the two fixed perceived effort intensities. This study (Chapter 5) has also been published and met the statistical power according to an a-priori calculation.

Chapter 5 – ANALYSING EXPERIENCED AND INEXPERIENCED CYCLISTS' ATTENTIONAL FOCUS AND SELF-REGULATORY STRATEGIES DURING VARYING INTENSITIES OF FIXED PERCEIVED EFFORT CYCLING: A MIXED METHOD STUDY

This chapter is formed by a major part of the recent publication by O'Malley et al. (2024) https://doi.org/10.1016/j.psychsport.2023.102544 with some adaptations made for the narrative of this thesis submission and in response to examiner's comments.

5.1. ABSTRACT

Using a think aloud approach during fixed perceived effort exercise is a unique method to explore the decision-making processes that guide the self-regulation of perceived effort during endurance-based activity. In a two-part study, authors investigated the attentional focus and self-regulatory strategies associated with: Part A - perceived effort corresponding to (RPE_{GET}) and above gas exchange threshold ($RPE_{+15\%GET}$); Part B - between experienced and inexperienced cyclists during fixed perceived effort cycling tasks. Eighteen (15 male, 3 female) healthy, active individuals completed three visits (visit 1 – ramped incremental test and familiarisation, visit 2 and 3 – 30-min fixed perceived effort cycling). During which, power output, heart rate, lactate, think aloud, and perceptual markers were taken. Random-intercepts linear mixed-effects models assessed the condition, time, and condition × time interactions on all dependent variables. Power output, heart rate, blood lactate, and instances of internal sensory monitoring ($t_{195} = 2.57, p = .011, \beta = 0.95$ [0.23,1.68]) and self-regulation ($t_{195} = 4.14, p = .001, \beta = 1.69$ [0.89,2.49]) were significantly higher in the $RPE_{+15\%GET}$ versus RPE_{GET} fixed perceived effort trial. No significant differences between inexperienced and experienced cyclists for internal sensory monitoring ($t_{196} = -1.78, p = .095, \beta = -1.73$ [−3.64,0.18]) or self-regulatory thoughts ($t_{196} = -0.39, p = .699, \beta = -1.06$ [−6.32,4.21]) were noted but there were significant condition × time interactions for internal monitoring ($t_{196} = 2.02, p = .045, \beta = 0.44$ [0.01,0.87]) and self-regulation

($t_{196} = 3.45, p = .001, \beta = 0.85$ [0.37,1.33]). Seemingly, experienced athletes associatively attended to internal psychophysiological state and subsequently self-regulate their psychophysiological state at earlier stages of exercise than inexperienced athletes. This is the first study to exhibit the differences in attentional focus and self-regulatory strategies that are activated based on perceived effort intensity and experience level in cyclists.

5.2. INTRODUCTION

Engagement in self-regulated physical exercise is naturally effortful (Preston & Wegner, 2009). Physically, individuals must voluntarily activate locomotor and respiratory muscles via central motor commands (Gandevia, 2001; Marcora, 2009). These motor commands have efferent copies (i.e., corollary discharge) which are processed within cerebral centres such as the supplementary motor area, anterior and middle cingulate cortices, and anterior insula (de Morree et al., 2012; Williamson, 2006; Williamson et al., 2001, 2002; Zénon et al., 2015) to generate the perception of effort (Pageaux, 2016).

Likewise, exercise tasks use mental resources to attend to changes in psychophysiological state (i.e., interoception) and engage in executive functioning decisions to best determine how to invest resources for optimum performance (Preston & Wegner, 2009; Steele, 2019). In this manner, perceived effort encompasses the awareness of voluntary application of physical *and* mental resources towards a task (Pageaux, 2016). Therefore, as perceived effort is very closely linked to the voluntary recruitment of resources towards a task, some have posited perceived effort is the determinant of exercise performance (Marcora, 2008, 2019; Staiano et al., 2018).

Previously, most studies have utilised time-trials or race events to understand perceived effort and its relation to exercise-based decisions and performance outcomes (McCormick et al., 2018). However, this relationship becomes blurred when conducting freely regulated tasks such as time-trials or races as the application of effort is dynamic and can change easily, causing further changes in perception of effort (O’Malley et al., 2023). Therefore, a recent method of assessing effort, its associated psychophysiological indices, and decisions relating to perceived effort, is with fixed perceived effort exercise (e.g., Cochrane et al., 2015a, b; Cochrane-Snyman et al., 2016; O’Malley et al., 2023). During these tasks, individuals must decide how to appropriately self-regulate their behaviour and inner psychophysiological states according to a set RPE. Thus, it becomes of interest what psychophysiological states individuals focus on/acknowledge during these tasks and what self-regulatory strategies they apply to adapt and maintain a set perceived effort.

Brick, MacIntyre, et al. (2016) highlight that during endurance-based activities, individuals possess metacognitive abilities which affords exercisers to be consciously aware of any changes to their psychophysiological states (Brick et al., 2014) and in turn, understand their agency over them (Brick, MacIntyre, et al., 2016). Furthermore, Brick, MacIntyre, et al. (2016) highlight previous models (e.g., Morgan & Pollock, 1977) which indicate that individuals govern their attentional control over which information is acknowledged during a task. In depth, Morgan and Pollock (1977) indicate that individuals have two main dimensions of focus. One of which refers to locality, whereby attention can be towards stimuli inside (internal) or outside (external) the body. In addition, there can also be a focus that is either task-relevant (associative) or task-irrelevant (dissociative). In the context of a fixed perceived effort task, monitoring of psychophysiological sensations such as muscle pain and respiratory cues would be deemed internal-associative, whilst acknowledgement of opposition behaviour would be considered as external-associative. In contrast, daydreaming would comprise internal-dissociative attention whilst purposeful distraction away from one's bodily sensations like looking at the scenery would be regarded as external-dissociative (Brick et al., 2014; Lind et al., 2009; Morgan & Pollock, 1977).

Other studies indicate that associative focus is linked to superior performance outcomes in endurance-based exercise settings, suggesting that these individuals are more interoceptive and that this provides a competitive advantage (Hutchinson & Tenenbaum, 2007; Masters & Ogles, 1998). Moreover, findings intimate that internal focus is more facilitative for exercise performance, particularly during higher intensity exercise wherein there is a naturally greater disruption from resting homeostatic state (Ekkekakis et al., 2011; Zenko et al., 2016). Particularly, as individuals are aware of their psychophysiological state, they can then apply more suitable self-regulatory strategies for further task performance benefits (Lind et al., 2009). Experienced athletes have also been found to attend to more internal *and* task-relevant cues to continually appropriate the self in accordance with task goals (McCormick et al., 2015, 2019). Meanwhile, inexperienced athletes have demonstrated a greater dissociative and task-irrelevant focus than experienced counterparts (Brick, MacIntyre, et al., 2016; Whitehead et al., 2018). Subsequently, there are individual elements to attentional focus as well as a dependency on the task (e.g., intensity of exercise).

Attention features heavily in the subsequent regulation of the self during exercise activity. Carver and Scheier (1982) proposed the cybernetics control theory which indicates that individuals will constantly entertain self-control loops to adapt their behaviour in relation to a specific standard/constant. Figure 10b shows that in the context of a fixed perceived effort trial, engagement in exercise will naturally elicit changes in psychophysiological state such as breathing rate or muscular heaviness (Carver & Scheier, 1982; Gross, 2015). Resulting from this awareness, neuronal processing of effort driving signals (e.g., corollary discharge) may be further impacted to change perceived effort (Pageaux, 2016). Therefore, to bring perceived effort back into accord with the required RPE set as part of fixed perceived effort task, individuals must apply self-regulatory techniques (Carver & Scheier, 1982, 2000; McCormick et al., 2019). Using the psychobiological model as a framework (Marcora, 2008), self-regulation during fixed perceived effort trials is primarily achieved through the alterations of physical output (e.g., power output via changes in motor command) and/or use of cognitive strategies. Specifically, these strategies target either: (1) the production of effort-driving signals like corollary discharge (de Morree et al., 2012); or (2) processing of effort-driving signals in cerebral centres such as the anterior cingulate cortex (Pageaux, 2016). An argument could also be made that self-regulatory strategies could also aim upregulate the motivational intensity of the individual (McCormick et al., 2018). Importantly, the athlete must feel efficacious in their ability to use these strategies (McCormick et al., 2015) and deem them useful to the situation (McCormick et al., 2019; Renfree et al., 2014).

Numerous studies have highlighted that during fixed perceived effort trials, power output/running velocity gradually decrease (Cochrane-Snyman et al., 2019; O'Malley et al., 2023). Therefore, individuals engaging in fixed perceived effort exercise naturally resort to behavioural strategies to regulate perceived effort back into accord with the required RPE for the task. On a neurophysiological level, this is understandable as the progressive impairment of the neuromuscular unit and its function (Amann et al., 2020; Taylor et al., 2016) causes a required compensatory increase in central motor command to maintain a given power/velocity/force (de Morree et al., 2012). If more central motor command is required, this causes a greater production of efferent copies (corollary discharge) which is processed in the presupplementary motor area, anterior and middle cingulate cortices, and anterior insula to increase perceptions of effort (de Morree et al., 2012; Pageaux, 2016; Williamson et al., 2001; Zénon et al., 2015). Thus, reductions in exercise intensity are a primary example of a behavioural strategy to bring perceived effort back into accord with the expected RPE of a fixed perceived effort trial (Carver & Scheier, 2000; Lasnier & Durand-Bush, 2022) due to the natural onset of fatigue (Behrens et al., 2023) and other psychophysiological phenomena (e.g., nociception/pain) that exacerbate central motor command requirements (Aboodarda et al., 2020; Azevedo de Almeida et al., 2022).

However, it has been posited that reducing physical outputs in the face of the natural vicissitudes of exercise is a dysfunctional and impulsive response (Englert et al., 2021; Evans et al. 2016). Conversely, individuals can instead enact self-control to opt for other strategies that does not compromise exercise intensity but still maintain a given perceived effort (Englert, 2016). For instance, cognitive strategies such as reappraisal are thought to be effective at improving performance in exercise contexts (Blanchfield et al., 2014a; Giles et al., 2018; Lazarus, 2000; Mejien et al., 2020). Numerous studies have documented that cognitive reappraisal can reduce perceived effort during physical endurance-based exercise (Arthur et al., 2019; Giles et al., 2018; Hase et al., 2019). Alongside this, reduced activity at cerebral centres such as the anterior and middle cingulate cortices, and anterior insula where effort signals are processed has also been found when individuals utilise reappraisal strategies compared to without reappraisal (Robinson et al., 2021). It has also been evidenced that reappraisal strategies impede any declines in affective valence during prolonged activity (Berman et al., 2019; Grandjean da Costa et al., 2022; Giles et al., 2018) which in turn may alter the neuronal processing of effort-driving signals (Ekkekakis, 2003, 2009a, c; Ekkekakis et al., 2011; Parfitt, Alrumh, et al., 2012; Parfitt, Evans, et al., 2012; Venhorst et al., 2018b).

In addition to reappraisal strategies, motivational self-talk has also been found to improve exercise performance via changes in motivational intensity (Barwood et al., 2008, 2015; Blanchfield et al., 2014a). Barwood et al. (2015) observed that when participants engaged in motivational self-talk this instigated higher physical output intensity for a given RPE response compared to when neutral self-talk was used. Inferentially, it could also be argued that self-talk upregulated the motivational intensity of athletes. In the case of a fixed perceived effort trail, if motivational intensity is enhanced, this may cause an increase in actual resources applied to the task at the same RPE rating due to linear scaling of the 15-point Borg (1970) scale and scaling of effort (resource application) according to task demands (Richter et al., 2016; Wright, 1996).

Finally, distraction techniques may also be effective at reducing perceptions of effort during exercise activities (Brick et al., 2014; Gross, 2013, 2015). On the one hand, distraction apportions extra stimuli into a finite bandwidth of signals that can be processed by the conscious brain at any one time (Gross, 2013). As a result, distraction techniques encumber a portion of a finite 'bandwidth' (Brick et al., 2014; Brick, Campbell, et al., 2016) so that less effort-generating signals can be processed at any one time, leading to a decrease in perceived effort. On the other hand, distraction techniques are also thought to divert attention away from negatively orientated sensations/perceptions like pain (Gross, 2015; Lasnier & Durand-Bush, 2022). Negative sensation/perceptions such as pain have been theorised to disturb the affective-motivational dispositions of an individual towards a task (Venhorst et al., 2018b). Akin to self-talk, distraction may help improve motivational intensity by blocking negative perceptions that arise due to exercise-related sensations. However, several studies admit that distraction can be a double-edged sword as relevant stimuli may be unaccounted, leading to deleterious effects on task performance (Gross, 2013). Amann et al. (2009) provide a prime example whereby participants rated perceived effort lower at the same exercise intensity but were unaware of key psychophysiological changes to the body when receiving epidural anaesthesia which cause a marked drop in exercise intensity halfway through a time-trial exercise.

Although it has been widely accepted that employing strategies that come under the wider term of 'self-regulation' are vital to increasing the likelihood of success within any goal-directed pursuit (Evans et al., 2016), current methodologies (e.g., questionnaires and interviews) lack the capacity to track the full extent of an individual's metacognitive and self-regulatory processes (McCormick et al., 2019). Any cognitions or feelings that an athlete has entertained during an event may be missed or forgotten when using *post hoc* data collection methods (Eccles & Arsal, 2017; Ericsson & Simon, 1980). However, the introduction of a *think aloud* (Ericsson & Simon, 1980) approach into the exercise domain enables researchers to monitor the active cognitions and feelings an athlete entertains *during* a task (Samson et al., 2017; Whitehead et al., 2018). As such, researchers can retrospectively analyse segments of an athlete's verbalisations to discern the cognitive processes (including attention and self-regulation) that moderated decision-making during endurance-based exercise (Eccles & Arsal, 2017).

Emerging within the exercise science field, a collection of studies has probed the regulation of pace whilst utilising a think aloud protocol during endurance-based cycling time-trials (e.g., Massey et al., 2020; Samson, 2014; Samson et al., 2017; Whitehead et al., 2018, 2019). Whitehead et al. (2018) observed that 63% of all verbalisations during a 16.1 km time-trial pertained to active self-regulation, highlighting the significance of self-regulatory processes during endurance-based activity. Furthermore, the authors determined that experienced athletes within the cohort would entertain more self-regulatory thoughts in earlier phases of the time-trial whilst internal sensory monitoring (e.g., focusing on pain) and distraction (e.g., focusing on irrelevant information) prevailed in the earlier phases for inexperienced athletes (Whitehead et al., 2018). Consequently, differences in focus allow experienced athletes to engage in a more directed and functional regulation of perceived effort to benefit endurance-based task performance (Whitehead et al., 2018). Meanwhile, distraction techniques used by inexperienced athletes are linked to suboptimal perceived effort regulation and performance-based results (Brick, Campbell, et al., 2016).

Resultantly, this study comprises two parts with two primary aims:

Part A – Investigating the attentional focus and self-regulatory strategies used to regulate indices of perceived effort at different fixed perceived effort intensities.

To further the recent explorations of self-regulatory processes and their influence on behaviour during time-trials, Part A investigated the differences in self-regulatory processes at varying fixed perceived effort intensities across a healthy, active population. It was hypothesised that participants would entertain more self-regulatory thoughts in the harder intensity compared to lower intensity fixed perceived effort trial.

Part B – Investigating the differences in attentional focus and strategies to cope with perceived effort between experienced and inexperienced cyclists during a fixed perceived effort cycling task.

Successively, Part B aimed to probe the potential differences in self-regulatory processes between experienced and inexperienced populations that have been identified in previous studies. It was hypothesised that experienced cyclists would entertain more self-regulatory cognitions compared to inexperienced counterparts whilst inexperienced cyclists would entertain more distractive thoughts compared to experienced counterparts.

5.3. METHODS

5.3.1. PARTICIPANTS

The present study consisted of 20 (15 male, 5 female) healthy, active individuals (Table 3). All participants were physically active, engaging in at least 150 $min \cdot wk^{-1}$ of exercise as well as engaging in some form of cycling-based activity (e.g., outdoor rides, ergometer rides, spin classes) during their week. Participants were allocated to specific performance level groups according to previous research (de Pauw et al., 2013). Namely, those who were: (1) currently active in cycling for over 150 minutes per week; (2) had over 3 years cycling experience; (3) demonstrated a $\dot{V}O_2max$ over 53 $mL.kg^{-1}.min^{-1}$ were considered level P3 and made up the 'experienced' group. All other participants who were considered physically active (> 150 minutes prolonged physical activity per week) but did not have cycling experience and/or had a $\dot{V}O_2max$ below 53 $mL.kg^{-1}.min^{-1}$ were considered level P2 and made up the 'inexperienced' group. For Part A, the sample included all 20 participants across both participation levels. For Part B, participants were equally split according to their participation level (10n experienced = P3, 10n inexperienced = P2). Due to failure to comply with the think aloud protocol, two participants were removed (one from each group) leaving nine participants in each of the experienced/inexperienced groups. An α-priori calculation using an f^2 value of 1.00, power of 0.95, and α-error of 0.05 determined a required total sample size of 14 with a critical t value = 1.83 and actual power = 0.96.

None of the participants suffered from any underlying cardiorespiratory, metabolic, neurological, or other pre-existing medical conditions or were taking any form of medication. The study was ethically approved (Prop 52_2019_20) and all procedures were in accordance with scientific standards outlined by the Declaration of Helsinki. All research sessions were scheduled at the same time of day (± 2 hours), and participants abstained from food (2 hours), caffeine (4 hours), alcohol (24 hours), intense exercise (48 hours) in the lead up to each session. Eating habits in the 24 hours leading up to each session were also replicated. All female participants were eumenorrheic and were scheduled to conduct all procedures during their luteal stage to minimise any confounding effects due to the stage of menses in the study (McNulty et al., 2020).

Table 3. Mean ± SD of participant anthropometrics and performance markers.

	Part A	Part B	
Group	All	Experienced	Inexperienced
Age (years)	27 ± 5	28 ± 5	25 ± 3
Activity ($h \cdot wk^{-1}$)	8.3 ± 4.4	10.4 ± 5.5	6.2 ± 1.8
Cycling experience (years)	7.8 ± 6.5	11.2 ± 7.1	4.4 ± 3.6
$\dot{V}O_2max$ ($mL.kg^{-1}.min^{-1}$)	54.3 ± 8.4	61.1 ± 6.7	47.6 ± 3.1

RPE_{GET}	13.2 ± 0.6	13.3 ± 0.4	12.9 ± 0.6
$RPE_{+15\%GET}$	15.1 ± 0.5	15.0 ± 0.7	15.3 ± 0.5

5.3.2. MEASURES

All scales were explained during recruitment and repeated explanations were provided at the start of every experimental session. Participants were informed that they could provide decimalised answers and reminded that there were no right/wrong answers but that they should provide responses that were most truthfully reflective of their current psychophysiological state.

5.3.2.1. RATINGS OF PERCEIVED EFFORT SCALE

Both parts of the study used the Borg 15-point RPE scale (Borg, 1970) which denoted *how hard, heavy, and strenuous does the exercise feel to drive the working muscles and for your breathing* (Marcora, 2010b). To maximise the measurement validity of the RPE scale, the semantic representation of perceived effort that researchers provided was precise and consistent according to the aforementioned definition (Halperin & Emanuel, 2020). Additionally, the same anchors for the minimum (*6 – like when you are sitting at rest, doing absolutely nothing*) and maximum (*20 – like giving everything you have got at the end of a* $\dot{V}O_2max$ *test*) ratings were provided (Malleron et al., 2023). Moreover, added scales that encapsulated similar psychophysiological phenomena were used in this study.

5.3.2.2. AFFECTIVE VALENCE SCALE

Responses for affective valence were collected via the single-item 11-point feeling scale (Hardy & Rejeski, 1989) denoting *how are you feeling at the current moment of the exercise*. Responses ranged from *+5 - I feel very good* to *-5 - I feel very bad* with a median of *0 - neutral*.

5.3.2.3. SELF-EFFICACY SCALE

Responses for self-efficacy were collected via an adapted single-item scale from Bandura's social-cognitive framework (1997) denoting *how confident are you that you can tolerate the physical and mental effort associated with the task to maintain your current performance level*. Responses ranged from *10 - extremely confident* to *0 - not at all confident* with a median of *5 - moderately confident*.

5.3.2.4. THINK ALOUD PROTOCOLS

During familiarisation and experimental sessions a think aloud protocol was employed to capture the participants' conscious thought processes during the fixed perceived effort cycling exercises. All think aloud data from all visits were recorded through a microphone which was fixed on the collar of the cyclists. Later, the audio files were transcribed *verbatim* and underwent thematic analysis post-data collection (see section 5.3.5. Analysis). Recent guidelines (Eccles & Arsal, 2017) were adhered to so that the quality of information disclosed by participants was maximised.

Firstly, in the week prior to any testing, a clear instructional set (see Appendix 3) including practice exercises was provided to participants. Exercises include practising a think aloud protocol for assigned tasks (e.g., anagram task) as well as a transference of this protocol to everyday tasks such as unpacking shopping. Finally, participants then progressed towards conducting a think aloud protocol during their general physical activity exercise (e.g., a recreational cycle).

During data collection sessions, participants were always instructed *to please think aloud by trying to say out loud anything that comes into your head throughout the trial*. *You do not need to try to explain your thoughts and you should speak as often as you feel comfortable in doing so*. To aid the participants, instructional cues were placed on the handlebars to prompt athletes. The lead researcher also provided a prompt by reemphasising the instructions relating the think aloud protocol should participants fall silent for more than two minutes. Finally, throughout all data collection, the researcher positioned themselves out of sight of the participant to minimise any intrusion. All these measures taken by the researchers are in keeping with previous research utilising and advising on think aloud protocols (Eccles & Arsal, 2017; Ericsson & Simon, 1980; Massey et al., 2020; Samson, 2014; Samson et al., 2017; Whitehead et al., 2018, 2019).

5.3.2.5. MIXED METHODS APPROACH

Quantitative and qualitative data were collected simultaneously during this study. Prior to data collection, authors adopted a clear post-positivist epistemological and objectivist ontological view as think aloud data were to be entered into pre-set themes via an adapted framework from Brick et al. (2014). This is similar to previous research using an identical framework and exercise tasks (Massey et al., 2020; Robinson et al., 2021; Whitehead et al., 2018, 2019). Adaptations to the framework were made to adjust the framework to the exercise task (fixed perceived effort trials) and were based on an initial inductive analysis of the think aloud data (see 5.3.4. Think Aloud Content Analysis).

Therefore, qualitative think aloud data were quantified for the number of times they appeared within a pre-set theme so that all data was analysed together (Bryman, 2006). Likewise, this ensured that our analysis of the qualitative data was consistent with our post-positivist and objectivist philosophical views (Creswell & Piano Clark, 2007).

5.3.3. PROCEDURES

This study implemented a randomised cross-over repeated measures design in which participants were required to visit the same laboratory (mean ± SD temperature, 18.9 ± 2.5 °C; humidity, 33 ± 9 %; barometric pressure, 780 ± 6 mmHg) on three separate occasions (Figure 16). After arrival, participants were provided with a heart rate monitor (Cyclus 2: ANT+, Leipzig, Germany) assessing heart rate on a beat-by-beat basis and provided a 20 μL resting blood lactate sample from the right index finger assessed using an automated lactate analyser (Biosen: C-Line, EKF Diagnostics, GmbH, Barlaben, Germany).

After initial preparation, participants were required to perform a ten-minute self-selected warm-up on the same cycle ergometer (Cyclus 2, Leipzig, Germany). After completion, the researcher provided a final explanation of the upcoming protocol and measures. After confirmation of an understanding, participants provided a resting value for each perceptual scale before remounting the cycle ergometer to begin the respective exercise tasks for each session. Within *Visit 1* only, participants were fitted to the gas analyser system (Cortex Metalyser: Model 3B, Leipzig, Germany) to assess pulmonary ventilation on a breath-by-breath basis to determine specific gas exchange parameters (e.g., GET) for the derivation of the fixed perceived effort intensities in subsequent visits (*Visit 2 and 3*). The gas analyser was pre-calibrated using a fixed three litre syringe (Hans Rudolph, Kansas, USA) and known gas concentrations.

5.3.3.1. VISIT 1 – RAMPED INCREMENTAL TEST AND FAMILIARISATION

After preparation and a warm-up, participants cycled for an initial three-minute period at 80% of the starting intensity so that gas parameters could stabilise before commencing the ramped incremental test. In accordance with previous pilot work to ensure that $\dot{V}O_2max$ was reached within eight - ten minutes (Keir et al., 2015), the starting intensity was set at 100 W for males and 50 W for females. During this time, participants were asked to cycle at a cadence of ~80 revolutions.min^{-1} but upon commencement of the ramp incremental task were recommended to gradually increase cadence over the course of the incremental test. At the commencement of the ramped incremental test, power output increased incrementally by 25 W.min^{-1}. At each minute (including at the starting intensity), RPE was recorded. Task cessation occurred when the participant believed they had reached volitional exhaustion or if cadence fell below 60 revolutions.min^{-1} for more than five seconds despite strong verbal encouragement. An additional RPE measurement was taken at exhaustion alongside a final blood lactate sample.

After the incremental test, participants had a 15-minute passive recovery. Once ready, participants then completed a ten-minute familiarisation at two pre-selected fixed perceived effort exercises (five minutes each) corresponding to *13 - somewhat hard* and *15 - hard* on the 15-point Borg scale (Borg, 1970). These values were selected based on estimated values from previous research to correspond to intensity conditions for Part A (Cochrane-Snyman et al., 2019; O’Malley et al., 2023). In addition, participants were also asked to practice the think aloud protocol during the familiarisation. During the fixed perceived effort cycling, all variables – except cadence - were blinded so that participants regulated the exercise according to a constant RPE without any extraneous influence. During the fixed perceived effort trials (familiarisation and experimental sessions), participants could change their power output at any point by using the virtual gears on the Cyclus 2 console to ensure that they maintained the same perceived effort throughout the trial.

5.3.3.2. DETERMINATION OF RPE_{GET} AND $RPE_{+15\%GET}$

Individual’s GET was determined by utilising a $\dot{V}$-slope method (Beaver et al., 1986) whereby GET corresponded to the point at which $\dot{V}O_2$ values above and below the breakpoint with $\dot{V}CO_2$ diverged from the intersection of the two linear regression lines. For validation, $\dot{V}$-slope was used in conjunction with secondary criteria including: ventilatory equivalents; end-tidal volumes and respiratory exchange ratio. A secondary researcher was used to confirm that GET was assigned at the same place. Once GET was determined, $\dot{V}O_2$ values that were 15% above GET were also calculated. Using these values, the power output that was exerted over the course of the ramped incremental test was plotted against the $\dot{V}O_2$ and a linear regression equation ($y = mx + c$) derived the power output that corresponded to GET and 15% above GET. Finally, the ramped incremental power output data were plotted against the obtained RPE values in which an identical linear regression equation was used to identify RPE at GET (RPE_{GET}) and 15% above GET ($RPE_{+15\%GET}$). These RPE values were rounded to the nearest whole number and used as reference values for the subsequent experimental visits (Table 3).

5.3.3.3. VISIT 2 AND 3 – FIXED PERCEIVED EFFORT CYCLING WITH THINK ALOUD

After an identical preparation and warm-up to other visits, participants completed a 30-minute fixed perceived effort cycle whilst adhering to the think aloud protocol. Conditions (i.e., RPE intensity) were randomised for each participant.

Initially, participants were asked to cycle at RPE *10 - between very light and light* for two minutes. Participants were asked to select a cadence between 80 - 90 revolutions.min^{-1} that was maintained throughout the cycle (± 2 revolutions.min^{-1}) and replicated between both sessions. Participants received the same think aloud instructions and were asked to begin thinking aloud. Once the two minutes elapsed, participants were afforded up to two minutes to ramp to the required RPE (mean time taken = 35 seconds) that corresponded to the given condition (i.e., RPE_{GET} or $RPE_{+15\%GET}$) by changing the virtual gears on the Cyclus 2. When this perceived intensity was reached, the timer was started. Hereon, participants could alter their power output as they wished via the virtual gears to ensure they maintained the same perceived effort throughout. During fixed perceived effort cycling, power output and heart rate were extracted continuously (each second) throughout the 30-minute exercise. Every five minutes, including Minute 0, blood lactate, affective valence and self-efficacy were recorded until completion of the trial. Participants could drink *ad libitum* throughout but were restricted to consuming the same amount of water between conditions. A prior study has established the test-retest reliability of this protocol for both intensities for power output and cardiorespiratory responses (O'Malley et al., 2023)

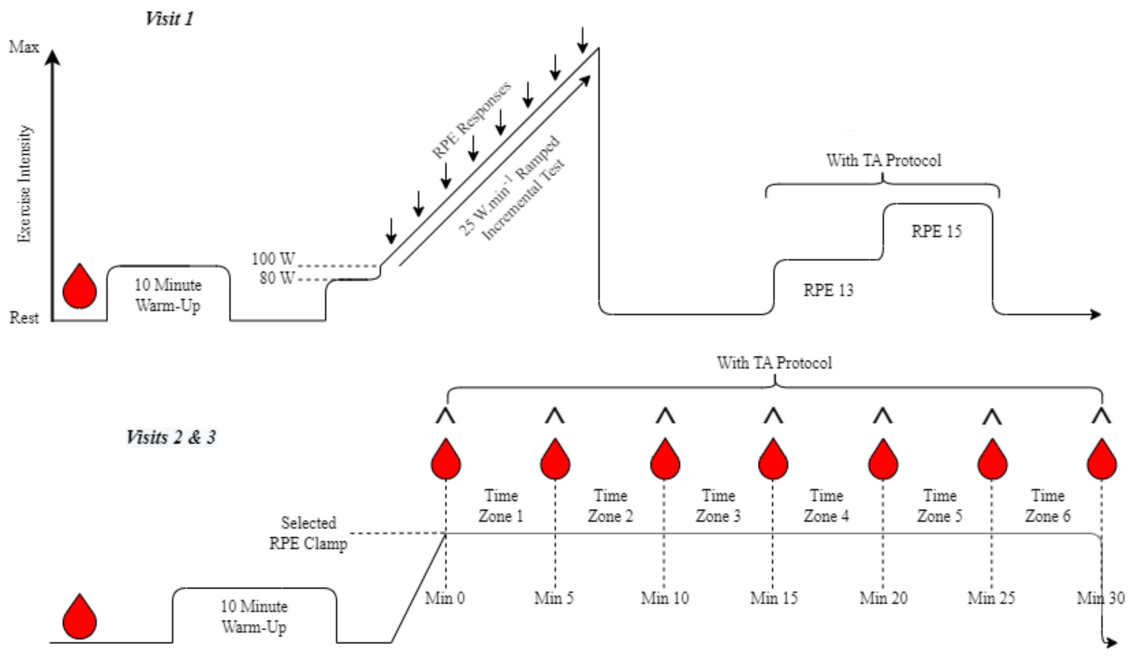


Figure 16. Visual representation of Study 2 protocols. W represents power output. ^ indicates affective valence and self-efficacy measurements. ⬧ represents blood lactate measurements. ↓ represent rating of perceived effort (RPE) measurements. TA represents the think aloud protocol.

5.3.4. THINK ALOUD CONTENT ANALYSIS

Consistent with the post-positivist and objectivist philosophical position, the researchers of this study chose an established framework to categorise think aloud data (Brick et al., 2014). This is identical to previous research in the field (Massey et al., 2020; Samson et al., 2017; Whitehead et al., 2018, 2019).

Prior to final allocation of think aloud data to themes, adaptations to the framework were made after inductive analysis that accounted for the difference in exercise task (time-trial vs fixed perceived effort) from previous studies (Brick et al., 2014; Massey et al., 2020; Whitehead et al., 2018) by removing irrelevant themes (e.g., distance as no distance markers were measured during this study) and adding relevant themes (e.g., monitoring of RPE) to this study. Deductive analysis then followed our adapted version of the metacognitive framework (Brick et al., 2014) as used in previous studies (Whitehead et al., 2018). First, all verbalisations were grouped into a primary theme which was further allocated to one of the four secondary themes: internal sensory monitoring; outward monitoring; active self-regulation; distraction/miscellaneous (see Table 4).

Set rules were pre-registered by the authors to denote one single ‘verbalisation.’ Any single verbalisation was considered as any speech that occurred with a minimum of two seconds prior to non-verbalisation. Exceptions to this rule had to meet the following criteria: 1a) the verbalisation was disrupted by the researcher due to protocol-based measures; 1b) *or* from exercise-induced behaviour (e.g., heavy breathing/drinking water) 2) *and* clearly followed the narrative of the previous verbalisation. If one verbalisation consisted of numerous themes it was allocated to all relevant themes. The number of verbalisations was calculated over the entire 30-minutes (‘overall’) and for each TZ.

5.3.5. ANALYSIS

All continuous data (power output, heart rate, coded think aloud data) were averaged across six, five-minute time zones (e.g., TZ1 = minute 0 – 5). Perceptual markers such as affective valence and self-efficacy, as well as blood lactate were analysed according to the minute they were taken (e.g., minute 0, 5, etc). Absolute counts were also calculated as percentages of total verbalisations according to each TZ and overall. The mean values for continuous data across the entire group, experienced subgroup, and inexperienced subgroup were used in subsequent analysis.

All data were exported to Jamovi (JAMOVI: v 2.3, Sydney, Australia). All data were assessed for normality and symmetry using Q-Q plots and a Shapiro-Wilk test before any further analysis. Any data that exceeded 2SD from the group mean was excluded from further analysis. A series of *t* tests were conducted to assess differences in resting responses for perceptual markers and blood lactate. A Wilcoxon signed ranks test was reported with a rank biserial correlation (*r*) denoting effect size if data violated normality.

A random-intercepts LMM was conducted to assess the condition, time, and condition × time interactions on all dependent variables data. The condition main effect for Part A was the intensity of the fixed perceived effort exercise (RPE_{GET} versus $RPE_{+15\%GET}$). The condition main effect for Part B was the training status of the participants (experienced versus inexperienced). The variable of *condition* and *time* were set as fixed effects. Models were fitted according to the group intercept. Results from the LMM were reported as *t* values (RPE_{GET} versus $RPE_{+15\%GET}$ or experienced versus inexperienced) as time was entered as a continuous variable. Another benefit to this method is that reporting of estimated marginal means (β-coefficient) denotes the raw mean differences between the two conditions as an effect size with supplementary 95% confidence intervals. A normality test was conducted on the residual values. If residuals were non-parametric, the researcher input the relevant primary or secondary think aloud themes into an aligned rank transformation software (Wobbrock et al., 2011).

After data were transformed using this software, the transformed values were entered into factorial ANOVA calculations for effects of conditions (Part A - RPE_{GET} versus $RPE_{+15\%GET}$, Part B - experienced versus inexperienced), time (differences between each time zone), or condition × time interactions (differences in changes over time between conditions). In addition, the aligned ranks transform ANOVA also allowed assessment of intensity × experience level which is reported in Appendix 6. Factorial ANOVAs on non-parametric data were reported as a F value, p value, and partial eta squared (η_p^2) for effect size. Effect sizes were interpreted as ≥ 0.01 “small”, ≥ 0.06 “medium”, or ≥ 0.14 “large” (Cohen, 1992).

5.4. RESULTS

5.4.1. RESTING VALUES AND STANDARDISATION

Resting values for blood lactate ($t_{17} = 1.85, p = .082, d = .44$) and affective valence ($Z = 45.00, p = .076, r = .64$) demonstrated no significant differences between fixed perceived effort intensities. Resting values for self-efficacy did differ significantly between fixed perceived effort intensities ($t_{17} = 3.78, p = .002, d = .89$). Resting values for blood lactate ($Z = 10.00, p = .155, r = .56$), affective valence ($t_{17} = 1.75, p = .099, d = .41$), and self-efficacy ($t_{17} = 0.68, p = .504, d = .16$) also demonstrated no significant difference between training status.

Cadence was not significantly different between intensities ($t_{195} = 1.43, p = .153, \beta = 0.26$ $[-0.10, 0.61]$), or training status ($t_{196} = -0.38, p = .709, \beta = -0.67$ $[-4.11, 2.77]$). There were also no significant condition × time interactions for exercise intensity ($t_{195} = 0.60, p = .550, \beta = 0.06$ $[-0.14, 0.27]$) or training status ($t_{196} = 1.02, p = .310, \beta = 0.11$ $[-0.10, 0.32]$). Cadence was observed to significantly increase over the course of the exercise ($t_{195} = 2.55, p = .012, \beta = 0.14$ $[0.03, 0.24]$) but observation of the raw values (mean at TZ1 = 86.5 revolutions.min^{-1} versus mean at TZ6 = 87.2 revolutions.min^{-1}) show this change was trivial and in keeping with the instructions delivered by the researcher (± 2 revolutions.min^{-1}).

5.4.2. PART A

5.4.2.1. POWER OUTPUT AND PHYSIOLOGICAL MARKERS

Power output demonstrated a significant condition effect as it was found to be significantly higher in the $RPE_{+15\%GET}$ than the RPE_{GET} condition ($t_{195} = 13.14, p = .001, \beta = 22.19$ $[18.88, 25.50]$). Power output also decreased over time in both conditions with main time effects ($t_{195} = -9.66, p = .001, \beta = -4.77$ $[-5.74, -3.81]$). There was also a condition × time interaction for power output changes ($t_{195} = -2.21, p = .028, \beta = -2.18$ [$-4.12, -0.25$]) to suggest trajectories in power output changes differed significantly between intensities (Figure 17ai).

Heart rate demonstrated a significant condition ($t_{195} = 18.06, p = .001, \beta = 14.65$ [13.06,16.24]) and time main effect ($t_{195} = 7.08, p = .001, \beta = 1.68$ [1.22,2.15]). However, there was not a significant condition × time interaction observed ($t_{195} = 0.77, p = .443, \beta = 0.37$ [-0.57,1.30]) suggesting heart rate was higher in the $RPE_{+15\%GET}$ compared to RPE_{GET} condition but both conditions involved a similar increase in heart rate between intensities (Figure 17bi).

Blood lactate demonstrated a significant condition ($t_{231} = 12.02, p = .001, \beta = 2.83$ [2.37,3.30]) and time ($t_{231} = 4.63, p = .001, \beta = 0.19$ [0.11,0.28]) main effect. A significant condition × time interaction was also observed ($t_{231} = 3.27, p = .001, \beta = 0.27$ [0.11,0.44]) suggesting that blood lactate was significantly higher in the $RPE_{+15\%GET}$ condition, increased over time across both conditions, but increased at a greater rate in the $RPE_{+15\%GET}$ versus RPE_{GET} condition (Figure 17ci).

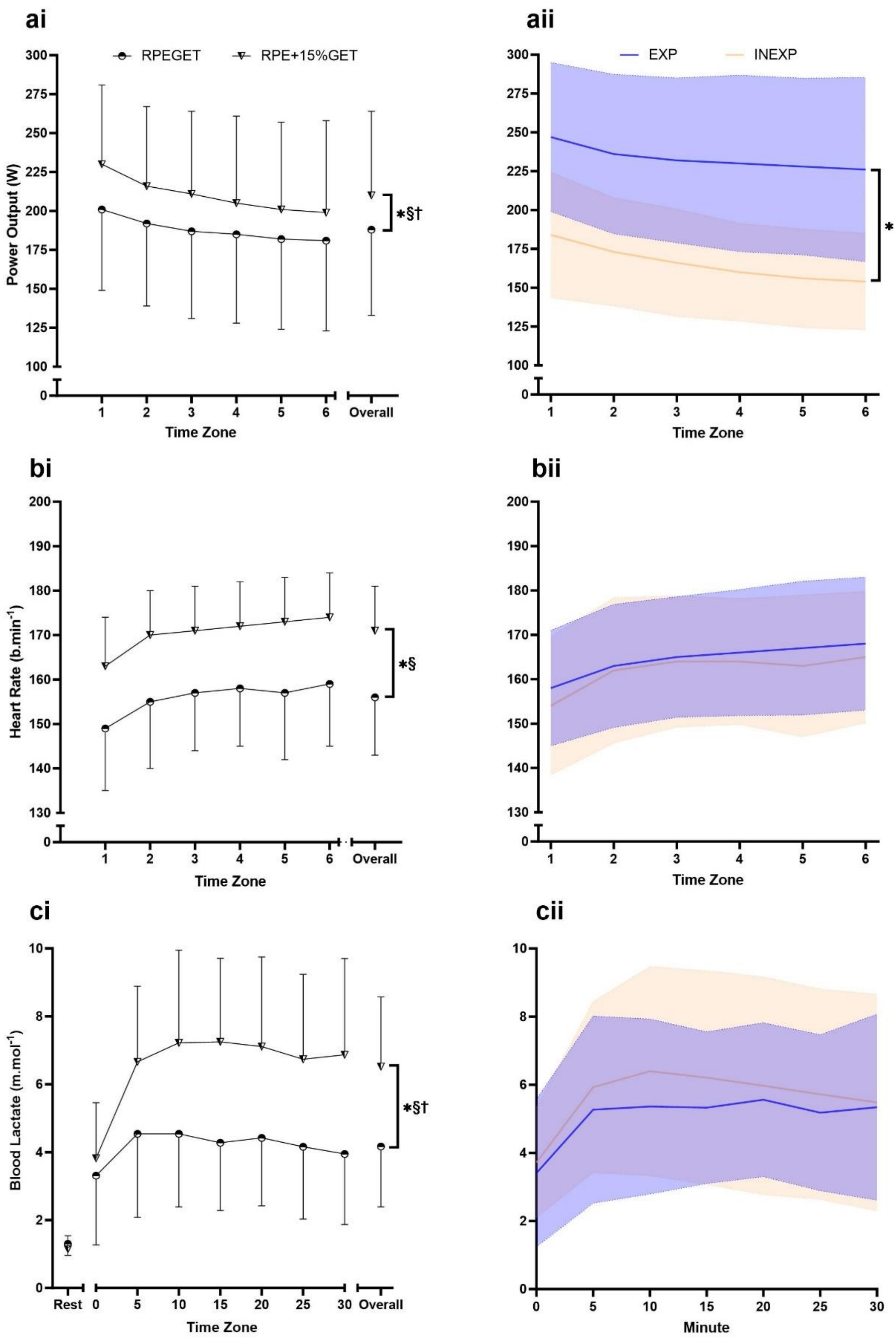


Figure 17. (i) Mean group (a) power output, (b) heart rate, and (c) blood lactate responses during fixed perceived effort cycling. (ii) Mean experienced (blue) and inexperienced (orange) power output, heart rate, and blood lactate responses during fixed perceived effort trials. Significant condition (✱), time (§), and condition × time (†) effects illustrated.

5.4.2.2. THINK ALOUD DATA

Instances of internal sensory monitoring were significantly higher in the $RPE_{+15\%GET}$ compared to RPE_{GET} conditions with significant main effects observed ($t_{195} = 2.57, p = .011, \beta = 0.95$ [0.23,1.68]). A significant main time effect was not observed across the entire cohort ($t_{195} = -1.82, p = .070, \beta = -0.20$ [−0.41,0.02]) and there was not a significant condition × time interaction ($t_{195} = 0.14, p = .890, \beta = -0.03$ [−0.40,0.46]) (Figure 18ai).

Data for outward monitoring were non-parametric. An aligned rank transformation ANOVA identified no main condition effects ($F = 0.16, p = .898$) or time effects ($F = 1.91, p = .094$).There was no significant differences in the changes in outward monitoring instances between conditions ($F = 0.34, p = .889$) (Figure 18bi).

Instances of self-regulation were significantly higher in the $RPE_{+15\%GET}$ versus RPE_{GET} condition with main condition effects observed ($t_{195} = 4.14, p = .001, \beta = 1.69$ [0.89,2.49]). Instances of self-regulation from the think aloud protocol did not demonstrate a main time effect ($t_{195} = 1.50, p = .134, \beta = 0.18$ [−0.05,0.41]) but there was a significant condition × time interaction ($t_{195} = 2.99, p = .003, \beta = 0.71$ [0.25,1.18]) indicating a greater increase in verbalisations relating to self-regulation as the exercise progressed in the $RPE_{+15\%GET}$ versus RPE_{GET} condition (Figure 18ci).

Data for miscellaneous/distraction verbalisation showed non-parametric residuals after initial regression modelling. An aligned ranks transformation ANOVA showed no significant condition ($F = 0.25, p = .621$), time ($F = 0.53, p = .753$), or condition × time interactions ($F = 0.66, p = .653$) (Figure 18di).

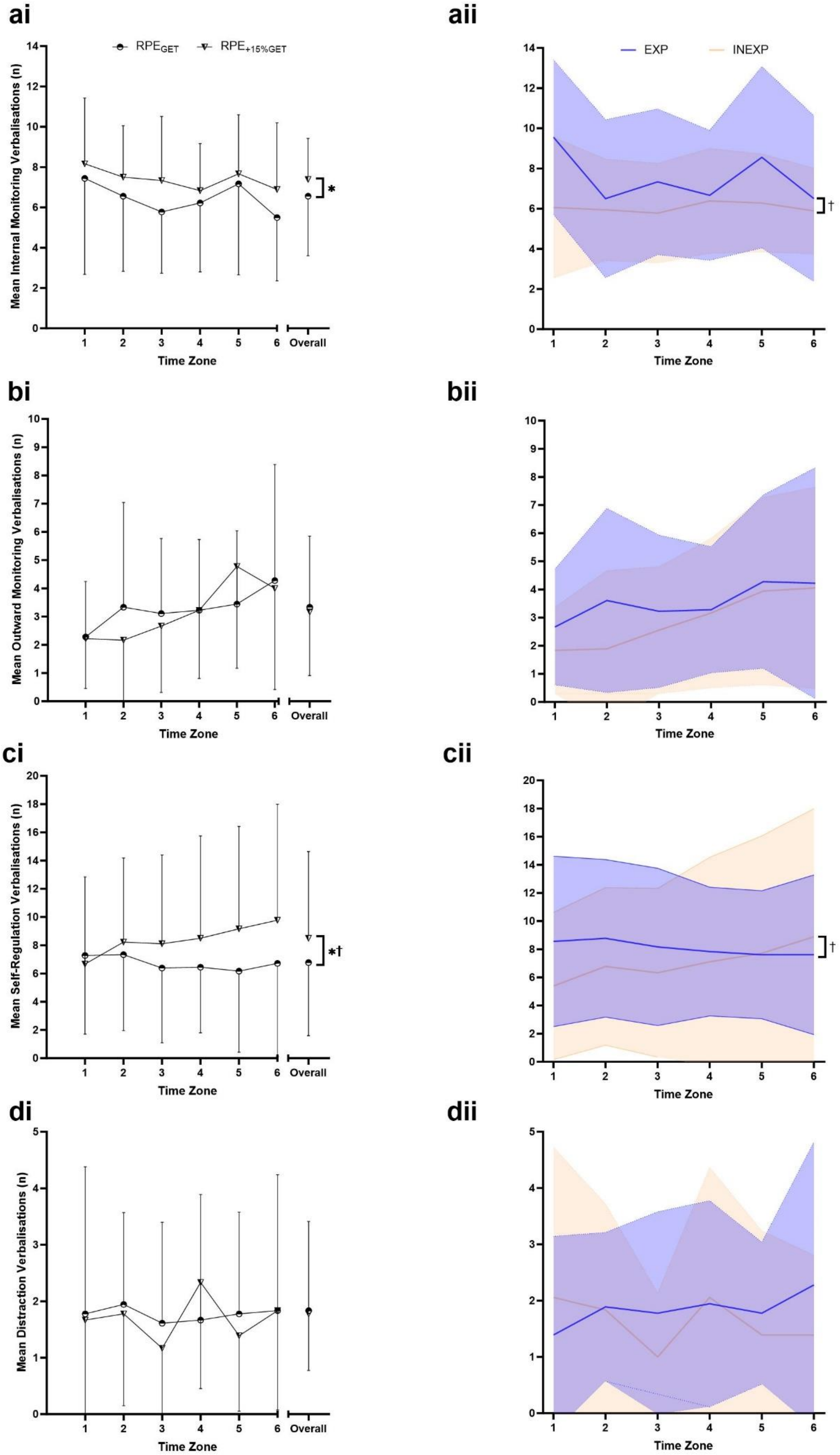
The total number of verbalisations was significantly higher in the $RPE_{+15\%GET}$ versus RPE_{GET} condition with significant main condition effects observed ($t_{195} = 3.89, p = .001, \beta = 2.46$ [1.22,3.71]). A significant time effect was also observed with more verbalisations towards the end of the exercise compared to the start ($t_{195} = 2.09, p = .038, \beta = 0.39$ [0.02,0.75]). Finally, there was also a significant condition × time interaction ($t_{195} = 2.61, p = .010, \beta = 0.97$ [0.24,1.70]) inferring that there is a difference in how the number of verbalisations changed based on the intensity of the fixed perceived effort exercise.

All primary themes for think aloud data were entered into factorial ANOVAs after undergoing aligned rank transformation. When analysing the primary themes of internal monitoring think aloud data, ANOVAs showed a significant condition main effects with small effect sizes on the number of verbalisations relating to breathing ($F = 6.18, p = .014, \eta_p^2 = .029$), fatigue ($F = 8.17, p = .005, \eta_p^2 = .039$), and physiological state (miscellaneous) ($F = 8.04, p = .005, \eta_p^2 = .038$). Specifically, verbalisation relating to breathing and fatigue were more prevalent in the $RPE_{+15\%GET}$ versus RPE_{GET} condition, whereas verbalisation relating to other physiological sensations such as hunger were more prevalent in the RPE_{GET} versus $RPE_{+15\%GET}$ condition. Factorial ANOVAs also showed significant time main effects with small to moderate effect sizes for verbalisations relating to temperature ($F = 2.36, p = .041, \eta_p^2 = .055$), RPE ($F = 2.96, p = .013, \eta_p^2 = .068$) and heart rate ($F = 2.84, p = .017, \eta_p^2 = .065$) whereby temperature and RPE appeared to be mentioned less as the task progressed whereas heart rate was mentioned more as the task progressed. Factorial ANOVAs also detected a significant condition × time interaction for verbalisation relating to heart rate ($F = 3.94, p = .002, \eta_p^2 = .088$) in which verbalisations relating to heart rate appeared to increase more during the latter parts of the RPE_{GET} compared to $RPE_{+15\%GET}$ condition.

When investigating the primary themes of outward monitoring think aloud data, ANOVAs showed a significant condition main effect with small effect sizes for the number of verbalisations relating to cycling movement ($F = 9.06, p = .003, \eta_p^2 = .043$), and time elapsed/remaining ($F = 4.25, p = .041, \eta_p^2 = .020$) . Specifically, verbalisations relating to the movement of the cycle ergometer and its parts were more prevalent in the RPE_{GET} versus $RPE_{+15\%GET}$ condition whereas verbalisations relating to time remaining/elapsed was consistently higher in the $RPE_{+15\%GET}$ versus RPE_{GET} condition. Factorial ANOVAs also detected a time main effect with a moderate effect size relating to verbalisations about time elapsed/remaining ($F = 2.75, p = .020, \eta_p^2 = .063$), wherein participants appeared to mention time-on-task more as the task progressed, specifically, postulating how much time was remaining (see Table 4). A condition × time interaction with moderate effects was detected for verbalisations relating to cycling movement ($F = 4.49, p = .001, \eta_p^2 = .099$).

When analysing the primary themes of self-regulation think aloud data, ANOVAs showed a significant condition main effect with small to moderate effect sizes on the number of verbalisations relating to self-talk ($F = 4.66, p = .032, \eta_p^2 = .022$), technique/form ($F = 7.82, p = .006, \eta_p^2 = .037$), imagery ($F = 6.07, p = .015, \eta_p^2 = .029$), power (up) ($F =

$8.48, p = .004, \eta_p^2 = .040$), and power (remain constant) ($F = 14.48, p = .001, \eta_p^2 = .066$). Specifically, instances of self-talk, discussing technique/form, and imagery were all higher in the higher intensity, $RPE_{+15\%GET}$ versus lower intensity RPE_{GET} condition. There was a similar case for verbalisations relating to power being increased or kept constant as analysis showed more verbalisations relating to power (up) and power (constant) within the $RPE_{+15\%GET}$ versus RPE_{GET} condition. (Appendix 5). In addition to a condition effect, imagery verbalisations also demonstrated a condition × time interaction with a moderate effect size ($F = 3.12, p = .020, \eta_p^2 = .071$).


ai
aii
RPE_GET
RPE_+15%GET
EXP
INEXP
Mean Internal Monitoring Verbalisations (n)
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Mean Self-Regulation Verbalisations (n)
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dii
Mean Distraction Verbalisations (n)

Figure 18. (i) Mean group (a) internal monitoring, (b) external monitoring, (c) self-regulation, and (d) distraction responses during fixed perceived effort cycling. (ii) Mean experienced (blue) and inexperienced (orange) think aloud responses during fixed perceived effort trials. Significant condition (✱), time (§), and condition × time (†) effects illustrated.

5.4.2.3. PERCEPTUAL MARKERS

A significant condition main effect demonstrated that affective valence was significantly lower in the $RPE_{+15\%GET}$ compared to RPE_{GET} condition ($t_{231} = -14.44, p = .001, \beta = -2.15$ $[-2.44, -1.86]$). There was also a significant time main effect with affective valence decreasing significantly over the course of the exercise ($t_{231} = -13.38, p = .001, \beta = -0.35$ $[-0.40, -0.30]$). In addition, there was a significant condition × time interaction ($t_{231} = -9.74, p = .001, \beta = -0.51$ $[-0.62, -0.41]$) indicating that affective valence became more negative at an earlier stage of the 30-minute exercise during the $RPE_{+15\%GET}$ versus RPE_{GET} condition (Figure 19ai).

Finally, a significant condition main effect demonstrated that self-efficacy responses were significantly lower in the $RPE_{+15\%GET}$ compared to RPE_{GET} condition ($t_{231} = -9.44, p = .001, \beta = -12.20$ $[-14.74, -9.67]$). No significant time main effects were observed for self-efficacy responses ($t_{231} = -1.45, p = .150, \beta = -0.33$ $[-0.78, 0.12]$). In addition, there was not a significant condition × time interaction for self-efficacy responses observed ($t_{231} = 0.16, p = .873, \beta = 0.07$ $[-0.82, 0.97]$) (Figure 19bi).

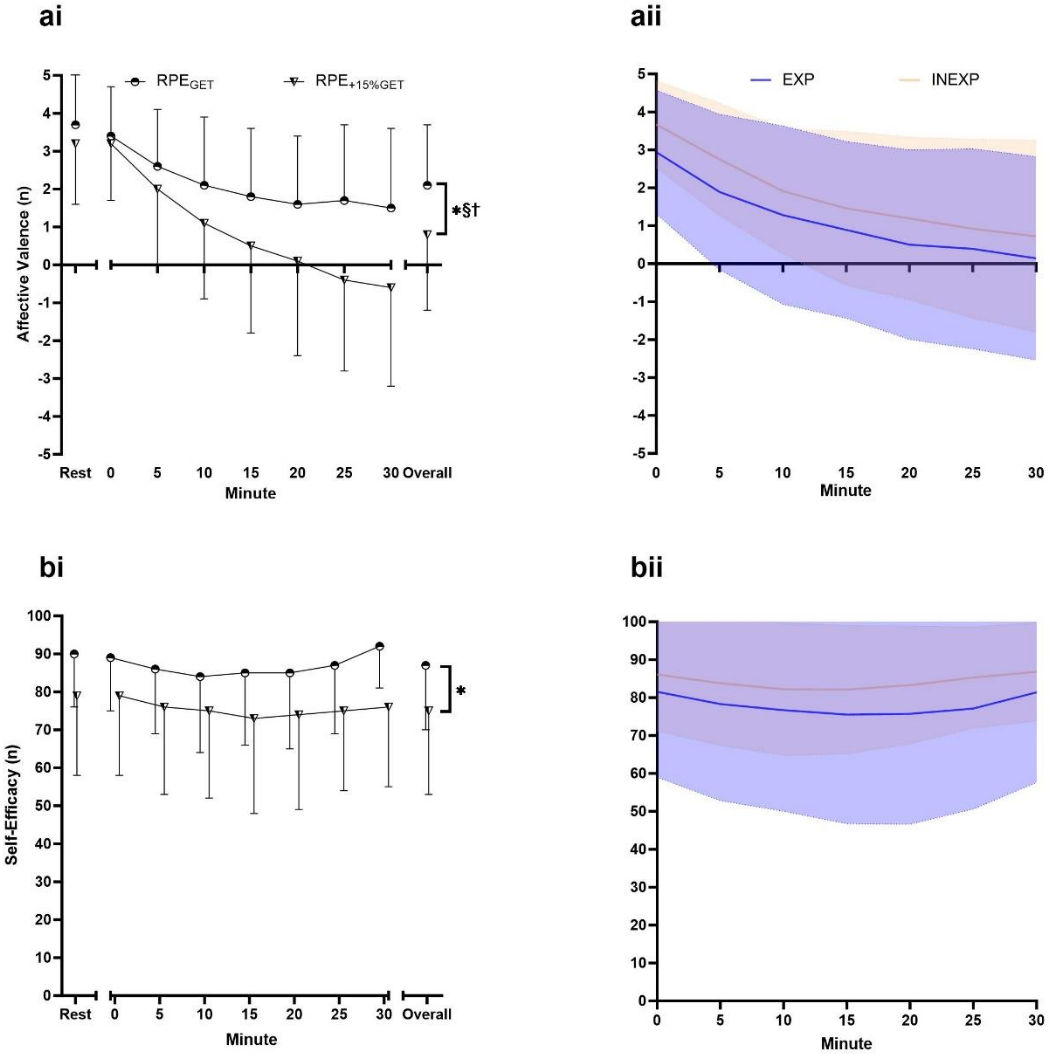

Figure 19. (i) Mean group (a) affective valence, and (b) self-efficacy during fixed perceived effort cycling. (ii) Mean experienced (blue) and inexperienced (orange) perceptual responses during fixed perceived effort trials. Significant condition (✱), time (§), and condition × time (†) effects illustrated.

5.4.3. PART B

5.4.3.1. POWER OUTPUT AND PHYSIOLOGICAL MARKERS

A significant condition main effect displayed that power output was significantly lower amongst inexperienced versus experienced cyclists ($t_{196} = -3.28, p = .005, \beta = -67.57$ $[-107.93, -27.22]$). However, there was not a condition × time interaction ($t_{196} = -1.65, p = .100, \beta = -2.24$ $[-4.89, 0.42]$) suggesting power output changes over the course of the fixed effort exercise did not vary between inexperienced and experienced cyclists (Figure 17aii).

No significant condition main effects ($t_{196} = -0.49, p = .633, \beta = -2.70\ [-13.59, 8.18]$) or condition × time interactions ($t_{196} = 0.04, p = .967, \beta = 0.03\ [-1.49, 1.55]$) were observed for heart rate (Figure 17bii). Likewise, no significant condition main effects ($t_{232} = 0.64, p = .529, \beta = 0.57\ [-1.16, 2.29]$) or condition × time interactions ($t_{232} = -0.38, p = .705, \beta = -0.05\ [-0.31, 0.21]$) were observed for blood lactate (Figure 17cii).

5.4.3.2. THINK ALOUD DATA

Instances of internal sensory monitoring were not significantly different between inexperienced and experienced cyclists ($t_{196} = -1.78, p = .095, \beta = -1.73\ [-3.64, 0.18]$) but there was a significant condition × time interaction ($t_{196} = 2.02, p = .045, \beta = 0.44\ [0.01, 0.87]$) as it appears experienced cyclists monitored internal sensations more at the start of the exercise compared to inexperienced counterparts, but experienced cyclists gradually shifted their focus away from internal sensations as the exercise continued (Figure 18aii). Instances of outward monitoring did not exhibit any significant condition ($t_{196} = -0.59, p = .567, \beta = -0.64\ [-2.78, 1.50]$) or condition × time interactions ($t_{196} = 1.55, p = .124, \beta = 0.23\ [-0.06, 0.52]$) (Figure 18bii).

Instances of self-regulatory thoughts did not differ between groups with no main condition effect observed ($t_{196} = -0.39, p = .699, \beta = -1.06\ [-6.32, 4.21]$). However, there was a significant condition × time interaction ($t_{196} = 3.45, p = .001, \beta = 0.85\ [0.37, 1.33]$) as experienced cyclists disclosed more self-regulatory thoughts at the earlier stages of the exercise with a gradual decrease as the exercise continued. In contrast inexperienced cyclists disclosed less self-regulatory thoughts at the start of the exercise but gradually disclosed more self-regulatory thoughts as the exercise continued (Figure 18cii). Aligned rank transformation ANOVAs for instances of miscellaneous/distraction, showed no significant condition ($F = 0.03, p = .871$), or time ($F = 0.38, p = .862$) main effects , or a condition × time interaction ($F = 0.06, p = .998$) Albeit insignificant, an inverse relationship for distractive thoughts were observed across different training status groups. For instance, experienced cyclists appeared to increase in distractions over time whereas inexperienced cyclists decreased the number of distractions as exercise progressed (Figure 18dii).

Finally, the total number of verbalisations did not differ between training status groups ($t_{196} = -0.83, p = .418, \beta = -3.65$ [$-12.25,4.96$]) suggesting a similar understanding of the think aloud protocol between groups. However, there was a significant condition × time interaction ($t_{196} = 3.41, p = .001, \beta = 1.29$ [$0.55,2.04$]) whereby experienced cyclists maintained a consistent number of verbalisations throughout the exercise whereas inexperienced cyclists progressively increased the number of verbalisations as the exercise continued.

After aligned rank transformation, and input into factorial ANOVAs, analysis of the primary themes of think aloud data showed significant condition main effects with small to moderate effect sizes for fatigue ($F = 9.16, p = .003, \eta_p^2 = .043$), RPE ($F = 15.37, p = .001, \eta_p^2 = .070$), psychological state ($F = 5.42, p = .021, \eta_p^2 = .026$), and physiological state (miscellaneous) ($F = 6.77, p = .010, \eta_p^2 = .032$). Specifically, verbalisations relating to fatigue, RPE, psychological state, and physiological state (miscellaneous) were all more prevalent amongst experienced versus inexperienced cyclists during both fixed perceived effort bouts. No significant condition × time interactions for any of the primary think aloud themes for internal sensory monitoring were detected.

When investigating the primary themes of outward monitoring think aloud data, ANOVAs showed a significant condition main effect with a large effect size for the number of verbalisations relating to cycling movement ($F = 40.21, p = .001, \eta_p^2 = .165$), indicating that experienced cyclists were more attuned to the way the cycle ergometer was operating compared to inexperienced counterparts.

Finally, factorial ANOVA analysis of aligned rank transformed think aloud data observed significant condition main effects for verbalisations relating to power (no direction) ($F = 12.74, p = .001, \eta_p^2 = .059$), power (down) ($F = 4.09, p = .045, \eta_p^2 = .020$), and power (constant) $\left(F = 5.42, p = .021, \eta_p^2 = .026\right)$. Specifically, whilst experienced appeared to ruminate about their power (no direction) more than inexperienced cyclists, experienced cyclists also appeared to talk about maintaining their power output (i.e., power [constant]), more than inexperienced cyclists, whereas inexperienced cyclists seemed to disclose more thoughts about lowering their power than experienced cyclists. A notion not quite reflected in the power output responses that were observed (Figure 17aii). Additional condition main effects with small to moderate effect sizes were also observed for verbalisations relating to reappraisal ($F = 9.15, p = .003, \eta_p^2 = .043$), technique/form ($F = 13.42, p = .001, \eta_p^2 = .062$), and imagery ($F = 14.00, p = .001, \eta_p^2 = .064$). In which, experienced cyclists seemed to utilise psychophysiological self-regulatory strategies like emotional control/reappraisal and imagery, as well as a focus on maintaining their technique/form more than experienced counterparts as a coping mechanism during fixed perceived effort cycling. Addition condition × time interactions were detected for verbalisations relating to gears ($F = 2.38, p = .040, \eta_p^2 = .055$) whereby experienced individuals focused more on gears at the start of the task than experienced counterparts, and for verbalisations relating to imagery ($F = 4.76, p = .001, \eta_p^2 = .104$) where again, experienced cyclists seemed to engage in more imagery at earlier phases of the fixed perceived effort trial whereas if inexperienced cyclists mentioned imagery it was in the latter phases of the trial.

5.4.3.3. PERCEPTUAL MEASURES

No significant condition main effects ($t_{232} = 0.75, p = .463, \beta = 0.66\ [-1.06, 2.37]$) or condition × time interactions ($t_{232} = -0.46, p = .647, \beta = -0.04\ [-0.19, 0.12]$) were observed for affective valence responses (Figure 19aii). Similarly, no significant condition main effects ($t_{232} = 0.68, p = .506, \beta = 6.19\ [-11.63, 24.01]$) or condition × time interactions ($t_{232} = 0.51, p = .609, \beta = 0.36\ [-1.00, 1.71]$) were observed for self-efficacy responses (Figure 19bii).

Table 4. Example *verbatim* quotes coded according to primary and secondary themes and their descriptors.

Secondary Themes	Primary Theme	Description	Example
Internal Sensory Monitoring	Breathing	Reference to breathing or respiratory-related signals	"I am thinking about my breathing a lot" (N11-UT5) "The breathing is quite rapid" (N18-T9)
	Pain / Discomfort	Reference to actual or potential tissue damage perceptions or general discomfort during the task	"Saddle is getting kind of painful" (N16-UT9) "Just concentrating on the pain, legs feel loaded" (N5-T3) "A little back pain as well as the legs" (N9-T6)
	Hydration	Reference to, or actual noting of needing and/or taking drink	"Time for my first bit of water" (N16-UT9) "Oh, I cannot wait to get a drink" (N14-UT8) "Mouth is a little dry, have some water" (N5-T3)
	Fatigue	Reference to mental or physical tiredness or difficulty to complete the task but independent of pain.	"Really heavy legs today" (N1-T1) "Feel tired and the legs are definitely worse than last time (N12-UT6)

			"Actually feel very rested coming into this" (N6-T4)
	Temperature	Reference to the self or room feeling hot/neutral/cold. Also included references to sweat.	"I can feel my face going really red" (N11-UT5) "I am dripping with sweat like a waterfall" (N14-UT8)
	Perceived Effort	Reference to remaining at a set perceived effort rating	"Maintaining that rating of 14 [RPE]" (N7-T5)
	Heart Rate	Reference to any acknowledgement of heart rate or speculation on its value	"Wonder what my heart rate is, 160s?" (N7-T5) Can definitely feel my heart beating" (N13-UT7) "Heart rate feels like it is maxing out" (N17-T8)
	Psychological State	Reference to any past, current, or future psychological state	"Probably passing into the negatives for affective valence now" (N8-UT3) "I am motivated, I am alert, but I am bored" (N6-T4)
	Physiological State (Miscellaneous)	Reference to any physiological state not included in previous themes	"I wonder what my lactate concentration is at, around 2?". (N4-T2) "Absolutely starving now" (N8-UT3)
Outward Monitoring	Time	Reference to time elapsed/remaining	"I underestimated how long this task feels it would take" (N9-T6) "Around 5 minutes passed, break it into those chunks" (N2-UT1)
	Cycling Movement	Reference to the movement of the cycle ergometer that are not related to technique	"The frame is a bit wavy" (N9-T6) "The bike frame makes you feel very upright" (N6-T4)
	Researcher Behaviour	Reference to the researcher's behaviour	"Will the researcher be able to get blood out of that finger prick?" (N16-UT9)
Active Self-Regulation	Cadence	Reference to pedal strokes and its value	"Cadence is high, but I have kept it stable" (N15-T7) "Just keep that cadence at 88-89 revs" (N3-UT2)
	Gears	Reference to the past, current, or planned gear selections	"This gear is good, comfortable" (N13-UT7) "Changing a gear could disrupt the rhythm" (N4-T2)
	Power (no direction)	Reference to the power output without note of its direction	"If I was to guess, I am in the 218 to 220 Watts range now" (N1-T1) "Reckon it feels like 320 Watts" (N17-T8)
	Power (increase)	Reference to increasing the power output	"Actually, I am going to put the power up a bit on this section, to not drop the RPE" (N2-UT1) "Do you know what, I can bump it [power] up as the end is in sight" (N1-T1)
	Power (decrease)	Reference to decreasing the power output	"I am going to have to lower it [power], as I am just really sore" (N10-UT4) "Think I will decrease the intensity a bit to keep the RPE at 15" (N4-T2)
	Power (remain constant)	Reference to maintaining the current power output	"Just try and see it through, see it out at this intensity now" (N12-UT6)
	Emotional Control /Appraisal	Reference to altering current perception of the situation or emotions	"It is just RPE 15, I have done much worse before, like a 40km time-trial" (N2-UT1) "Change the way you think about things, that is all you can do" (N1-T1)
	Self-Talk	Reference to any talk directed to the self	"Great job, keep it going, keep the legs turning" (N3-UT2)
	Technique / Form	Reference to the movement and execution of the task on the ergometer	"Keep those legs ticking, tuck in, find that nice rhythm" (N3-UT2) "Keep the legs aligned with the pedal" (N4-T2)

			“Keeping a relaxed position with my arms, neck and shoulders” (N15-T7)
	Imagery	Reference to imagined experience related to the task	“Imagine… you are at Belvedere now, only five minutes from home” (N16-UT9) “Imagine like a nice long ride around the country lane” (N14-UT8)
Distraction	Distraction	Reference to specifically trying to ignore or forget about the present task	“My head wants to avoid it, or get outside the thought of the exercise” (N18-T9) “It is pleasurable to not think about the exercise” (N14-UT8) “I am going to start counting to distract myself” (N11-UT5)
	Miscellaneous	Reference to any irrelevant information or other verbalisations that do not match any other theme.	“Today made me realise I really need a haircut” (N8-UT3) “Think I will pick some chestnuts later” (N10-UT4)

Legend: N = Participant’s number; T = Trained participant; UT = Untrained participant; RPE = rating of perceived effort

Table 5. Mean absolute counts and (percentages [%]) of verbalisations across between intensities, training status, and time zones.

RPE_{GET}														
	Experienced							Inexperienced						
Time Zone	1	2	3	4	5	6	Overall	1	2	3	4	5	6	Overall
Internal Sensory Monitoring	84 (42)	69 (36)	53 (32)	55 (35)	76 (42)	44 (26)	381 (36)	50 (36)	49 (32)	51 (37)	57 (36)	53 (34)	55 (34)	315 (35)
Outward Monitoring	24 (12)	37 (19)	33 (20)	31 (20)	33 (18)	39 (23)	197 (19)	17 (12)	23 (15)	23 (17)	27 (17)	29 (19)	38 (24)	157 (17)
Self-Regulation	82 (41)	69 (36)	62 (37)	60 (38)	56 (31)	65 (38)	394 (37)	49 (35)	63 (42)	53 (38)	56 (35)	55 (35)	56 (35)	332 (37)
Distraction	8 (4)	19 (10)	18 (11)	11 (7)	14 (8)	22 (13)	92 (9)	24 (17)	16 (11)	11 (8)	19 (12)	18 (12)	11 (7)	99 (11)
$RPE_{+15\%GET}$														
	Experienced							Inexperienced						
Time Zone	1	2	3	4	5	6	Overall	1	2	3	4	5	6	Overall
Internal Sensory Monitoring	88 (44)	77 (37)	79 (39)	65 (33)	78 (35)	73 (36)	460 (37)	59 (43)	58 (40)	53 (37)	58 (33)	60 (31)	51 (25)	339 (34)
Outward Monitoring	24 (12)	28 (13)	25 (12)	28 (14)	44 (20)	37 (18)	186 (15)	16 (12)	11 (8)	23 (16)	30 (17)	42 (22)	35 (17)	157 (16)
Self-Regulation	72 (36)	89 (43)	85 (42)	81 (41)	81 (37)	72 (36)	480 (39)	48 (35)	59 (41)	61 (42)	72 (40)	84 (44)	104 (51)	428 (43)
Distraction	17 (8)	15 (7)	14 (7)	24 (12)	18 (8)	19 (9)	107 (9)	13 (10)	17 (12)	7 (5)	18 (10)	7 (4)	14 (7)	76 (8)

5.4.4. INTENSITY × EXPERIENCE INTERACTIONS

Instances of internal sensory monitoring ($p = .320$), outward monitoring ($p = .755$), self-regulation ($p = .479$), and miscellaneous/distraction ($p = .164$) did not show any significant intensity × experience interactions, indicating that there were no significant combined effect of the task intensity or experience level on what participants disclosed as part of the think aloud protocol. A factorial ANOVA of aligned rank transformed values showed that the total number of verbalisations had no significant intensity × experience interactions ($p = .639$).

Primary themes of internal sensory monitoring such as verbalisations relating to RPE ($F = 7.21, p = .008, \eta_p^2 = .033$), physiological state (miscellaneous) ($F = 8.09, p = .005, \eta_p^2 = .037$), and heart rate ($F = 8.28, p = .004, \eta_p^2 = .038$) showed significant intensity × experience interactions with small effect sizes. Experienced cyclists seemed to mention RPE a similar amount between fixed perceived effort RPE conditions, whereas inexperienced counterparts seemed to mention RPE much more often in the lower intensity RPE_{GET} condition than higher intensity $RPE_{+15\%GET}$ condition. Meanwhile, inexperienced cyclists appeared to mention miscellaneous physiological states such as hunger relatively more during higher intensity $RPE_{+15\%GET}$ versus RPE_{GET} conditions than experienced cyclists. In contrast, inexperienced appeared to mention heart rate relatively more during lower intensity RPE_{GET} conditions than experienced counterparts did under the same conditions.

Primary themes of outward monitoring such as verbalisations relating to cycling movement ($F = 8.28, p = .004, \eta_p^2 = .038$) showed significant intensity × experience interactions with small effect sizes. In particular, experienced cyclists mentioned cycling movement similarly between RPE intensities but inexperienced cyclists appeared to mention cycling movement even more during the $RPE_{+15\%GET}$ condition.

Primary themes of self-regulation such as verbalisations relating to gears ($F = 4.62, p = .033, \eta_p^2 = .021$) and power (constant) ($F = 13.50, p = .001, \eta_p^2 = .060$) showed significant intensity × experience interactions with small to moderate effect sizes. Both groups seemed to mention gears and gear selection similarly during the RPE_{GET} condition, but experienced cyclists mentioned gears and gear selection relatively more during the higher intensity $RPE_{+15\%GET}$ condition. As for maintaining power output, experienced cyclists mentioned power (constant) verbalisations similarly across fixed RPE bouts whereas inexperienced cyclists only seemed to mention maintaining power output during the lower intensity RPE_{GET} condition.

5.5. DISCUSSION

The main aims of this study were: Part A - to investigate the attentional focus and self-regulatory strategies used to alter behavioural and psychophysiological state during different fixed perceived effort intensities; and Part B – to investigate the differences in attentional focus and self-regulatory strategies to alter behavioural and psychophysiological state between experienced and inexperienced cyclists during a fixed perceived effort cycling tasks.

For Part A, the main findings were that power output was significantly higher in the $RPE_{+15\%GET}$ versus RPE_{GET} condition with a sharper decrease in the $RPE_{+15\%GET}$ versus RPE_{GET} condition also observed. Physiologically, this difference in power output was paired with significantly higher heart rate and blood lactate levels in the $RPE_{+15\%GET}$ condition. Perceptually, participants also demonstrated significantly lower/worse affective responses (which also worsened at a faster rate) and ratings of perceived self-efficacy in the $RPE_{+15\%GET}$ versus RPE_{GET} condition. Finally, participants disclosed significantly more verbalisations concerning internal sensory monitoring and engagement in self-regulatory strategies to cope with perceived effort during the $RPE_{+15\%GET}$ versus RPE_{GET} condition.

Findings relating to the physiological and perceptual responses to exercise at two separate fixed perceived effort intensities were expected based on previous studies which have demonstrated similar changes to power output, heart rate, blood lactate, affective valence, and self-efficacy (Cochrane et al., 2015b; O'Malley et al., 2023; Robinson et al., 2021). It appears that at a higher perception of effort (i.e., RPE *15 – hard* versus RPE *13 – somewhat hard*), participants resort to more behavioural strategies to regulate perception of effort by lowering exercise intensity to maintain a given RPE. In respect to think aloud data, findings of the present study were also consistent with previous studies which have found that individuals' main cognitions concern internal sensory monitoring and active self-regulation (Whitehead et al., 2018) during self-regulated exercise (Table 5).

Specifically, internal sensory monitoring appeared more prominent at the start of the exercise than in the latter stages whilst self-regulation remains relatively stable throughout. Findings of this nature are self-explanatory as engagement in a higher intensity exercise (e.g., $RPE_{+15\%GET}$) involves individuals exercising mostly within the heavy domain (Cochrane et al., 2015b; O’Malley et al., 2023), causing a natural accumulation of metabolites that are more salient than when exercising at a lower intensity of exercise (RPE_{GET}) (Burnley & Jones, 2018). Consequently, the increase in physiological afferent signals to the central nervous system are integrated into perceptions that are then evoked in the think aloud data (Brick et al., 2014; Brick, Campbell, et al., 2016; Ekkekakis et al., 2011; Hutchinson & Tenenbaum, 2007). Results from this study which noted a greater focus on breathing (Laviolette & Laveneziana, 2014; Nicolò et al., 2016) and fatigue (Behrens et al., 2023) particularly at the earlier stages of the exercise where power output was higher, are consonant with this notion.

Although understanding *what* individuals are focusing on during a fixed perceived effort trial is useful, understanding *how* they are coping with perceived effort is of real interest for application to the real world (Lazarus, 2000). Findings of this study indicate that although more behavioural strategies (i.e., lowering power output) were used to self-regulate perceived effort at a higher intensity ($RPE_{+15\%GET}$), equally, participants also used more cognitive strategies such as self-talk, imagery, and a focus on technique/form to cope with the task. Meanwhile, distraction strategies remained similar across exercise intensities.

In relation to self-talk, Blanchfield et al. (2014a) discerned that individuals who could effectively motivate themselves with motivational self-talk could forestall their time-to-task exhaustion. Seemingly, individuals in this study engaged more in self-talk during higher intensity exercise (e.g., $RPE_{+15\%GET}$) to maintain a higher motivational intensity (Blanchfield et al., 2014a) and alter their perceptions of negative sensations when they were more intense. This is consonant with previous studies which indicate self-talk strategies are particularly useful to athletes for coping with high levels of effort and pain (McCormick et al., 2018). Resultantly, evidence suggests that reappraisal and self-talk have the scope to reduce disturbances in physiological state (Arthur et al., 2019; Hase et al., 2019; Sammy et al., 2017) and improve psychological state (Berman et al., 2019; Blanchfield et al., 2014a; Giles et al., 2018; Grandjean da Costa et al., 2022; McCormick et al., 2015; Sammy et al., 2017) so that less change in behaviour (i.e., lowering power output) is required at a set perceived effort (Carver & Scheier, 1982).

For Part B, the main findings were that experienced athletes exerted significantly higher power output than inexperienced athletes despite no difference in physiological (heart rate, blood lactate) or psychological (affective valence, self-efficacy) state. Next, although there were no significant differences between experienced and inexperienced participants for the frequency of think aloud data relating to the secondary themes, there were some significant condition × time interactions. Notably, experienced verbalised more absolute and a higher percentage of total thoughts pertaining to internal sensory state and instances of self-regulation at the start of the exercise (Table 5), whereas inexperienced showed a gradual increase in thoughts pertaining to internal sensory states and self-regulation towards the end of the fixed perceived effort exercise.

It was interesting to note that experienced cyclists appeared more attuned towards internal sensations/perceptions such as fatigue and psychological state than inexperienced counterparts. This may be indicative of a prevailing associative attentional focus amongst experienced athletes who may be more attuned towards important psychophysiological phenomena associated with exercise than inexperienced cyclists (Brick, MacIntyre, et al., 2014; Hutchinson & Tenenabaum, 2007) and the need to regulate these states earlier on to complete a task more efficiently or effectively (Ekkekakis et al., 2011; Lind et al., 2009; Venhorst et al., 2017). Relatedly, significant condition × time interactions for self-regulation provide an interesting insight into *when* experienced cyclists identified self-regulatory strategies to maintain a constant perception of effort compared to inexperienced cyclists who acknowledged the need to self-regulate their psychophysiological state much later into the task.

. Delving further into the primary themes, experienced cyclists also mentioned several themes of self-regulation more than the inexperienced group. For example, the experienced group mentioned keeping their power output constant more often and also discussed lowering their power output less often than inexperienced cyclists. The actual power output changes partially reflect this as power output was significantly higher amongst the experienced group but whilst experienced cyclists appeared to discuss maintaining power output more there were no condition × time interactions to show a difference in power output trajectories between groups.

Other primary themes of self-regulation were also discussed more by the experienced than the inexperienced group. For example, experienced cyclists seem to engage more in psychophysiological self-regulatory strategies like emotional control/reappraisal and imagery. Reappraisal has been identified as a highly functional cognitive strategy to alter the perception of aversive sensations associated with exercise (Lazarus, 1991, 2000; McRae et al., 2012; Smith & Lazarus, 1993; Urry, 2009). First, Giles et al. (2018) exhibited that when runners utilised cognitive reappraisal strategies during a prolonged activity, they reported lower perceived effort than when no cognitive appraisal was used. Moreover, other studies have also seen that cognitive reappraisal mitigates the decreases in affective valence during prolonged exercise (Berman et al., 2019; Grandjean da Costa et al., 2022). Finally, Sammy et al. (2017) demonstrated that reappraisal elicited more functional cardiovascular responses with less peripheral resistance than without reappraisal. Jointly, increases in self-efficacy were also observed in this study when appraisal was used. Therefore, reappraisal appears to be a functional cognitive self-regulatory strategy that participants of this study identified with to bring their own state/self into accord with the required perceived effort instead of always resorting to behavioural strategies like lowering power output (Carver & Scheier, 2000).Overall, findings relating to primary themes may suggest that experienced athletes appear to use cognitive strategies to avoid reductions in power output as a constant source of self-regulating the self in accord with the task. Whereas inexperienced athletes seem to opt for more cognitive self-regulatory strategies later in the task when physiological intensity of the exercise is lower.

Moreover, based on previous research, the pattern of attentional focus and self-regulation indexed by experienced athletes may be more functional on a neuro-psychophysiological level (Chong et al., 2018; Lind et al., 2009). To explain, reappraisal is a resource-demanding cognitive strategy (Gross, 2015; Jones et al., 2009), meaning a higher activation of cerebral areas such as the prefrontal cortex as well as perceived efficacy to implement reappraisal is required for it to be executed effectively (Chong et al., 2008; Gross, 2013; Meijen et al., 2020; Müller & Apps, 2019). Robinson et al. (2021) identified that cerebral oxygenation in the prefrontal cortex (an indicator of resources present in the brain area largely associated with executive function) progressively decreases as perceived effort increases. Unfortunately, authors in that study did not report if there were significant differences between experienced and inexperienced cyclists in cerebral haemodynamics over time (Robinson et al., 2021). Yet, others have discerned that individuals who are well-trained have a unique adaptation to maintain cerebral oxygenation during intense physical exercise that untrained exercisers cannot (Santos-Concejero et al., 2015).

Thus, in relation to this study, experienced athletes may have evidenced a functional use of appraisal at earlier stages of the exercise before they accrued mental and physical fatigue (Behrens et al., 2023) which would hinder their perceived ability to implement reappraisal strategies (Gross, 2013; Santos-Concejero et al., 2015). Relatedly, experienced athletes appeared intent on maintaining their power output (as they mentioned keeping power output constant more). Whilst this may not have been reflected in condition × time interactions of the power output data, there may be an underlying sentiment that experienced cyclists will not automatically turn towards behavioural self-regulatory strategies like lowering power output to maintain a perception of effort during exercise but utilise a mixture of cognitive and behavioural strategies to change the perceived value of investing effort towards a task. Accordingly, future studies could benefit greatly from utilising cerebral oxygenation measures to ascertain a link between cognitive coping strategies, and cerebral activation during endurance-based activities to regulate perceptions of effort.

Briefly, it is also worth discussing some potential limitations and possible reasons for the lack of differences between experienced and inexperienced of this study. Namely, the recruitment and allocation to experienced/inexperienced groups used in this study may have been the cause of this. Principally, all participants were currently active cyclists with the only differing factors being the number of years that they had been active cyclists (experienced = ≥ 3 years) and their physiological capacity ($\dot{V}O_2max$). Consequently, despite there being a difference in performance level according to previous research (see de Pauw et al., 2013), the participants completed submaximal exercise (maximum *RPE 15 - hard*) which may not be intense enough to accentuate differences in most behaviours between participants that only differ in number of years cycling experience and $\dot{V}O_2max$. Therefore, future studies may wish to identify other means of classifying participant groups.

A final area for future research is that there is a remaining ambiguity surrounding the cost-benefit of utilising cognitive strategies like reappraisal and self-talk (Chong et al., 2017; Manohar et al., 2015). As noted, effort refers to the application of physical *and* mental resources towards a task (Preston & Wegner, 2009). Accordingly, the employment of cognitive strategies seem to be effortful (Englert, 2016) and could therefore impact perceived effort (Englert et al., 2021). However, in this context, there appears to be a use of cognitive strategies particularly by experienced athletes to avoid reducing power output for a set RPE. In short, cognitive strategies seem to be used to allow the individual to get more '*bang for their buck'* at a given RPE (Figure 2). If that is the case, this must mean that experience may lead to cognitive strategies becoming more autonomous and mentally effortless (Cos, 2017). Certainly, an exploration into this potential adaptation is eagerly anticipated.

5.6. CONCLUSION

In summary, this study observed that participants exerted a higher power output paired with significantly higher heart rate and blood lactate, and significantly lower ratings of affective valence and self-efficacy during the $RPE_{+15\%GET}$ versus RPE_{GET} condition. During the $RPE_{+15\%GET}$ condition, participants focused more on negative internal sensory states such as heavy breathing, and fatigue. However, participants also engaged with more active self-regulation of these states via imagery and self-talk during the $RPE_{+15\%GET}$ condition to counter the negative perception of these sensations and to maintain higher motivational intensity. When investigating if the training status of athletes (experienced versus inexperienced) impacted the types of foci and self-regulatory strategies used, this study found that there were no significant differences in the number of verbalisations relating to internal sensory states or the instance of self-regulatory strategies. However, this study did observe that experienced participants acknowledged their negative internal sensations earlier in the exercise with subsequently earlier cognitive self-regulatory strategies being used compared to inexperienced counterparts. This may indicate a more facilitative use of self-control by adopting cognitive strategies to maintain perceived effort versus behavioural interventions like lowering power output. Furthermore, it may be a more functional adaptation to address their psychophysiological state changes due to the exercise via cognitive strategies like reappraisal earlier on.

Chapter 6 – ELEVATED MUSCLE PAIN INDUCED BY A HYPERTONIC SALINE INJECTION REDUCES POWER OUTPUT INDEPENDENT OF CHANGES TO PHYSIOLOGICAL STATE DURING FIXED EFFORT EXERCISE

6.1. ABSTRACT

Pain is a naturally occurring phenomenon that consistently inhibits exercise performance by imposing unconscious, neurophysiological alterations (e.g., corticospinal changes) as well as conscious, psychophysiological pressures (e.g., shared effort demands). Although, several studies indicate that pain would elicit lower task outputs for a set intensity of perceived effort, no study has tested this. Therefore, this study investigated the impact of elevated muscle pain through a hypertonic saline injection on the power output, psychophysiological, cerebral oxygenation, and perceptual changes during fixed perceived effort exercise. Ten participants completed three visits (one familiarisation + two fixed perceived effort trials). Fixed perceived effort cycling corresponded to 15% above gas exchange threshold (mean RPE = 15; hard). Before the 30-minute fixed perceived effort exercise, participants received a randomised, bilateral hypertonic or isotonic saline injection in the vastus lateralis. Power output, cardiorespiratory, cerebral oxygenation, and perceptual markers (e.g., affective valence) were recorded during exercise. Linear mixed model regression assessed the condition and time effects and condition × time interactions. Significant condition effects showed that power output was significantly lower during hypertonic conditions ($t_{107} = 2.08, p = .040, \beta = 4.77$ Watts, $95\% CI$ [0.27 to 9.26 $Watts$]). Meanwhile all physiological variables (e.g., heart rate, oxygen uptake, minute ventilation) demonstrated no significant condition effects. Condition effects were observed for deoxyhaemoglobin changes from baseline ($t_{107} = -3.29, p = .001, \beta = -1.50$ ΔμM, $95\% CI$ [-2.40 $to - 0.61$ ΔμM]) and affective valence ($t_{127} = 6.12, p = .001, \beta = 0.93, 95\% CI$ [0.63,1.23]). Results infer that pain impacts the self-regulation of fixed perceived effort exercise, as differences in power output mainly occurred when pain ratings were higher after hypertonic versus isotonic saline administration.

6.2. INTRODUCTION

Effort-based decision-making is central to task performance (Marcora, 2019). Ultimately, individuals will enact a behaviour if the subjective evaluation about whether the potential reward meets/exceeds the effort to obtain the outcome (Chong et al., 2017). Naturally, exercise imposes a catalogue of new sensory and perceptual experiences (Mauger, 2013) that impact the perceived value of a task (Chong et al., 2016; 2017). Consequently, it becomes important for individuals to self-regulate their behaviour and psychophysiological state to promote a continued investment of effort (McCormick et al., 2019).

Muscle pain is a perception arising from the integration of nociceptive stimulations of type III and IV muscle afferents (Raja et al., 2020). Notably, pain has been observed to consistently inhibit exercise performance (Aboodarda et al., 2020; Cook et al., 1997; Graven-Nielsen, Svensson, et al., 1997; Mauger, 2013; Norbury et al., 2022a, b; Smith et al., 2020). On the one hand, the nociceptive element tends to impose numerous, inhibitive neurophysiological alterations along the corticospinal pathways (Chowdhury et al., 2022; Sanderson et al., 2021). For instance, Martinez-Valdes et al. (2020) identified that during conditions with higher nociception, the recruitment threshold of fatigue-prone, fast-twitch fibres was lowered whereas fatigue-resistant, slow-twitch fibres saw reduced firing rates. Concomitantly, numerous studies demonstrate that experimental methods which increase nociception/pain (e.g., hypertonic saline, ischaemia, electrical, and/or thermal stimulation) causes an increase in corticospinal inhibition as well as a decrease in corticospinal excitability (Chowdhury et al., 2022; Ciubatoriu et al., 2004; Farina et al., 2004; Martinez-Valdez et al., 2020; Sanderson et al., 2021). Thus, the underlying nociceptive aspect to pain elicits a compensatory increase in central drive to maintain an exercise intensity compared to conditions with less/lower nociceptive stimulation (Norbury et al., 2022a, b). Thereby increasing perceptions of effort for a set intensity of exercise (de Morree et al., 2012; Smith et al., 2020).

On the other hand, pain also inflicts conscious, psychophysiological changes (Venhorst et al., 2018a, b). To illustrate, pain has evidenced a marked impact on the hedonic (e.g., less pleasurable) and motivational (e.g., less willing to apply effort) aspects of the affective experience causing people to feel and perform worse when in pain (Rainville, 2002). Subsequent data from neurophysiological studies indicate an increased activation of cortical areas associated with inhibitory control (Legrain et al., 2009), particularly when performing with a negative affective valence due to pain (Marcora, 2019; Rainville, 2002; Venhorst et al., 2018b). In turn, continued engagement in inhibitory control is believed to exact a motivationally fatiguing effect (Müller & Apps, 2019) as well as being associated with a subjective feeling of effort (Marcora, 2019). Therefore, it is unsurprising that during painful tasks which require inhibitory control, a given exercise intensity feels more effortful (de Morree et al., 2012; Marcora, 2019).

Relatedly, researchers have aimed to incorporate neuroscientific methods to understand the underlying neurological changes during effortful tasks (Ekkekakis, 2009b; Pinti et al., 2019). Some studies have indicated that regions of the prefrontal cortex may be involved with effort signal processing (Williamson, 2006). Others also indicate that the prefrontal cortex likely functions as a centre for regulating aversive sensations and perceptions that are associated with exercise like pain, effort, and affect (Ekkekakis, 2009b). Namely, changes in oxy-, deoxy, and total haemoglobin assessed through near infrared spectroscopy are thought to reflect regional changes in cerebral blood flow, and associated cerebral metabolic activity (Obrig & Villringer, 2003). Therefore, providing a global indication of activation of select cerebral sites (Ekkekakis, 2009b). Notably, prior studies in the thesis have indexed a markedly lower affective valence during fixed perceived effort exercise of a higher intensity, and other studies indicate that pain would impress more psychophysiological disruptions (e.g., lower affective valence) compared to less painful conditions (Venhorst et al., 2018a). As such, it would be interesting to note the neurological changes in prefrontal cortex oxygenation as a surrogate measure of the regulation of psychobiological indices (e.g., pain, affect) during fixed perceived effort cycling.

In summary, past studies imply that pain and its underlying nociceptive component tend to have negative psychophysiological effects (Venhorst et al., 2018b) as well as a net inhibitive effect on corticospinal transmission of central drive (Chowdhury et al., 2022; Sanderson et al., 2021). Therefore, for a fixed task intensity like a time-to-exhaustion trial, a compensatory increase in central drive is required to maintain the intensity causing a higher perception of effort for a given intensity (de Morree et al., 2012). Alternatively, when the task paradigm is flipped to a fixed perceived effort task, pain conditions would be expected to cause a reduced intensity/workload compared to non-painful conditions. However, no study has tested this yet. Moreover, as pain is a compelling sensory and emotional experience that must be endured when undertaking exercise (Van Damme et al., 2008) it is important to understand the methods that individuals use to self-regulate and cope with pain without compromising exercise performance (McCormick et al., 2019; Van Damme et al., 2008). More insight into the regulation of cognitive factors such as pain during fixed perceived effort exercise can possibly be gleaned from neuroscientific methods such as functional near infrared spectroscopy (fNIRS) by tracking the changes in oxy-, deoxy-, and total haemoglobin at sites such as the prefrontal cortex (Ekkekakis, 2009b; Robinson et al., 2021).

Therefore, the aims of this study were twofold. Primarily, the present study aimed to investigate the impact of elevated pain perceptions through a hypertonic saline injection on power output and psychophysiological state during a fixed perceived effort task. Second, the present study also aimed to investigate the self-regulatory responses (i.e., changes in power output [behavioural] and prefrontal cortex haemodynamics [cognitive] as indicators of the self-regulatory strategies) that were used to maintain a fixed perceived effort during conditions of pain (hypertonic) or a control (isotonic).

It was hypothesised that mean power output would be lower in the pain versus isotonic condition (condition effect). Second, it was hypothesised that the decreases over time in power output would be steeper in the pain versus isotonic condition (condition × time interactions). It was also hypothesised that changes in cerebral oxygenation markers from baseline would be greater in the pain versus isotonic condition indicating more inhibitive control (Rooks et al., 2010; Secher et al., 1985). Finally, a series of secondary hypotheses were made that markers of physiological strain (e.g., heart rate, ventilatory parameters, blood lactate) would be lower in the pain than the isotonic condition, whilst perceptual markers like affective valence would be lower in the pain versus isotonic condition.

6.3. METHODS

6.3.1. PARTICIPANTS

Ten healthy and recreationally trained cyclists (two female) all considered P3 level (de Pauw et al., 2013) with a mean ± SD age: 28.9 ± 6.6 years, height 175.8 ± 6.1 cm, mass: 72.1 ± 8.0 kg, physical activity: 6.1 ± 2.9 h·week^{-1}, maximum relative oxygen uptake ($\dot{V}O_2.kg^{-1}$): 52.6 ± 7.2 ml.kg^{-1}.min^{-1} volunteered to participate in this study. An α-priori calculation using an effect size (*dz* = 1.09) from Norbury et al. (2022a) which used an identical saline injection procedure, α = .05, and β = 0.8, determined a required sample size of 10 to determine a sufficient effect on power output during a fixed effort trial with an actual β = 0.82. All participants reported at least three years of cycling experience, current engagement in cycling activity, and an 'excellent' $\dot{V}O_2max$ according to de Pauw et al. (2013) to qualify for this study. All participants were free from any musculoskeletal injuries in the previous six months, with no cardiovascular disease, neurological disorders, or blood-borne viruses, and participants did not use dietary supplements or medication throughout the entire study. Prior to all data collection sessions, participants abstained from food (2 hours), caffeine (4 hours), analgesics (8 hours), alcohol (48 hours), and refrained from vigorous exercise (48 hours). Eating habits were also asked to be replicated in the 24 hours leading to each session. Female participants reported being eumenorrheic and were scheduled so that all visits were conducted within the same stage of menses (luteal phase). All participants provided written informed consent before testing for this School of Sport and Exercise Sciences Research Ethics Advisory Group approved study (Prop #11_20_21) which was conducted according to the scientific principles outlined within the Declaration of Helsinki.

6.3.2. PROCEDURES

The present study implemented a randomised, with-subject design. Although blinding of both the participants and lead researcher was implemented, naturally the infusion of hypertonic saline results in an immediate and salient pain response (Graven-Nielsen, 2006). Meanwhile, the isotonic condition is not expected to elicit a pain response due to no/very little nociceptive stimulation however, some individuals do provide a rating indicative of some pain response (see Figure 25b, response at Minute 0). Furthermore, even though the lead researcher was blinded to the conditions, they may be able to glean which condition related to which based on participants responses. Identical blinding procedures have been used in prior studies from the same laboratory (e.g., Norbury et al., 2022a, b; Smith et al., 2020, 2021), Therefore, there is a case that this study was a double-blinded study design. Equally however, it could also be indicated that this study – as with all studies using hypertonic pain stimulation – was not a blinded study due to the natural intuition and reactions of participants and researchers involved.

Participants were required to visit the same laboratory on three separate occasions (Figure 20) separated by a minimum of three days and maximum of seven days. Each visit was conducted at the same time of day (± 2 hours) in similar ambient environments (mean ± SD temperature: 19.6 ± 3.8 °C, humidity: 51.9 ± 8.4 %, barometric pressure: 751.9 ± 7.7 mmHg). At the start of each session, participants' anthropometrics were recorded, and they were provided with a full brief of the procedures, equipment, and perceptual scales. Participants were fitted to the functional near infrared spectroscopy (fNIRS) device (Artinis Medical Systems BV: Portamon, Arnhem, Netherlands) and asked to sit completely still for five minutes during baseline measures. Participants were also fitted with a heart rate monitor (Cyclus 2: ANT+, Leipzig, Germany) to assess heart rate on a beat-by-beat basis and provided a 20 µL resting blood lactate sample from the right index finger to be assessed using an automated lactate analyser (Biosen: C-Line, EKF Diagnostics, GmbH, Barlaben, Germany). Finally, participants provided baseline values for each perceptual scale (see 6.3.3. perceptual scales).

Participants performed identical ten-minute warm-ups at RPE *11 – light*, on the cycle ergometer (Cyclus 2, Leipzig, Germany). After the warm-up, participants were afforded five minutes of passive recovery. Participants provided baseline values for each perceptual scale (see Section 6.3.3) before remounting the cycle ergometer to begin the respective exercise tasks for each session. During exercise tasks, participants were fitted to a calibrated gas analyser system (Cortex Metalyser: Model 3B, Leipzig, Germany) to assess pulmonary ventilation (e.g., $\dot{V}O_2.kg^{-1}$, $\dot{V}_E$, and breathing frequency) on a breath-by-breath basis. After exercise, participants completed a battery of psychometrics.

6.3.2.1. VISIT 1 – RAMPED INCREMENTAL TEST AND FAMILIARISATION

The first visit consisted of a ramped incremental test and a familiarisation to fixed effort cycling with bilateral hypertonic saline administration. The ramped incremental test involved an initial three-minute stabilisation period at 80% starting intensity (80 W – males, 40 W females). Participants were asked to initially cycle at a comfortable cadence ~80 revolutions.min^{-1} and were recommended to gradually increase cadence over the course of the test. The incremental ramped test began at 100 W (males) or 50 W (females) with 25 W.min^{-1} increments. These intensities were selected according to pilot test data to ensure ramped incremental tests lasted between eight – twelve minutes as previously recommended (Keir et al., 2015).

During the ramped incremental tests, the following measures were taken: a breath-by-breath analysis of gas parameters ($\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$, and breathing frequency); RPE at each minute (including starting intensity and at the point of exhaustion); and a blood lactate at the point of exhaustion. Cerebral oxygenation via fNIRS, affective valence, and self-efficacy were not measured during the ramped incremental test. Task cessation demarcated when the participant believed they reached volitional exhaustion or if cadence fell below 60 revolutions.min^{-1} for more than five seconds despite strong verbal encouragement.

After the ramped incremental test, participants received 15 minutes passive recovery and were then prepared for a familiarisation of ten-minute fixed perceived effort cycling at RPE *15 - hard* after receiving a bilateral hypertonic saline intramuscular injection. A full explanation of the fixed perceived effort trials can be seen in section 6.3.2.3.

6.3.2.2. DETERMINATION OF FIXED PERCEIVED EFFORT INTENSITY IN VISIT 2 AND 3

Using the $\dot{V}$-slope method (Beaver et al., 1986), GET was corresponded to the point at which $\dot{V}O_2$ values above and below the breakpoint of $\dot{V}CO_2$ diverged from the intersection of the two linear regression lines. Secondary criteria including ventilatory equivalents, end-tidal volumes, respiratory exchange ratio, and a secondary researcher confirmed GET identification (Keir et al., 2015). Once GET was determined, $\dot{V}O_2$ values 15% above GET ($GET_{+15\%}$) were calculated. Plotting $GET_{+15\%}$ $\dot{V}O_2$ against power output from the ramped increment test, a regression equation (y = mx + c) derived what power output corresponded to the $GET_{+15\%}$ $\dot{V}O_2$. Finally, power output data was plotted against ramped incremental RPE responses in which a similar regression equation was used to identify RPE ($RPE_{+15\%GET}$) at the corresponding power output at $GET_{+15\%}$. This RPE was rounded to the nearest whole number and used as the RPE clamp value for subsequent fixed effort cycling in *Visits 2 and 3* (mean ± SD $RPE_{+15\%GET}$ = 14.7 ± 0.4, 8n = RPE 15, 2n = RPE 14).

6.3.2.3. VISIT 2 AND 3 – FIXED PERCIEVED EFFORT TRIALS

Both experimental sessions were double-blinded and randomised. After the same preparation, baseline, and warm-up protocols, participants were prepared to receive two simultaneous, bilateral saline injections before commencing a 30-minute fixed perceived effort cycle. Injections involved a bolus of 1 mL saline (hypertonic = 5.85% NaCl, isotonic = 0.9% NaCl) injected into the middle third of the muscle belly of the vastus lateralis on each leg. Injection sites were measured and marked to ensure consistent locality of injection. Sites were cleaned with an alcoholic swab and saline was manually infused using a 3 mL Luer-Lok syringe (BD, New Jersey, USA) connected to a 3.8 cm 25-gauge hypodermic needle (SurGuard2, Terumo, Japan) over a 20 s window (insertion, 5 s pause, 10 s infusion period, 5 s pause, withdrawal). A hypertonic saline model was utilised as several studies have validated its ability to mimic exercise-induced pain experiences across different physical task modalities (Cuibotariu et al., 2004; Farina et al., 2004; Graven-Nielsen, Arendt-Nielsen, et al., 1997; Graven-Nielsen, Svensson, et al., 1997; Norbury et al., 2022a, b; Smith et al., 2023) as well as demonstrating its replicability (Smith et al., 2023).

Immediately after the injection procedure, participants began cycling and ramped up to the required RPE (mean ± SD time to begin fixed effort: hypertonic = 27 ± 9 s, isotonic = 29 ± 9 s). Following this, the fixed perceived effort trial commenced. During which, power output, heart rate, gas parameters, cerebral oxygenation parameters via fNIRS, and pain measurements were assessed continually whilst perceptual scales and blood lactate were assessed every 5 minutes.

Crucially, the task was a fixed perceived effort trial (see O'Malley et al., 2023). Therefore, throughout the trial, participants were blinded from all test variables except for cadence. In doing so, participants' sole focus was to maintain a fixed perceived effort. Participants were asked to maintain a cadence between 80 - 90 (± 2) revolutions.min^{-1} that was replicated across both sessions (mean ± SD 86 ± 3 revolutions.min^{-1}). However, power output could be changed at any point throughout the exercise in order to maintain the fixed perceived effort using virtual gears on the Cyclus 2 ergometer console which changed the resistance at the set cadence. The researcher provided a reminder of the RPE definition (Marcora, 2010b) and need for the participant to be at a fixed perceived effort every two minutes.

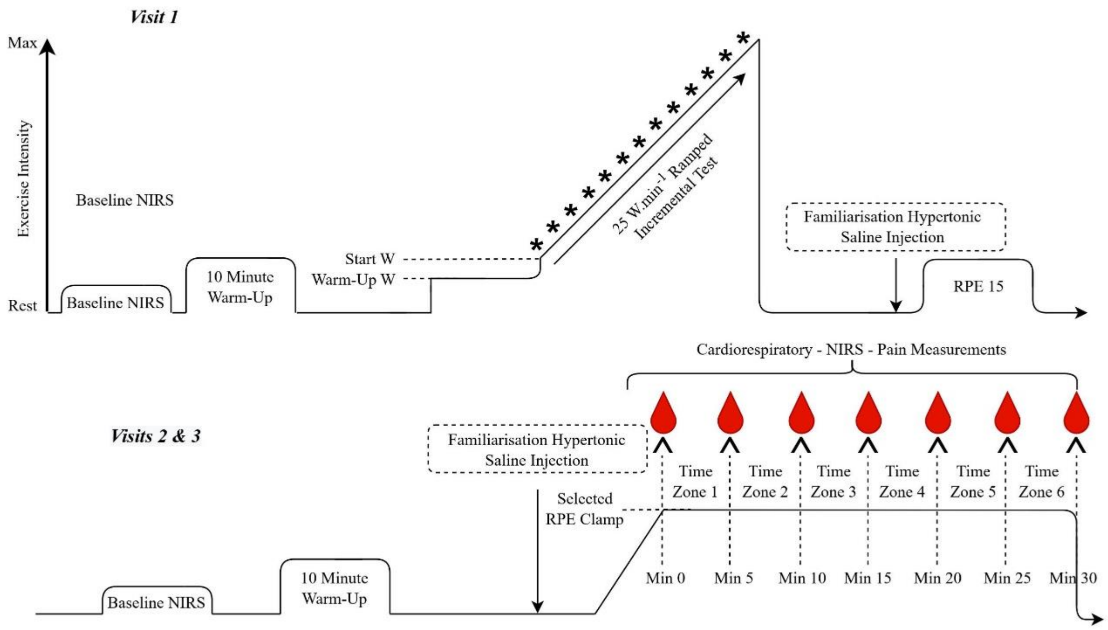

Figure 20. Visual representation of Study 3 protocols. W represents power output. ^ indicates affective valence and self-efficacy measurements. ♦ represents blood lactate measurements. ∗ represent rating of perceived effort (RPE) measurements. NIRS represents near infrared spectroscopy measures.

6.3.2.4. fNIRS MEASUREMENT

Cerebral oxygenation was assessed through a portable fNIRS device. The device was placed on the surface of the forehead aligned with the left prefrontal cortex between Fp1 and F3 (international EEG 10-20 system) as this aligns with relevant cerebral centres for executive motor control (Thomas & Stephane, 2008). Prior to application, the skin was wiped with an alcohol swab and a thin transparent film was placed over the site to prevent any sweat interfering with the device. To protect from light interference, a black bandana was placed over the device which held it stationary. Furthermore, the wire leading from the optode to the laptop was taped tightly onto the cycle ergometer and adjoining table to avoid movement artifacts. Pre-calibration adjusted an age-dependent differential path-length factor and data were sampled at 10 Hz from six optodes at wavelengths between 760 – 850 nm according to manufacturer's guidelines. Data were sampled from single, long-separation channels. Moreover, according with the manufacturer's guidelines and prior studies (Pinti et al., 2019), a low-pass filter of 0.1 Hz was applied to all participant data and a visual inspection of all data was completed to identify and remove any movement artifacts present in the data. A five-minute resting baseline was completed at the beginning of each session, whereby any fNIRS data obtained during subsequent exercise tasks was represented as changes from baseline (Δ) (Komiyama et al., 2015). Therefore, fNIRS data during exercise was expressed as change in oxyhaemoglobin (ΔO_2Hb), deoxyhaemoglobin (ΔHHb), total haemoglobin (ΔtHb), and tissue saturation index ([TSI] = $\Delta O_2Hb/\Delta tHb$ x 100) compared to resting baseline with an arbitrary average baseline value denoting 0 μM, in accordance with previous research (Subudhi et al., 2008; Williams et al., 2019).

6.3.3. PERCEPTUAL SCALES

6.3.3.1. RPE SCALE

The 15-point Borg RPE scale (Borg, 1962, 1970) denoted *how hard, heavy, and strenuous does the exercise consciously feel to drive the working muscles and for your breathing* (Marcora, 2010b). Responses ranged from *6 - no effort, like when you were sat during the fNIRS baseline doing absolutely nothing* to *20 - maximum effort, like giving everything you have got like at the end of a* $\dot{V}O_2$ *max test*. Appropriate anchors were given before exercising to facilitate the consistency of participant responses (Halperin & Emanuel, 2020; Malleron et al., 2023). According to recent suggestions (Halperin & Emanuel, 2020), an in-task affective valence measure was incorporated to acknowledge similar phenomena such as discomfort and tiredness which may not be fully captured by the RPE scale alone. Similarly, an adapted single item self-efficacy was used to capture the relative changes in coping self-efficacy directly associated with the task.

6.3.3.2. AFFECTIVE VALENCE SCALE

The feeling scale (Hardy & Rejeski, 1989) denoted *how are you feeling at the present moment of the exercise*. Responses ranged on an 11-point Likert scale from *+5 - I feel very good* to *-5 - I feel very bad* with a middle value of *0 - neutral*.

6.3.3.3. SELF-EFFICACY SCALE

Participants were asked *how confident are you that you can tolerate the physical and mental effort associated with the cycling task*. Responses ranged from *10 - extremely confident* to *0 not at all confident* with a middle value of *5 - moderately confident*. The scale was developed and adapted based on recommendations from Bandura (1997).

6.3.3.4. PAIN MEASURES

At the start of each session, participants were asked to rate on a visual analogue scale how much EIP (as the saline mimics the experience of exercise-induce pain) they expected to experience (*0 - no pain* to *100 - worst possible pain*), and their self-efficacy to cope with expected pain (*0 - not confident at all* to *10 - completely confident*), which provided a measure of pain-specific self-efficacy to predict pain tolerance and subsequent performance. During experimental exercise trials, a rating of exercise-induced pain intensity could be changed at any point by using a moveable cursor on an electronic visual analogue scale (which automatically sampled pain rating every five seconds) with responses ranging from *0 - no pain* to *100 - extremely intense pain*. This device was placed on the handlebars of the ergometer for ease. Participants were instructed to anchor the uppermost pain rating to the worst exercise-induced pain they had previously experienced (Astokorki & Mauger, 2017b).

Furthermore, pain quality was assessed using the long form McGill pain questionnaire (MPQ) (Katz & Melzack, 2011) to assess several pain elements such as sensory, affective, and evaluative qualities. Therefore, the MPQ allows a more multidimensional consideration of pain that goes beyond the simple magnitude of pain. The MPQ comprises of 20 categories of adjectives that describe four major subclasses of pain experience (sensory, affective, evaluative, miscellaneous). Each category contains adjectives that are ranked in ascending order according to implied pain intensity (e.g., descriptor one assigned a value of 1). A subclass rating index (SRI) denoted a sum for each subclass and a total pain rating index (PRI) denoted a sum of all subclasses. The MPQ was administered after each fixed effort exercise task where participants were required to select one word from each subcategory if any of the descriptors applied.

6.3.4. ANALYSIS

Power output data was averaged across each minute of the 30-minute fixed perceived effort trials. All other continuous data (e.g., physiological [except blood lactate], cerebral oxygenation markers) and pain intensity ratings were averaged across six, five-minute time zones (e.g., time zone 1 = minute 00:00 – 04:59). Affective valence and blood lactate were analysed according to the minute they were extracted (e.g., minute 0, 5, etc).

All data were exported to Jamovi (JAMOVI: v 2.3, Sydney, Australia) and was assessed for normality and symmetry using a Q-Q plots and a Shapiro-Wilk test before any further analysis. Any data that exceeded 2SD from the group mean was excluded from further analysis although subsequent analysis evidenced that no participants data exceeded 2SD from the group mean. A series of paired samples *t* tests were conducted to assess differences between conditions in resting responses for perceptual markers and blood lactate.

A random-intercepts linear mixed-effects models regression was conducted to assess the condition and/or time effects as well as the condition × time interactions on all dependent variables data. Condition effects observed differences between pain (hypertonic) and control (isotonic) conditions. Time effects observed differences over the course of the 30-minute perceived effort task. Condition × time interactions observed the differences between conditions in changes to a set variable over time. The generalised form for the linear mixed model regression is presented below (a) showing that the grouping/cluster variable was each participant.

(a) (Dependent Variable) = Condition + Time Zone + Condition:Time Zone + (1|Participant)

The variable of *condition* and *time* were set as fixed effects. Models were fitted according to the group intercept. Results from the linear mixed-model regression were reported as *t* values as time was entered as a continuous variable. Another benefit to this method is that reporting of estimated marginal means (β-coefficient) denotes the raw mean differences between the two conditions as an effect size with supplementary 95% confidence intervals (95%*CI*). A normality test was conducted on the residual values and if they violated normality, a Wilcoxon signed ranks test was reported with a rank biserial correlation (*r*) denoting effect size. All data reported for the mixed models regression is according to isotonic – hypertonic comparisons with positive t and β values showing a higher value in the control (isotonic) versus pain (hypertonic) condition.

Data from the McGill pain questionnaire underwent a basic frequency analysis whereby each descriptor was assigned a score (1 – 5) according to its severity. Each of the 20 categories of descriptors were grouped according to their subclass and a total score for each subclass was calculated for each condition and participant. Next all subclass totals were calculated to also create a total pain rating index across each condition and participant. Mean scores across the cohort for each subclass as well as the total pain rating index underwent a series of t tests to assess the differences between conditions. For clarity, only descriptors which were selected by over one third of the cohort are presented in Table 1. A Wilcoxon signed ranks rest was reported if data violated normality and a Cohen's d was reported to denote effect size. The alpha level for all tests was set at $P \leq 0.05$.

6.4. RESULTS

6.4.1. STANDARDISATION

Prior to beginning the experimental fixed perceived effort cycling trials, all participants rated no pain (0) and blood lactate was not significantly different between conditions (hypertonic = 1.53 m.mol^{-1} versus isotonic = 1.45 m.mol^{-1}, $p = .327, d = .18$). In addition, affective valence did not differ between conditions prior to exercise (hypertonic = 2.2 versus isotonic 2.6, $p = .111, d = .21$). Finally, self-efficacy did not differ between conditions prior to exercise (hypertonic = 7.9 versus isotonic = 8.1, $p = .522, d = .14$).

6.4.2. POWER OUTPUT AND PHYSIOLOGICAL MARKERS

Power output was found to be significantly lower in the hypertonic compared to isotonic condition with significant main effects for condition ($t_{107} = 2.08, p = .040, \beta = 4.77\ Watts$ [0.27,9.26]) being observed. Power output also decreased over time in both conditions with main effects for time ($t_{107} = -6.11, p = .001, \beta = -5.80\ Watts$ $[-7.66,3.94]$) being observed (Figure 21). The trajectories of power output changes did not significantly differ between conditions as there was no condition × time interaction ($t_{107} = -1.32, p = .189, \beta = -1.78$ $[-4.41,0.86]$).

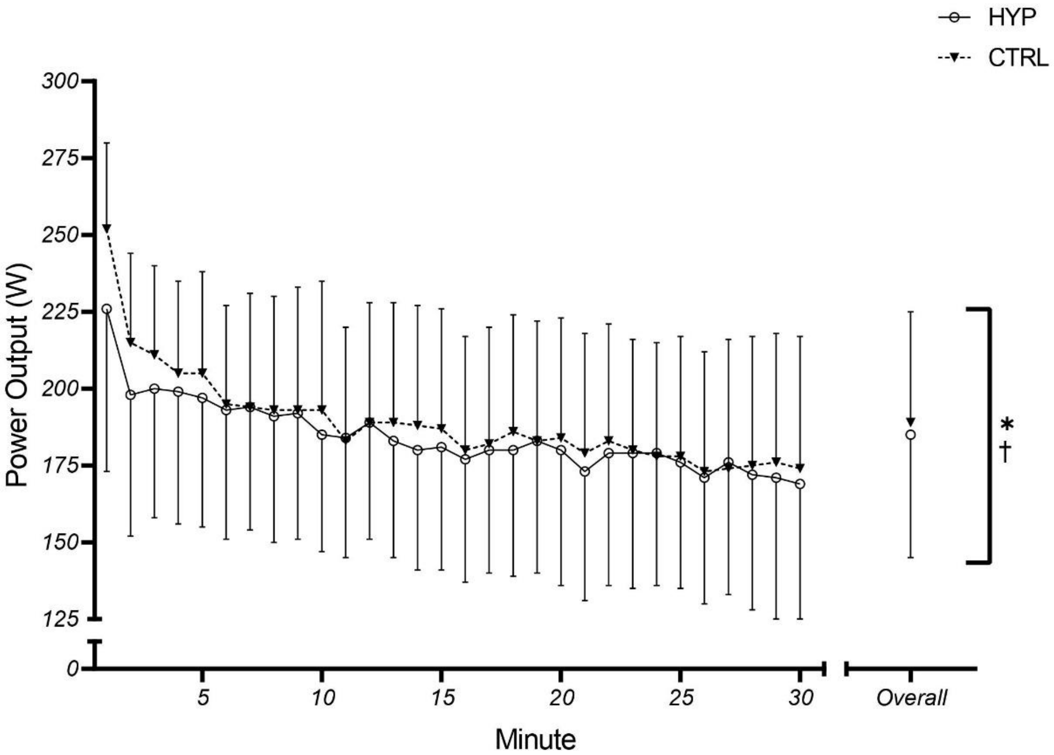

Figure 21. Mean group power output data during fixed perceived effort trials. HYP – hypertonic, CTRL – isotonic condition. Significant condition (∗) and condition × time (†) effects illustrated.

There were no differences in heart rate between conditions ($t_{107} = 1.69, p = .094, \beta = 1.82\ b.min^{-1}$ $[-0.29,3.92]$). However, heart rate did increase across both conditions as a significant main effect for time ($t_{107} = 5.63, p = .001, \beta = 1.77\ b.min^{-1}$ $[1.15,2.39]$) was observed (Figure 22a). Trajectories in heart rate changes did not differ between conditions ($t_{107} = -1.17, p = .246, \beta = -0.73$ $[-1.97,0.50]$).

Similarly, $\dot{V}O_2.kg^{-1}$ ($t_{107} = 1.34, p = .182, \beta = 0.57\ mL.min^{-1}.kg^{-1}$ $[-0.26,1.39]$) and $\dot{V}_E$ $t_{107} = 1.43, p = .157, \beta = 2.12\ L.min^{-1}$ $[-0.79,5.04]$), did not demonstrate a significant condition effect. However, $\dot{V}O_2.kg^{-1}$ ($t_{107} = -5.29, p = .001, \beta = -0.65\ mL.min^{-1}.kg^{-1}$ $[-0.90,-0.41]$) and $\dot{V}_E$ ($t_{107} = -4.31, p = .001, \beta = -1.88\ L.min^{-1}$ $[-2.73,-1.02]$) did demonstrate significant changes in values over time (Figure 22b and c). No significant condition × time interactions were observed for $\dot{V}O_2$.kg^{-1} ($t_{107} = -0.86, p = .394, \beta = -0.21$ [-0.70,0.27]) or $\dot{V}_E$ ($t_{107} = -1.10, p = .273, \beta = -0.96$ [-2.67,0.75]).

Breathing frequency was not significantly different between conditions ($t_{107} = 1.72, p = .088, \beta = 1.00$ [-0.14,2.14]) and did not differ over time ($t_{107} = 1.82, p = .072, \beta = 0.31$ [-0.02,0.64]) (Figure 22d). In addition, breathing frequency did not show a significant condition × time interaction ($t_{107} = -0.32, p = .750, \beta = -0.11$ [-0.77,0.56]). Finally, no significant main effects for condition ($t_{127} = 1.84, p = .068, \beta = 0.45$ [-0.03,0.92]), or time ($t_{127} = -1.29, p = .200, \beta = -0.02$ [-0.04,0.01]), were observed for blood lactate. To add, condition × time interactions for blood lactate ($t_{127} = -0.27, p = .789, \beta = -0.01$ [-0.05,0.04]) were insignificant (Figure 23).

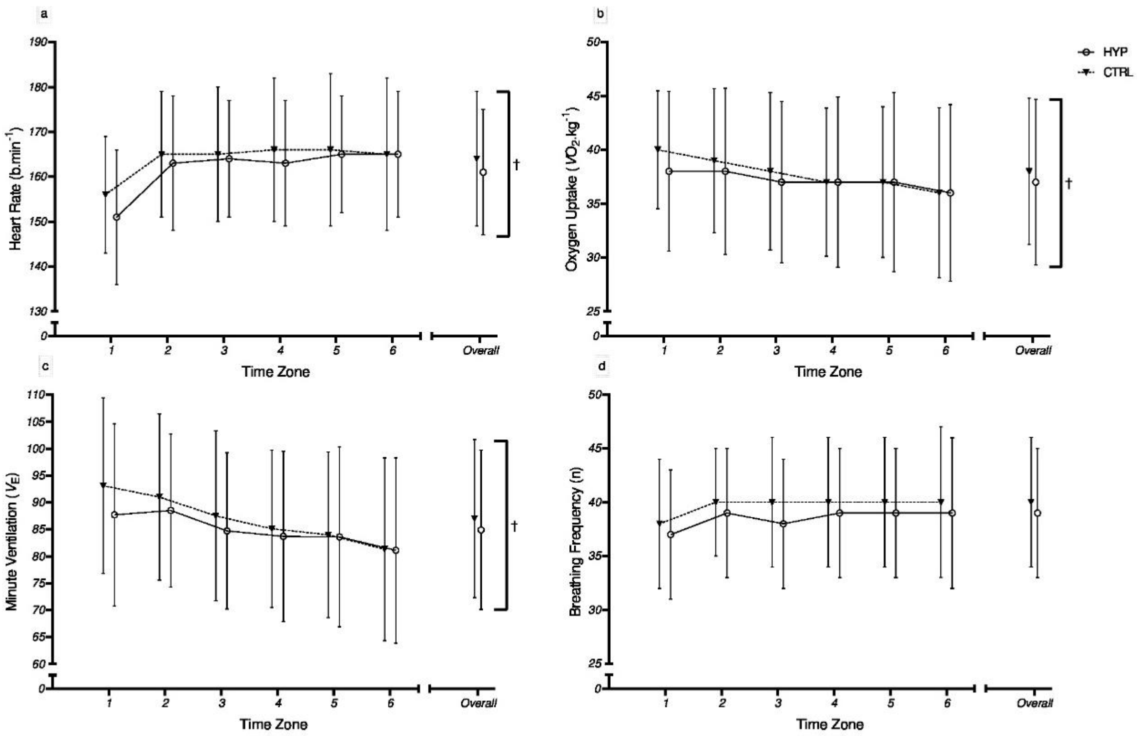

Figure 22. (a) heart rate, (b) relative oxygen uptake ($\dot{V}O_2$.kg^{-1}), (c) minute ventilation ($\dot{V}_E$), (d) breathing frequency cardiorespiratory data during fixed perceived effort trials. Significant condition (✱), time (§), and condition × time (†) effects illustrated.

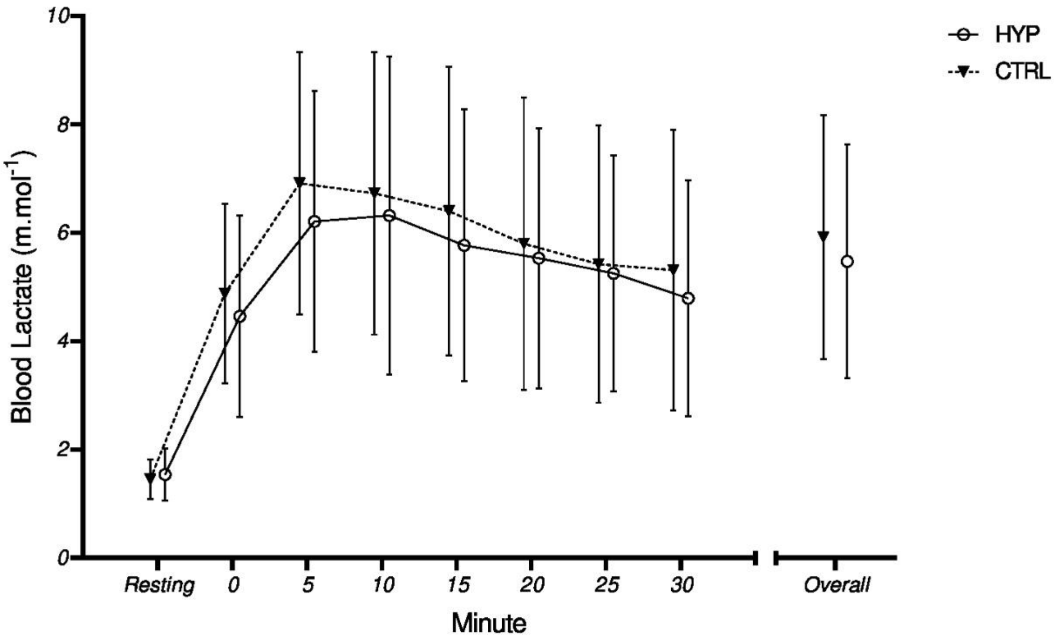

Figure 23. Mean group blood lactate responses during fixed perceived effort exercise. HYP – hypertonic, CTRL – isotonic condition. Significant condition (✱) and condition × time (†) effects illustrated.

6.4.3. CEREBRAL OXYGENATION MARKERS

A condition effect for ΔO_2Hb was not observed ($t_{107} = -1.71, p = .091, \beta = -1.48\ \Delta\mu M\ [-3.17, 0.22]$). However, a significant main effect for time ($t_{107} = 6.81, p = .001, \beta = 1.72\ \Delta\mu M\ [1.22, 2.22]$) was observed for ΔO_2Hb as it increased over the course of the exercise in both conditions (Figure 24a). The linear mixed-model regression showed no condition × time interaction for ΔO_2Hb ($t_{107} = -0.70, p = .486, \beta = -0.35\ [-1.35, 0.64]$).

Alternatively, ΔHHb ($t_{107} = -3.29, p = .001, \beta = -1.50\ \Delta\mu M\ [-2.40, -0.61]$) and ΔtHb ($t_{107} = -4.15, p = .001, \beta = -5.46\ \Delta\mu M\ [-8.04, -2.88]$) were observed to be significantly lower in the isotonic compared to hypertonic condition (Figure 24b and c). Both ΔHHb ($t_{107} = 4.04, p = .001, \beta = 0.54\ \Delta\mu M\ [0.28, 0.80]$) and ΔtHb ($t_{107} = 5.65, p = .001, \beta = 2.18\ \Delta\mu M\ [1.42, 2.94]$) also showed a significant time-based main effect with both increasing over the course of the exercise. However, no significant condition × time interaction was noted for ΔHHb ($t_{107} = -0.44, p = .659, \beta = -0.12\ [-0.64, 0.41]$) or ΔtHb ($t_{107} = -0.83, p = .407, \beta = -0.64\ [-2.15, 0.87]$). Lastly, no significant condition ($t_{107} = 1.94, p = .055, \beta = 0.52\ \%\ [-0.01, 1.04]$) or time ($t_{107} = -0.58, p = .566, \beta =$

$-0.04\ \% \ [-0.20, 0.11]$) main effects were found for ΔTSI (Appendix 7). Also, there was not a significant condition × time interaction for ΔTSI ($t_{107} = 1.91, p = .059, \beta = 0.30\ [-0.01, 0.60]$).

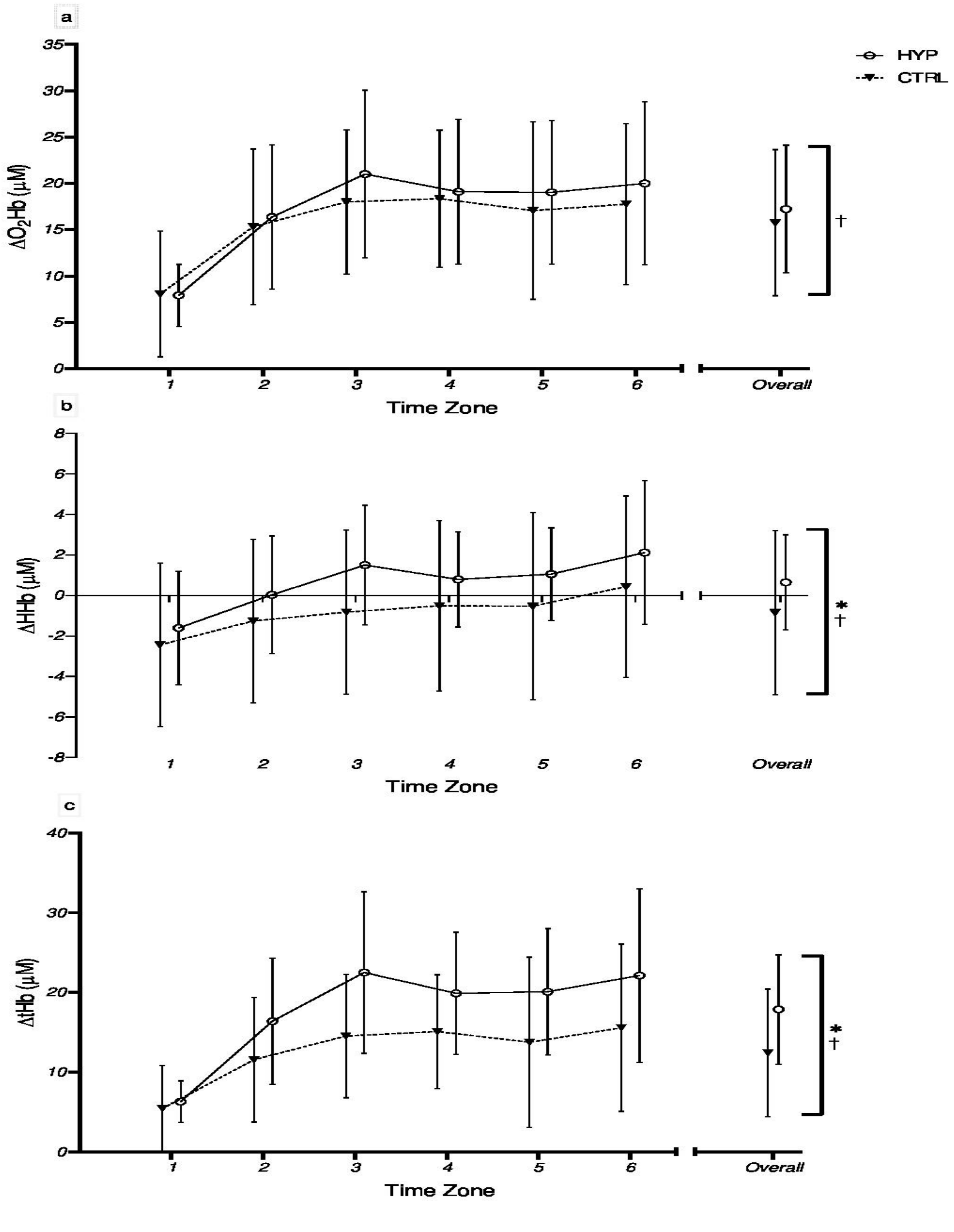

Figure 24. (a) oxyhaemoglobin (ΔO_2Hb), (b) deoxyhaemoglobin (ΔHHb), (c) total haemoglobin (ΔtHb) changes during fixed perceived effort trials. HYP – hypertonic, CTRL – isotonic condition. Significant condition (✱) and condition × time (†) effects illustrated.

6.4.4. PERCEPTUAL MARKERS

Affective valence was found to be significantly lower in the hypertonic compared to isotonic condition with a significant condition main effect ($t_{127} = 6.12, p = .001, \beta = 0.93$ [0.63,1.23]), as well as a significant main effect for time ($t_{127} = -3.96, p = .001, \beta = -0.03$ $[-0.04, -0.02]$). Notably, time-based changes in affective valence differed between condition as a LMM also observed a significant condition × time ($t_{127} = -3.16, p = .002, \beta = -0.05$ $[-0.08, -0.02]$) interaction. Particularly, affective valence responses were more negative in earlier stages of the exercise in the hypertonic compared to isotonic condition (Figure 25a).

A significant time-based effect ($t_{127} = 3.38, p = .001, \beta = 0.03$ [0.01,0.04]) was observed for self-efficacy as both conditions showed gradual increases in self-efficacy responses (see Appendix 8). Yet, no significant condition main effect ($t_{127} = 0.69, p = .491, \beta = 0.10$ [−0.18,0.38]) or condition × time interactions were observed ($t_{127} = -0.17, p = .863, \beta = -0.03$ [−0.03,0.03]).

Last, pain ratings were significantly higher in the hypertonic compared isotonic condition ($t_{127} = -5.90, p = .001, \beta = -9.97$ $[-13{,}28, -6.66]$) (Figure 25b). Trajectories in the changes of pain ratings were significantly different between conditions with an LMM showing a condition × time interaction ($t_{127} = 6.00, p = .001, \beta = 0.95$ [0.61,1.28]). Particularly, pain decreased then plateaued in the hypertonic condition and pain increased then plateaued in the isotonic condition. However, time-based main effects were found not to be significant ($t_{127} = -1.78, p = .077, \beta = -0.15$ [−0.32,0.01]).

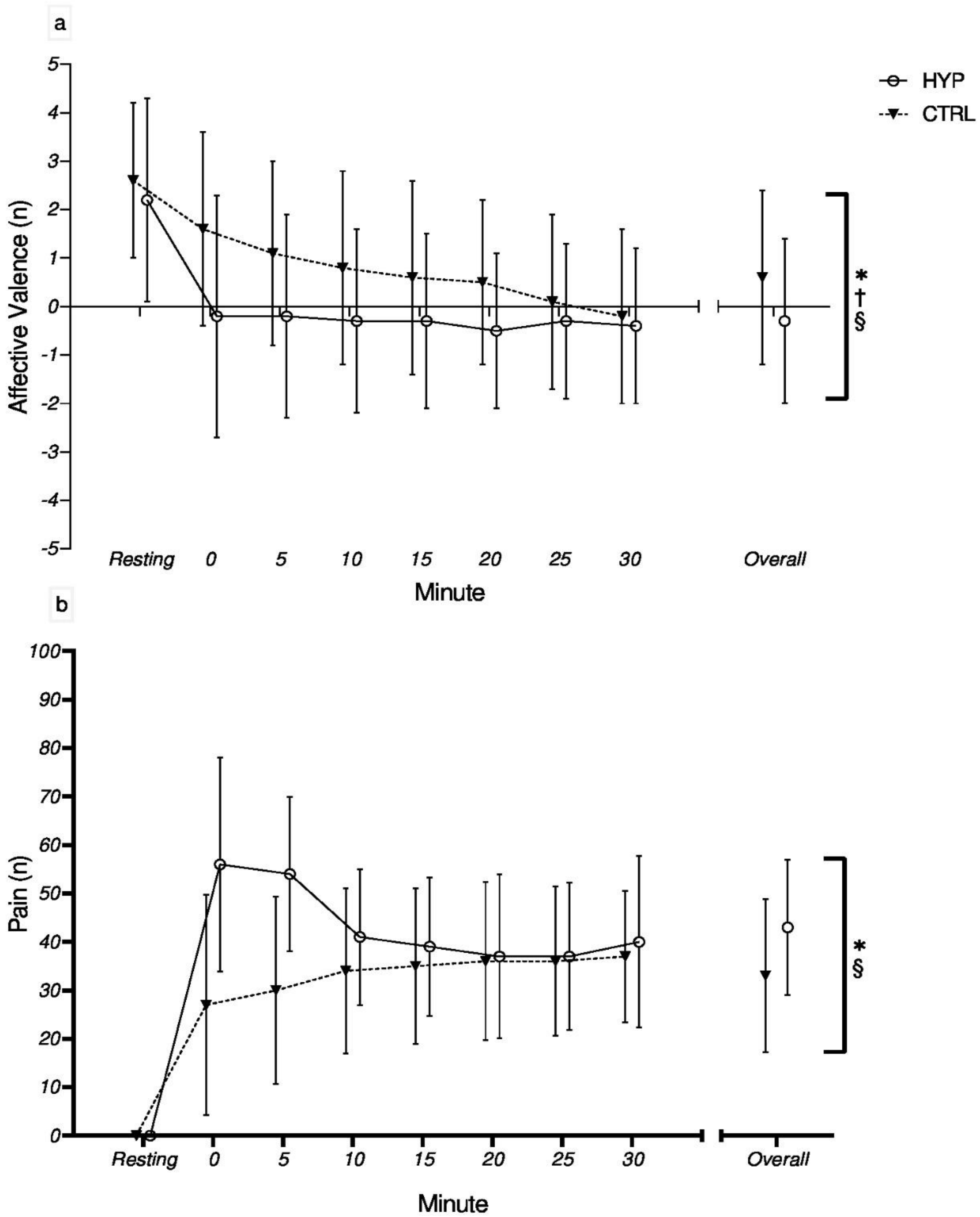

Figure 25. (a) affective valence, (b) pain intensity perceptual responses during fixed perceived effort trials. HYP – hypertonic, CTRL – isotonic condition. Significant condition (✱), time (§), and condition × time (†) effects illustrated.

Table 6 demonstrates the dimensional quality of perceived pain during trials. Total scores for subclasses of sensory and affective domains did not demonstrate significant differences between conditions, however, a moderate effect ($d = .55$) in the sensory and a large effect ($d = .80$) in the affective domain were observed. Total scores for dimensions of evaluative ($Z = 2.392, p = .017, d = .67$), miscellaneous ($t = 3.139, p = .012, d = .50$), and PRI ($Z = 2.075, p = .038, d = 0.84$) did demonstrate significant differences between conditions with moderate and large effect sizes.

Table 6. Frequency of descriptors selected and mean ± SD subclass scores for pain quality.

Subclass		**hypertonic**	**isotonic**	
Sensory		Hot (40%) Sharp (50%) Tender (60%) Burning (40%) Throbbing (50%) Tugging (50%)	Hot (60%) Sharp (50%) Tender (60%) Pricking (40%) Dull (40%) Aching (40%) Pulling (50%) Tingling (50%) Pressing (60%)	
	SRI	17 ± 5	14 ± 6	#
Affective		Gruelling (40%) Tiring (70%) Sickening (40%) Fearful (40%) Wretched (40%)	Gruelling (40%) Tiring (70%)	
	SRI	5 ± 3	3 ± 2	‡
Evaluative		Intense (60%)	Annoying (40%)	
	SRI	3 ± 1	2 ± 2	∗ #
Miscellaneous		Tight (40%) Radiating (40%)	Tight (80%) Spreading (40%) Nagging (50%)	
	SRI	5 ± 2	4 ± 2	∗ #
	PRI	30 ± 8	22 ± 11	∗ ‡

Legend: Subclass Rating Index (SRI); Pain Rating Index Total (PRI) all presented as mean ± SD.
∗ denotes significant difference between conditions, # denotes a moderate effect size, ‡denotes a large effect size.

6.5. DISCUSSION

This study aimed to investigate the impact of elevated muscle pain through a hypertonic saline injection on the power output changes, psychophysiological state, and prefrontal cortex oxygenation variables during a fixed perceived effort exercise task. Knowledge of the changes in the power output, psychophysiological indices and cerebral haemodynamics also contributed to a secondary question which explored the self-regulatory strategies that were used to maintain a fixed perceived effort during conditions of pain (hypertonic) or a control (isotonic).

The main finding of the present study is that the hypertonic condition elicited a significantly lower power output (by an average of 5 Watts) than the isotonic condition. Alongside which, there were no significant condition effects on any physiological variables like heart rate, $\dot{V}O_2.kg^{-1}$, $\dot{V}_E$, breathing frequency, or blood lactate. However, differences in power output between conditions were paired with significant differences in pain intensity and quality responses which were found to be significantly higher in the hypertonic compared to isotonic condition. Likewise, this study demonstrated significantly worse/more negative affective valence responses in the hypertonic compared to isotonic condition. Finally, there was a significantly higher change in deoxyhaemoglobin levels from baseline in the hypertonic versus isotonic condition.

Findings pertaining to power output confirmed our initial hypothesis. Numerous studies have demonstrated a reduced task output (e.g., power output, force, duration on task) during painful compared to non-painful conditions (Aboodarda et al., 2020; Cook et al., 1997; Graven-Nielsen, Svensson, et al., 1997; Mauger, 2013; Norbury et al., 2022a, b; Smith et al., 2020). Notably, muscle pain imposes neurophysiological alterations such as changes in corticomotor conductance of central drive (Chowdhury et al., 2022; Ciubotariu et al., 2004; Sanderson et al., 2021) and muscle fibre recruitment (Farina et al., 2004; Martinez-Valdes et al., 2020) as well as heightened psychophysiological demands such as reduced affect (Rainville, 2002; Venhorst et al., 2018b).

Relatedly, this study observed lower/worse affective valence responses during the hypertonic versus isotonic condition. This infers that individuals may have experienced a less hedonic experience (Rainville, 2002) due to the pain with further implications on their motivation to continue exercising at the same perception of effort (Berridge, 2019), thus resulting in a negatively valenced affective response (Berridge & Kringelbach, 2013). According to Ekkekakis’ (2009a) dual-mode theory, exercise at a higher intensity such as a hard perceived effort is likely to feel averse, unpleasant, and cause a negative affective response. Namely, during higher intensity exercise, an individual is expected to experience salient interoceptive sensory cues signalling chemical, mechanical, and proprioceptive changes across the body (Ekekkakis, 2009a; Ekkekakis et al., 2011; Iannetta et al., 2022). Whilst some individuals may be able to assuage these sensations to continue feeling positive (Ekkekakis, 2009a) it is also suggested that somatic sensations such as pain are inherently negative and that it is increasingly hard to effect control over the quality and implications of the pain experience (Cook et al., 1997; Ekkekakis, 2009a; Mauger, 2013). Thus, nociceptive signals and the subsequent pain experience tends to result in a negative affective response that individuals must cope (O'Connor & Cook, 1999) with and may result in inferior motor performance (Mauger, 2013).

Furthermore, this study measured the neurological changes via fNIRS to probe into the possible differences in activation at the prefrontal cortex which is thought to be associated with regulating aversive sensations and perceptions associated with exercise. Notably, this study observed that relative changes in deoxyhaemoglobin from a resting baseline were significantly higher in the painful, hypertonic versus less painful, isotonic condition. Specifically, deoxyhaemoglobin changes are thought to reflect the utility of oxygen at respiring cells within a specific cerebral region (in this case the prefrontal cortex) and therefore the *activation* of the specific area (Hoshi, 2005). Ekkekakis (2009b) posits that the prefrontal cortex likely functions as a regulation centre for negative affective components that are associated with higher-intensity exercise such as displeasure, tenson, and fatigue. Therefore, the results of this study provide some evidence that individuals during the painful, hypertonic condition engaged in more self-regulatory control to cope with the negative aspects of pain such as displeasure and fatigue (Ekkekakis, 2009a, b; Friedman & Robbins, 2021; Robinson et al., 2021; Santos-Concejero et al., 2015).

Connecting these findings back to changes in power output between conditions, it may be that an enhanced need to regulate cognitive state as well as neurophysiological factors like central drive in the presence of pain compared to the isotonic control continued results in enhanced activity of cortical areas associated with effort processing (Ciu et al., 2011; de Morree et al., 2012; Freidman & Robbins, 2021; Rainville, 2002) as well as a motivationally fatiguing effect (Müller & Apps, 2019). Consequently, exercise in the presence of higher pain is more effortful than exercise without pain (de Morree et al., 2012; Marcora, 2019; Mauger, 2013; McCormick et al., 2019). When the task paradigm is switched to a fixed perceived effort trial, it is expected that the task output such as power output would be lower within conditions of pain versus a control (Aboodarda et al., 2020; Graven-Nielsen, Svensson, et al., 1997; Norbury et al., 2022a, b; Smith et al., 2020).

Yet, some caution is warranted when considering some of the haemodynamic responses as part of this study. First, all participants had the optodes placed on the left side of their head. However, there is a potential risk of left and right asymmetries in prefrontal cortex activation based on participant handedness which was not accounted/measured in this study (Ekkekakis, 2009b). Therefore, if this study did consist of any left-handed participants, they may have indexed lower activation (e.g., changes in deoxyhaemoglobin) than was actually true. Second, this study utilised a system that involved continuous wave measurements whereby differences between conditions and time were assessed according to a relative change from a baseline for oxy-, deoxy-, and total haemoglobin. In doing so, the Beer-Lambert law was not applied and changes in cerebral blood flow that could have varied both within and between participants and the effects this may have on prefrontal cortex activation (Ekkekakis, 2009b; Obrig & Villringer, 2003; Raichle & Mintun, 2006) were not accounted. As a result, whilst it is interesting to consider that changes in regional cerebral oxygenation markers may indicate an increased regulatory control of psychophysiological state, this cannot be firmly surmised, and future studies may wish to build upon this study.

Nevertheless, it was interesting to note that there were no differences in any of the physiological/cardiorespiratory markers despite significant differences in power output, leading the authors to reject some aspects of their secondary hypotheses. Certain models of exercise regulation insist that exercise behaviour is governed by afferent feedback loops that relay information through the central nervous system concerning metabolic and proprioceptive changes (Amann & Secher, 2010). Yet, the results of this study appear in conflict with this suggestion as physical outputs at a constant perceived intensity were not proportional to the subconscious changes in cardiorespiratory and metabolic parameters that were monitored. Alternatively, it may be worthwhile acknowledging other models (e.g., psychobiological model [Marcora, 2019]) which claim that afferent feedback impacts exercise behaviour *via* changes in effort perceptions. Relatedly, a recent study by Mauger et al. (2023) discerned that after trained cyclists were administered tramadol (a very potent painkiller), performance in a subsequent time-trial was significantly faster compared to a placebo-controlled condition. In addition, Mauger and colleagues (2023) required participants to conduct a fixed intensity cycle prior to their time-trial and found that RPE responses were significantly lower after tramadol ingestion versus control. Therefore, some indications could be made to justify the effect afferent feedback like nociception/pain has on the exercise performance due to its combined neurophysiological *and* psychophysiological influences on effort perceptions (Aboodarda et al., 2020).

Consecutively, this study aimed to explore the self-regulatory strategies that operate during fixed perceived effort cycling in the presence of painful (hypertonic) or less/non-painful (isotonic) conditions. Mainly, condition × time interactions can illustrate the differences in the changes for power output (behavioural) or cerebral haemodynamics (cognitive) self-regulation over time. Furthermore, researchers of this study were aware that a hypertonic saline procedure typically peaks at ~3 minutes and dissipates within ~5-6 minutes after administration (Graven-Nielsen, Arendt-Nielsen, 1997; Graven-Nielsen, Svensson, et al., 1997; Norbury et al., 2022a, b; Smith et al., 2020; 2023) yet the fixed perceived effort task lasted 30 minutes. However, this generated another question as to whether a pain experience imposes *residual* effects at later stages of an exercise task as previous studies have shown that even after a pain experience, neurophysiological markers do not immediately return to baseline, perhaps due to a retained motor adaptation (Martinez-Valdes et al., 2020).

Results conflicted our prior hypotheses with no significant condition × time interactions for power output, any markers of physiological strain, or cerebral oxygenation parameters. Figure 21 illustrates that both conditions exhibited an expected decrease in power output (O'Malley et al., 2023) but the rate at which power output decreased was unaffected. Meanwhile, markers of physiological strain (Figure 22) indexed a plateau which would be expected for certain markers like breathing frequency during fixed perceived effort exercise (Nicolò et al., 2016). Similarly, changes in oxy-, deoxy-, and total haemoglobin over the course of the fixed perceived effort bouts were not significantly different between conditions (Figure 24). Instead, the only significant condition × time interactions that were observed related to the pain intensity and affective valence responses (Figure 25). Naturally, differences in pain intensity responses were expected as the hypertonic condition evoked higher perceptions of pain compared to the isotonic at the start of the exercise whereas the progressive engagement in exercise caused naturally occurring muscle pain to reach similar levels in the latter stages of the task (Cook et al., 1997). Second, the affective valence responses exhibited that the painful hypertonic saline conditions caused affect to become more negative/worse much sooner and whereas the isotonic condition caused affect to become negative at a much steadier rate. However, it is interesting that this difference in affective valence did not instigate any differences in self-regulatory behaviour (i.e., changes in power output) as some may expect (Ekkekakis et al., 2011).

Consequently, two main conclusions may be drawn about the self-regulation of perceived effort during conditions of pain versus less/non-painful conditions. First, it appears that pain does prompt a difference in task outputs at a set perception of effort as shown by the condition effects for power output and cerebral oxygenation markers. A second conclusion is that the pain ratings and power output data indicate that pain does affect the perception of effort and associated outputs but only when it is *experienced*. Alternatively, pain does not seem to demonstrate any *residual* effects which impact exercise behaviour at a later stage of a task when elevated muscle pain has dissipated. To illustrate, there were no significant condition × time interactions suggesting that although higher pain ratings at the start of the exercise may be indicative of increased engagement in inhibitory control, this may not be an enduring effect on exercise behaviour as prior resource models of self-regulation would suggest (McCormick et al., 2019).

Yet, it is worth reiterating that some aspects of this study's methodological approach could be adapted in future studies to understand more about the effect of pain on perceived effort and the subsequent self-regulation of exercise behaviour. One note is that this study did not control for the volume of the saline bolus in accordance with muscle mass. Instead, all participants were administered a bolus of 1 mL of saline. As a result, those with lower vastus lateralis mass may have experienced a higher intensity of pain versus those with greater muscle mass. Observations of the pain data (Figure 25b) does show a varied response to the hypertonic saline when it was most potent (minutes 0 and 5). As a result, this may in part, contribute to the slightly larger variances in power output (95%*CI* = 0 – 9 Watts lower in the hypertonic versus isotonic condition over 30 minutes).

Another aspect of the varied power output response may have been due to the duration of the fixed perceived effort task. As noted previously, whilst the 30-minute task duration afforded researchers to observe any potential residual effects of pain on exercise behaviour, the differences in later stages of the task were negligible (2 – 4 Watts). Thus, skewing the observed effects and increasing the likelihood of a type II error. However, the results did show an average difference of 10 - 25 Watts at minutes 0 – 5 whilst the pain intensity was higher due to the hypertonic saline (Figure 21). A result that is both statistically as well as physiologically meaningful. In context, individuals experiencing high levels of pain are likely to conduct a given task at a much slower rate with potentially inferior performance (Graven-Nielsen, Arendt-Nielsen, 1997; Graven-Nielsen, Svensson, et al., 1997; Legrain et al., 2009; Müller & Apps, 2019; Norbury et al., 2022a, b; Smith et al., 2020; 2023). To add, an overall average (i.e., the entire 30-minute group mean) exhibited a ~5 Watts lower power output in the painful versus isotonic condition. Though this result may not be entirely meaningful for everyday situations, it is still statistically significant and could still be considered relevant to elite sporting populations. For instance, RPE responses ~15; “hard” are commonplace at the initial phases of a prolonged time-trial (de Koning et al., 2011). Therefore, if a competitor can gain an initial advantage due to a higher power output at the start of a race-type situation due to being free from any existing pain, this is contextually meaningful (de Koning et al., 2011).

Finally, whilst this study aims to incorporate the best practice for fNIRS measurement (Pinti et al., 2019), some aspects of data collection were not viable. For example, Pinti et al. (2019) suggest that the additional use of short separation channels to obtain fNIRS data may allow a better interpretation of fNIRS neuroimaging data when analysed with linear mixed model regression like those used in this study. To add, short separation channels can detect additional noise from extracerebral signals (e.g., cardiac cycles) which can subsequently factor into the analysis of data to eradicate confounds. However, as this study was concerned with oxy-/deoxy-haemoglobin changes at the prefrontal cortex, long separation, single channels we used due to the need for penetration to deeper tissues (e.g., versus muscle fNIRS). However, filters identical to previous studies in the area were used to eradicate potential noise and confounds (Komiyama et al., 2015; Subudhi et al., 2008; Thomas & Stephane, 2008; Williams et al., 2019). Moreover, this study has also discussed the implications for using a continuous wave fNIRS assessment and the drawbacks of this approach (e.g., unable to account for cerebral blood flow changes). As a result, some caution is warranted in the interpretation of fNIRS data and conclusions that fNIRS changes may reflect increased cognitive self-regulation of affective state though there is considerable evidence to suggest increased cognitive control is expected during conditions of pain versus no pain/control (e.g., Ekkekakis, 2009a).

In accordance with these shortcomings, future research may wish to control for the volume of saline that is applied according to muscle mass. Furthermore, the duration of a task could be curtailed to fit the expected time saline procedures remain effective (~5-6 minutes). Beyond, other suggestions for future research could involve other markers of cognitive effort. Whilst several studies have hinted towards cerebral oxygenation markers as being indicative of cognitive effort (Friedman & Robbins, 2021; Robinson et al., 2021; Santos-Concejero et al., 2015), other methods such as pre-ejection period and eye-tracking (e.g., measurement of pupil diameter and/or variability in fixation locations) are potentially effective at measuring cognitive load/effort through another physiological approach (Richter et al., 2008;

Skaramangas et al., 2023). Characteristically, exercise tasks impose physical and cognitive demands, but little is known about ways in which individuals choose between applying physical or cognitive effort (Chong et al., 2016; 2017). Therefore, future research could explore this area as it could shed light into how psychophysiological constructs like pain and effort are regulated and influence exercise behaviours and performance.

6.6. CONCLUSION

The current study aimed to investigate the impact of elevated pain perceptions through a hypertonic saline injection on power output and psychophysiological state during a fixed perceived effort task. It was observed that the painful hypertonic condition caused a significantly lower power output, a greater increase in deoxyhaemoglobin compared to rest, and a lower/worse affective response compared to a placebo-controlled isotonic condition. However, there were no differences in any markers of physiological strain between conditions. Therefore, it may be that the regulation of exercise behaviour like power output is not directly related to physiological parameters but may operate via the perception of effort.

In addition, the present study also aimed to investigate the changes in power output [behavioural] and cerebral haemodynamics [cognitive] as indicators of the self-regulatory strategies that were used to maintain a fixed perceived effort during conditions of pain (hypertonic) or a control (isotonic). However, no significant condition × time interactions were detected for power output, physiological, or cerebral oxygenation markers. Therefore, it was concluded that pain could impact the self-regulation of fixed perceived effort exercise, as differences in power output mainly occurred when pain ratings were higher after hypertonic versus isotonic saline administration.

An emphasis in our discussion highlights the potential impacts our approach may have for the conclusions on pain’s effect of perceived effort and subsequent exercise behaviour. Furthermore, we pose potential avenues for future research to account for the shortcomings of our approach and other ways that physical and cognitive effort contributions operate during self-regulated exercise tasks.

Chapter 7 – GENERAL DISCUSSION

The present thesis intended to explore the psychophysiological indices associated with fixed perceived effort exercise and how certain perceived effort intensities are self-regulated and the decision-making processes that underpin that regulation. Study 1 aimed to establish whether recreationally trained cyclists conducting fixed perceived effort exercise indexed reliable measures of power output and psychophysiological responses whereby selected RPE values corresponded to known physiological thresholds. In tandem, the initial study also examined whether the power output and underlying psychophysiological indices associated with fixed perceived effort cycling differed based on perceived effort intensities. Subsequently, Study 2 also explored the differences in power output and psychophysiological indices between fixed perceived effort intensities but moreover, investigated differences in the self-regulation of the psychophysiological indices and overall perceived effort during these trials (Part A). Furthermore, potential differences concerning self-regulation of fixed perceived effort cycling between experienced and inexperienced cyclists was also studied (Part B). Finally, Study 3 introduced a specific intervention of hypertonic saline which elicited elevated perceptions of pain to examine how self-regulation of power output and psychophysiological indices at a fixed perceived effort may differ.

7.1. PSYCHOPHYSIOLOGICAL RESPONSES TO FIXED PERCEIVED EFFORT EXERCISE

Central to this thesis is the exploration of the psychophysiological indices associated with perceived effort and the self-regulation of those indices and perceived effort during fixed perceived effort trials. For clarity, this section will aim to tailor its narrative towards the psychophysiological responses observed throughout the studies of this thesis. Subsequently, a discussion will then progress onto the decision-making processes of self-regulation perceived effort and its associated psychophysiological responses. However, as there is a close interrelation between the psychophysiological responses and subsequent self-regulation of behaviour like power output and the associated cardiorespiratory and perceptual markers with the exercise (McCormick et al., 2019), some aspects of self-regulation will feature in this section.

To recap briefly, two main fixed perceived effort intensities lasting 30-minutes were used throughout the current thesis for a cycling exercise: RPE_{GET} – a RPE reference value corresponding to each participant's GET; and $RPE_{+15\%GET}$ – a RPE reference value corresponding to 15% above GET for each participant. The first study in this thesis identified that participants could reliably produce similar outputs (e.g., power output) across several fixed perceived effort bouts. In addition, physiological markers such as heart rate, relative oxygen uptake, breathing frequency demonstrated high to excellent test-retest reliability. Thus, the researchers assumed that any singular fixed perceived effort bout (i.e., like those used in Studies 2 and 3 of the thesis) could be used as an accurate reflection of the psychophysiological and behavioural responses if the task were to be repeated several times over.

One possible explanation for the high reliability within this study was that participants may become habituated to the psychophysiological aspects of a fixed perceived effort bout (Siddle, 1991; Venhorst et al., 2018b). As part of this habituation, several studies/models of exercise regulation indicate that over repeated bouts of an exercise, individuals may become more attuned to specific psychophysiological aspects such as respiratory effort, heart rate, perceptions of pain and fatigue (Elferink-Gemser & Hettinga, 2017; Mauger, 2014; Mauger et al., 2009b; Micklewright et al., 2010; Venhorst et al., 2018a, b) of the exercise task which the exerciser may use as information to judge the effort they are applying towards the task (Boya et al., 2017; Venhorst et al., 2018b). Accordingly, it is worthwhile reviewing the changes in psychophysiological markers that occurred across the studies of this thesis before postulating why participants chose to regulate their behaviour during fixed perceived effort exercise in the way they did.

7.1.1. CARDIORESPIRATORY RESPONSES

Unequivocally, cardiorespiratory responses during exercise are closely associated with the physical output of the activity (Burnley & Jones, 2007). However, it is of paramount importance to reiterate why the phrasing in this discussion identifies the psychophysiological responses that are discussed can *influence* the perception of effort and are therefore *associated* with power output/exercise intensity. Alternatively, some researchers who champion afferent feedback models (e.g., Amann et al., 2015, 2020, 2022) would argue that psychophysiological responses *determine* perceived effort and the subsequent power output/exercise intensity due to previous studies finding strong correlations between cardiorespiratory indices and exercise intensity (e.g., Amann et al., 2006, 2008, 2009, 2010). Yet, it has been reasoned clearly in the introduction (sections 2.1, 3.1, and 3.2.1) why afferent feedback models are not the most viable at explaining the perception of effort and subsequent exercise outputs according to a fixed perception of effort. A further explanation is provided again in section 7.3 for clarity in discussing the cardiorespiratory responses that were observed in the studies of this thesis.

Particular to the cardiorespiratory indices measured across the several studies of the present thesis, some markers showed varying responses during the fixed perceived effort exercises. Due to the varying responses, this discussion will systematically work through a rationale as to why each response may have been produced in relation to previous research findings.

7.1.1.1. STUDY 1 AND 2 RESPONSES

In these studies, a plateau in cardiorespiratory parameters like $\dot{V}O_2.kg^{-1}$, and $\dot{V}_E$ occurred within both fixed perceived effort conditions. Similarly, blood lactate exhibited an initial increase but then plateaued. In contrast, heart rate (Study 1) and breathing frequency (Study 1 only) did not demonstrate a steady response, instead displaying a slight increase throughout the RPE_{GET} and $RPE_{+15\%GET}$ conditions.

Discussing the respiratory indices first, $\dot{V}O_2.kg^{-1}$ responses achieved a plateau across most participants withing the studies of this thesis. Namely, plateaued responses for $\dot{V}O_2.kg^{-1}$ were expected and can be largely attributed to the exercise operating within the moderate intensity domain in which the $\dot{V}O_2$ kinetics response can match the intensity of the task's physical output (Burnley & Jones, 2007, 2018). Therefore, it seems likely that the progressive decrease in power output throughout the exercise intensity allowed the $\dot{V}O_2$ kinetics to continue to match the aerobic demands of the task (Cochrane et al., 2015a).

Next, studies such as Nicolò et al. (2016) have previously demonstrated that RPE and breathing frequency are strongly correlated during time-trial events. Therefore, it is interesting that breathing frequency did not exhibit a steady response in either condition during Study 1 as perceived effort remained constant. Although, it is highly important that $\dot{V}_E$ did achieve somewhat of a plateau (Figure 13c). Marcora (2008) indicates that perceived effort encompasses a combined locomotor and respiratory effort. Central motor commands are projected to the muscles of the periphery as well as the respiratory muscles like the intercostal muscles and diaphragm (Bigliassi, 2015). Furthermore, studies have also evidenced that respiratory-related signals undergo neuronal processing within the same cerebral centres as locomotor effort such as the anterior cingulate cortex (Gigliotti, 2010). Therefore, as respiratory effort involves the perceived difficulty to breathe (Kearon et al., 1991), it is well recognised that respiratory components factor heavily into the overall perception of effort (Bigliassi, 2015; Gigliotti, 2010; Marcora, 2008, 2009; Nicolò et al., 2016).

Subsequently, it is important to acknowledge breathing frequency and $\dot{V}_E$ responses within the wider context of perceived respiratory effort. Drivers behind the frequency and depth of breath revolve around the partial pressures of the oxygen and carbon dioxide which are detected by chemoreceptors at respiring sites like the working muscles (Dempsey, 2012; Dempsey et al., 2008; Taylor et al., 2016). Therefore, afferent feedback from the periphery is highly relevant to the regulation of respiratory effort, but in a lateral manner (Nicolò et al., 2016; O'Donnell et al., 2009). Precisely, chemoreceptive detection of changes in oxygen and carbon dioxide partial pressures stimulate an increased need to provide more oxygen as part of the electron transport chain in tandem with increased demand to expel carbon dioxide (Dempsey et al., 2008). Increasing the frequency or depth of breath to effect these changes necessitates a greater central motor command towards respiratory muscles which causes more corollary discharge production for neuronal processing (Nicolò et al., 2016) and result in an increased perception of effort (Marcora, 2008, 2009).

Moreover, respiratory effort forms a major constituent of the sensation of dyspnea (O'Donnell et al., 2009). Some aspects of the dyspnea sensation may also shed some light on the unexpected breathing frequency responses observed in Study 1. Identified as a higher-order sensation, dyspnea involves the subjective experience of breathing discomfort that consists of several qualitatively distinct sensations that vary in intensity (O'Donnell et al., 2020). Dyspnea includes physical components such as chest tightness and affective components like unsatisfied inspiration and subsequent air hunger (O'Donnell et al., 2009). In addition, a significant inputting sensation/perception is the inspiratory/respiratory effort which as discussed is the perceived difficulty to breathe due to the motor commands relayed to the respiratory muscles

(Gigliotti, 2010; Kearon et al., 1991; Marcora, 2009). In review, it may be that although breathing frequency indexed increases across both conditions in Study 1, the overall amount of air inhaled ($\dot{V}_E$) remained relatively constant. Therefore, it appears that the frequency of breath as opposed to the depth of breath was increased. Indeed, Appendix 2 shows that the $\dot{V}_T$ actually showed a proportional decrease as breathing frequency increased. Consequently, the affective components of dyspnea (i.e., feeling an appropriate intake of air) and respiratory effort may not have increased as $\dot{V}_E$ remained constant throughout both conditions.

To then address heart rate and blood lactate results, autonomic cardiovascular responses are put into effect in aim of providing the respiring site (i.e., the muscle) with an ample supply of blood flow containing oxygen for the metabolic needs of the exercise (Amann, 2011; Williamson, 2010). During Study 1 and 2 of this thesis, it is anticipated that the progressive onset of fatigue caused participants to reduce the power output in aim of not experiencing a compensatory increase in central motor command and thus perceived effort (de Morree et al., 2012; Pageaux, 2014). Despite power output declines, heart rate showed increases in both RPE_{GET} and $RPE_{+15\%GET}$ conditions across Study 1 and 2. In contrast to perceived effort, cardiovascular responses are *directly* governed by peripheral stimulants like afferent feedback and their interaction with arterial baroreflexes (Amann et al., 2006; Gandevia, 1996) as these operate on a subconscious level (Amann, 2011). Heart rate increases are initiated when afferents detect an insufficient supply of resources and/or removal of noxious metabolites from the muscle (Anrep & Segall, 1926). Thus, increases in heart rate that were observed in these studies indicate continual negative feedback from afferents which signalled that metabolic costs of the exercise were not being met by the current cardiovascular supply (Coyle & González-Alonso, 2001). This indicates that the recreational cyclists that were recruited as part of these studies experienced a cardiovascular drift which may be due to an increased cutaneous blow flow (Rowell, 1986) or decreased stroke volume (Fritzsche et al., 2001) when exercising at a fixed perceived effort. Yet, as neither of these measures were taken during any of the studies it is hard to surmise the exact reason why heart rate increased. Furthermore, a quick review of the blood lactate data suggests that a steady state in metabolite production/clearance occurred as blood lactate responses plateaued across both conditions, in both studies. Furthermore, there was even a slight decline towards the last five - ten minutes of each fixed perceived effort task suggesting a greater removal versus production of metabolic by-products.

Consequently, rationalising that the increase in heart rate in the face of power output declines is difficult. Most prior studies have used fixed power output tasks which find that a steady state in heart rate is expected in moderate intensity (RPE_{GET}) as well as heavy intensity ($RPE_{+15\%GET}$) whole-body exercise (Burnley & Jones, 2007, 2018; Iannetta et al., 2020, 2022; Jones et al., 2009). However, unlike fixed power output exercise, fixed perceived effort cycling involves a change in the resource demands associated with the task. Thus, power output changes are likely to occur as the ultimate purpose of the task is not to maintain a given physical output but instead to maintain a perceived effort corresponding to the RPE value that has been predetermined (Eston & Williams, 1988; O'Malley et al., 2023). As a result, *steady states* which are expected within set intensity domains (Burnley & Jones, 2007) during fixed workloads (i.e., no change in resource demand) may not occur due to the changing of power when resource demand does change during fixed perceived effort work. Therefore, it can become more nuanced to equate findings from prior studies that have discussed exercise domains and the associated physiological responses as these studies have used an altogether different nature of task demands.

Proponents of more afferent feedback centred models assume a more direct relation between cardiovascular responses and exercise intensity/performance as afferent feedback and baroreflexes also impact the central motor command responses towards an exercise (Amann et al., 2006; Gandevia et al., 1993). However, the behavioural responses (i.e., power output) as part of Study 1 and 2 of this thesis appear distinguishable from the heart rate responses. Namely, as power output decreased, heart rate continued to increase instead of both tracking in a similar direction. Alternatively, the behavioural, power output response appears to be related to the conscious self-regulation of perceived effort required as part of the task (via central motor commands), meanwhile, cardiorespiratory responses are a product of a separate process involving subconscious, reflexive afferent signalling (Marcora, 2019; Pageaux, 2016). Therefore, it seems that the cardiorespiratory responses measured as part of these studies are best described as an *associated* variable with the power output during fixed perceived effort exercise but are not the *cause* of the power output changes observed. Instead, the close association between physiological indices of exercise and behavioural responses at set perceptions of effort may only be due to the concomitant effect afferent signalling can have on the central motor command projections (Amann, 2011; Gandevia, 1996) which likely underpin the perception of effort (de Morree et al., 2012; Marcora, 2019; Pageaux, 2016).

Leading on from this ambiguity, an interesting area for future research would involve a further exploration of the central motor command effects on the cardiorespiratory responses during fixed perceived effort exercise. Literature is saturated with studies which have used time-trial or time-to-exhaustion tasks to assess the relative effects of afferent signals on central command and the associated physiological responses and *vice versa* (e.g., Amann & Dempsey, 2006; Amann et al., 2009, 2010, 2011, 2015; Marcora et al., 2008). However, no study has yet to explore this relationship and the potential mechanisms during a fixed perceived effort tasks like that used in the present thesis. As such, future studies could opt for added measures during fixed perceived effort cycling such as electromyographic traces or other forms of measuring the central command projections during exercise. In addition, studies could implement afferent nerve blockades to take effect throughout a fixed perceived effort cycle like those employed by Amann et al. (2009, 2010, 2011). Beyond these suggestions, studies could also incorporate matched intensity conditions which involve electrically evoked (e.g., Laginestra, Cavicchia, et al., 2022) or imagined (Jacquet et al., 2021) muscular actions as this would mean that central motor command projections are not made directly from the motor areas of the brain like normal voluntary exercise, but some form of perceived effort is present. Taken together, these propositions for future research could shed more light onto the mechanisms of how cardiorespiratory responses are *associated* with submaximal, self-regulated exercise at set perceptions of effort as well as the relative impacts of afferent feedback on central motor command projections.

7.1.1.2. STUDY 3 RESPONSES

Reviewing the cardiorespiratory responses during Study 3 there are some slight differences compared to those identified within Studies 1 and 2. Before a wider discussion, it is worth reiterating that Study 3 only involved exercise at the $RPE_{+15\%GET}$ condition, therefore comparisons are limited to this fixed perceived effort intensity. Furthermore, Study 3 occurred in the presence of either a hypertonic or placebo-controlled isotonic saline injection. Whilst an isotonic saline acted as a placebo-control is not expected to exacerbate perceptions of exercise-induced pain or elicit changes in the intramuscular environment (Graven-Nielsen, 2006), some slight increases in perceived pain from the needle-stick or placebo conditions as well as changes in cardiorespiratory responses may manifest (Smith et al., 2023b). For instance, the injection protocol has been found to initiate increases in heart rate and ventilatory responses before the injection has been administered (Smith et al., 2023b). In addition, those elevated responses may remain in the intermediate period between the injection being administered and the ensuing exercise protocol/task commencing. Therefore, some elevated responses from the injection procedure may persist at the onset of the exercise task (Mense, 2003). Briefly, these elevated cardiovascular and ventilatory responses are likely accountable to the threat of a needle being inserted into the skin which elicits natural autonomic responses to increase heart rate, blood pressure and vascular resistance (Cechetto, 2013). Ventilatory responses like $\dot{V}O_2.kg^{-1}$ and $\dot{V}_E$ within Study 3 demonstrated gradual decreases over time, whilst breathing frequency plateaued after the initial five minutes of the exercise. Cardiovascular responses like heart rate also plateaued after approximately five minutes. Finally, blood lactate showed a marked increase at the start of the exercise but quickly plateaued and then gradually decreased in the closing minutes.

Similar to what was mentioned in section 7.1.1.1, declines in $\dot{V}O_2.kg^{-1}$ and $\dot{V}_E$ are self-explanatory as they are thought to be the product of the exercise intensity that is being exerted. As power output was declining, these indices are also expected to decrease. It is likely that these indices did decline in Study 3 due to the slightly greater rate of power output decline, particularly in the earlier phases of the exercise (Figure 21). According to prior research (Nicolò et al., 2016), a plateau in breathing frequency during fixed perceived effort exercise would be expected. Specifically, breathing frequency is directly related to the respiratory effort (Bigliassi, 2015). Respiratory effort in turn is a component the overall perception of effort which remained constant throughout this study (Gigliotti, 2010). Therefore, the results of this study agree with this notion as breathing frequency remained constant for a majority of the trial (Nicolò et al., 2016).

Finally, the plateaus in heart rate and blood lactate indicate that the declines in exercise intensity meant that participants were not physiologically strained to maintain blood flow and oxygen supply to the working muscles. In fact, the blood lactate response showed declines after an initial plateau which suggests that physiological strain of the exercise was not high as the clearance of noxious metabolites exceeded production for a prolonged period at the end of the trials (~10-15 minutes). A final remark concerning the heart rate response is that whilst earlier studies in the present thesis demonstrated a cardiovascular drift-like response with gradual increases in heart rate throughout trials, this study did not. A potential explanation is that Study 3 exclusively recruited participants considered trained and experienced (Level P3 de Pauw et al. (2013)), whereas Study 1 and 2 involved a mixed cohort of recreationally trained cyclists of varying experience levels. As noted by Coyle and González-Alonso (2001), the cardiovascular drift response is more likely to occur within inexperienced individuals. Though stroke volume measures were not taken and a conclusive argument cannot be made, it is possible that in Study 1 and 2, the participants experienced an increase in heart rate due to a stabilisation/slight decrease in stroke volume during the exercise whereas the cohort involved within Study 3 were trained and would be expected to maintain/increase their stroke volume in the face of the exercise and thus, not require an increase in heart rate to maintain cardiac output (Coyle & González-Alonso, 2001).

7.1.2. PERCEPTUAL RESPONSES

In equal parts, perceived effort has associated physiological and psychological responses (Halperin & Emanuel, 2020; Marcora, 2019). Therefore, it is advisable to acknowledge the psychological as well as the physiological indices that exist during fixed perceived effort exercise (Andreassi, 2013; Caccioppo et al., 2012; Rejeski, 1985). Mainly, because psychological state disturbance can also factor into perceived effort changes which must then be subsequently self-regulated (Brick et al., 2014; McCormick et al., 2019). Evidently, (neuro)physiological changes involving afferent signalling are a factor that can influence perceived effort (Pageaux, 2016) and therefore, affect self-regulatory strategies used to maintain a fixed perceived effort (Elferink-Gemser & Hettinga, 2017; McCormick et al., 2019; Renfree et al., 2014; Venhorst et al., 2018b). Though, psychological factors are also impactful components that can also impact the perception of effort and self-regulatory strategies to maintain a fixed perceived effort (Lind et al., 2009; Marcora & Staiano, 2010; McCormick et al., 2015, 2018, 2019).

A major psychological variable that was monitored throughout the present thesis was affective valence. As noted earlier, affective valence was initially conceived as an antecedent of perceived exertion (Borg, 1962). However, whilst regions of the brain such as the anterior and middle cingulate cortices may demonstrate similar activities when examining perceived effort and affective valence, there is a distinctive neuronal process involved with each phenomenon (Berridge & Kringelbach, 2013). Hence, it is likely that they act in parallel wherein the individual must account for their affective valence that is associated with the perception of effort during a task like exercise (Hardy & Rejeski, 1989).

During this thesis it was consistently found that affective valence became less positive/more negative as time elapsed during the fixed perceived effort exercise (Figures 15, 19, 25). However, it is worth acknowledging that some participants did provide positive affective valence responses throughout some RPE_{GET} cycling bouts. Nevertheless, the affective valence responses regularly exhibited a sharper decline (i.e., became negative sooner) during $RPE_{+15\%GET}$ exercise than the RPE_{GET} condition. It is particularly interesting to note that during some parts of the fixed perceived effort cycling throughout the studies in this thesis, physical output (e.g., power output) may have been similar but the affective valence responses were markedly different. For example, during Study 3, although there was a condition effect for power output between hypertonic and isotonic conditions, the actual mean power output difference in the latter stages of the fixed perceived effort cycle (e.g., minutes 20 – 30) were approximately three - five Watts. However, the difference in affective valence responses was much more disparate with a *0 – neutral* rating in the isotonic versus a *-1 – fairly bad* or *-2 – between fairly bad and bad* response in the hypertonic condition. Thus, indicating that affective valence and perceived effort are dissociable but also that affective valence may not be entirely contingent on task intensity as previously suggested (Ekkekakis, 2003; 2009a).

To recap, affective valence involves hedonistic as well as motivational aspects (Berridge, 2019). Hedonistic components of affective valence are tied closely with the emotional and mood states of the individual and can be split into positive (pleasure) and negative (displeasure) dimensions (Cabanac, 1979, 1992, 2002; Ekkekakis, 2003). Meanwhile, motivational components are associated with the active pursuit or passive avoidance of goals (Berridge, 2019; Richter, 2013). Combined, the hedonistic and motivational aspects constitute a valenced affective state which has a positive or negative direction simply captured on the feeling scale (Hardy & Rejeski, 1989).

Ekkekakis and colleagues have conducted extensive work on the intensity-affect dynamic. Initially, it was viewed that higher intensity exercise tends to elicit greater feelings of displeasure and therefore predisposes individuals towards a more negative affective response (Brand & Ekkekakis, 2021; Ekkekakis, 2003, 2009a, c; 2011; Ekkekakis et al., 2011; Lind et al., 2009). Therefore, it is understandable that responses in this study demonstrated a shift towards more negative affect during exercise than at rest, particularly when exercising at a higher perceived effort (Ekkekakis et al., 2011; Lind et al., 2009). Naturally, exercise at higher intensity exercise usually involves greater perturbations from a resting homeostatic state (St Clair Gibson et al., 2018). Applied to this thesis, exercising at a higher perceived effort requires individuals to apply more physical and cognitive resources (Steele, 2019), often resulting in a greater accumulation of metabolites (Amann, 2011). These metabolites include noxious, hydrogen or potassium ions which are relayed via negative feedback loops and processed through the central nervous system via afferent fibres (Taylor et al., 2016). Signals are also integrated at supraspinal sites to develop a conscious awareness of the sensations within the body (Siddle, 1991). Typically, these sensations (e.g., pain, fatigue, dyspnea) are warning signals to inform the individual that unsustainable changes have arisen across the exercising body from its initial resting homeostatic state (Behrens et al., 2023; O'Donnell et al., 2009; St Clair Gibson et al., 2018; Vadivelu et al., 2009). As a result, exercise at higher perceived effort is likely to cause greater decreases in affective valence because of the greater salience and intensity of interoceptive cues that are triggered by more metabolites through afferent feedback systems (Amann et al., 2009; Ekkekakis, 2003; Ekkekakis et al., 2011). Indeed, Study 2, Part A did find that a greater associative focus to internal states did occur which is likely due to increased intensity and salience of internal sensory signals at higher physical intensities (Ekkekakis, 2003, 2009a; Ekkekakis et al., 2011).

Furthermore, there is a time-based effect that may impact the affective valence response. Engagement in prolonged exercise depletes resources such as glycogen which in turn, triggers greater reliance on fat oxidation for energy production (Achten et al., 2002). Fat oxidation requires greater oxygen supply therefore increased cardiorespiratory demand to supply oxygen to the respiring sites (Burke & Hawley, 2002). Regularly this increased demand cannot be fully met by the aerobic system causing some form of anaerobic metabolic contributions to the exercise (Gastin 2001). As a result, prolonged exercise involves a natural inclination towards negative affective valence as negative emotions and underpinning physiological states promote feelings of displeasure (Lind et al., 2009; Ekkekakis et al., 2011).

However, it was briefly alluded to that some participants provided positive affective responses throughout the entire fixed perceived effort exercise during the RPE_{GET} condition. As noted previously, RPE_{GET} exercise is expected to operate exclusively within the moderate intensity domain (Cochrane et al., 2015a, b; Cochrane-Snyman et al., 2016). Notedly, Ekekkakis et al. (2011) identified that exercise conducted within the moderate and low intensity domains (i.e., exercise intensities below the GET) can elicit positive affective responses. To add, Ekkekakis and Brand (2019) also proposed that pleasant/unpleasant experiences of exercise based on its intensity is highly individualised. A potential reason for this is due to the motivational and sensory reward aspects of the exercise. Berridge and Kringelbach (2013) recently summarised that affect is the hedonic quality of pleasure or displeasure in which affective pleasure is highly related to the sensory reward one feels. Therefore, the presence of tolerable negative sensations during prolonged exercise can involve a sense of achievement (Zenko et al., 2016) causing feelings of positive affective valence when exercising at lower intensities (Ekkekakis & Brand, 2019). Furthermore, some participants may have garnered an intrinsic reward from the exercise for completing a prolonged bout of effortful work, particularly when the saliency of negative sensations was lower (Lind et al., 2009). Thus, it is important to consider the motivational aspects of affective valence in tandem with the hedonic qualities of the exercise (Berridge, 2019).

Meanwhile, salient negative sensations during prolonged engagement in exercise at higher intensities inherently involves less sensory reward (Ekkekakis, 2003). Hence, the natural tendency for *most* participants throughout these studies responding with more negative affective ratings as the salience of the negative sensations outweighed the perceived sensory reward of the task (Ekkekakis et al., 2011). Again, another rationale behind negative affective responses may relate to the motivational aspects of affective valence (Berridge, 2019). Higher actual workloads inherently involve more averse sensations via inhibitory afferent feedback (e.g., during $RPE_{+15\%GET}$ conditions) or conditions which directly involve elevated nociception and more intense negative sensory experiences like pain (e.g., cycling after a hypertonic saline injection) may have caused an individual to feel that their pursuit of finishing the task was being hindered and further perpetuated negative perceptions and emotions (e.g., frustration, lower hedonism). Thereby causing a potential dissonance between the expectations they had about completing the task and the experience they actually had when exercising (Carver & Scheier, 1988; Parfitt, Alruhm, et al. 2012; Parfitt, Evans, et al., 2012). Furthermore, several studies and theories (e.g., self-efficacy theory, appraisal theory) indicate that when an individual feels incapable of exercising control over factors that can impact/impede goal attainment (i.e., continuing exercise at a fixed perceived effort), such as unexpected pain or fatigue, this can foster a negative affect (Bandura, 1997; Deci & Ryan, 2000; Ekkekakis, 2009a; Jones et al., 2009). Meanwhile, at lower intensities associated with a lower perception of effort, certain studies have found that individuals find this pleasant and results in a positive affective response which authors implicated may be due to a continued sense of achievement and control over goal pursuit (Parfitt, Evans, et al., 2012).

This generates another interesting discussion concerning the relative contributions hedonic and motivational components have on the overall affective response. Granted, the perceived positive/negative ratings of affective valence are largely influenced by the pleasure/displeasure experienced as part of the exercise (Ekkekakis, 2003; Ekkekakis et al., 2011; Lind et al., 2009). However, the motivational impacts of the sensory state of the individual could theoretically offset the perceived pleasure/displeasure of the exercise (Richter, 2013). Indeed, sensory reward involves multiple neuropsychological components such as hedonism, motivation, and reward-related learning from previous experience (Bandura, 1997; Berridge & Kringelbach, 2013; Manohar et al., 2015). To illustrate, though an exercise may elicit a build-up of metabolites at the muscle which stimulates negative emotions, the individual could also perceive that the presence of metabolites is indicative of working towards goal achievement (Berridge, 2019; Lind et al., 2009). On the flipside, if an individual deems that the presence of metabolites is incongruent with a previous experience where they attained their goal/reward, this could diminish affective valence (Venhorst et al., 2018b). As a result, it is difficult for researchers to determine when the motivational or hedonic aspects "*take precedence*" in the overall affective valence response during an exercise task. Related to the present thesis, as the participants were subject to completing the fixed perceived effort exercise, individuals were conscious that there was no option to reduce the effort and its associated vicissitudes towards the task and make it "*feel better*" until it was completed. As a result, participants may have acknowledged that there was no escaping the negative sensations associated with the exercise and therefore participants would have to cope with the negative affect and/or try to enhance motivation to keep going.

The other psychological measure that was measured throughout the present body of work was perceived self-efficacy. Briefly, self-efficacy reflects the belief in one's capabilities to mobilise resources and courses of action needed to meet the given situational demands (Wood & Bandura, 1989). Centrally, self-efficacy can influence the amount of effort an individual is willing to expend (Bandura, 1997). The current thesis mainly probed the individuals perceived ability to tolerate the perceived effort of the cycling tasks. Thus, a single-item measure of coping self-efficacy aimed to simply capture participant's current beliefs as to how effectively they could mobilise their resources (i.e., effort) towards the cycling task in accord with the set perceived effort intensity (Chesney et al., 2006; McCormick et al., 2019).

In contrast to affective valence, self-efficacy responses were found to be stable for most of the 30-minute fixed perceived effort cycle until an uptick in self-efficacy responses as the exercise endpoint drew near (e.g., last five - ten minutes) across both conditions in all studies. Additionally, a markedly higher self-efficacy rating was provided throughout the RPE_{GET}

versus $RPE_{+15\%GET}$ condition. Whilst exercise time elapsed/remaining along with all other task-related data were blinded from participants throughout all studies and conditions, participants appeared to infer when exercise endpoint drew near (Siddle, 1991), leading to a higher self-efficacy response (Crivio do Carmo et al., 2022). A central assumption of self-efficacy theory is that self-efficacy concerns the perceived capabilities of the individual, *not* their veridical ability and skill for the specific task (Bandura, 1997). Mindful of this key tenet, it validates why the observed responses across all studies and conditions were as they were.

All participants of these studies were recreationally active cyclists. As such, they would be expected to exhibit high self-efficacy beliefs for the fixed perceived effort task. Foremostly, the exercise was at a fixed perceived effort that was submaximal (e.g., *13 – somewhat hard* or *15 – hard* in most instances) and that participants knew that their only requirement was to maintain this fixed perceived effort which could involve self-regulation of output or internal state. Consequently, participants knew that they would not need to apply their maximal capacity to execute or complete the task. Furthermore, as each study recruited currently active recreational cyclists, it is highly likely that participants had conducted similar types of cycling activity, adding to their perceived capabilities to conduct the task (Anstiss et al., 2020; McCormick et al., 2015, 2019).

Despite these positives, most participants did not rate their self-efficacy as maximal throughout the fixed perceived effort exercises, indicating some sources of ambiguity for the participants to question their capabilities. For instance, affective valence responses imply that aversive sensations/perceptions were present that reduced the pleasantness of the exercise (Berridge, 2019; Ekkekakis, 2003). Physiological responses (e.g., increases in heart rate) consolidate this view. To add, though participants appear to have been able to predict the forthcoming endpoint of the exercise in the latter stages of the cycling bouts, Study 2 demonstrated that participants were unable to accurately predict the remaining time on task in earlier stages of the exercise (Table 4). As a result, factors which created ambiguity of perceived demands and capabilities may have acted to reduce self-efficacy beliefs and cause lower ratings (Anstiss et al., 2020; Bandura, 1997; McCormick et al., 2019). Moreover, as aversive responses were greater in the $RPE_{+15\%GET}$ versus RPE_{GET} condition, this further validates that aversive sensations arising from psychophysiological strain were influential in inflating the demands of the exercise and/or reducing the perceived capability to tolerate the perceived effort of the task (McCormick et al., 2019). However, results also indicate that in the face of feeling worse (affective valence) about the exercise does not always implicate a reduced perceive ability to complete the task (self-efficacy). Namely, affective valence responses reduced over the course of each study, but self-efficacy remained constant until an uptick towards task end-point. Finally, as self-efficacy influences the amount of effort one is willing to expend in the face of task difficulties (Bandura, 1997), it features heavily in the activation of strategies to deal with the demands of the task (McCormick et al., 2019). As such, it provides an appropriate segue into second aim of the current thesis which was to investigate the decision-making processes that guide how the perception of effort is self-regulated.

7.2. SELF-REGULATION OF PERCEIVED EFFORT

As indicated throughout this thesis, the perception of effort is believed to be central to task performance (Marcora, 2010a, 2019) as it is a perceptual awareness of the resources being applied towards a task (effort) for the achievement of a preconceived goal (Preston & Wegner, 2009; Steele, 2019). This is applicable to motor tasks, cognitive tasks, or other tasks that combine physical and cognitive components (Preston & Wegner, 2009; Steele, 2019). However, upon engagement in tasks, there are a range of additional factors which enforce changes on the required resources needed to continue the task or to maintain a set performance level (e.g., exercise intensity). Therefore, varying amounts of effort need to be invested to continue (Chong et al., 2017) with subsequent changes on perceived effort regularly observed (Borg, 1982; Tucker, 2009). In response, engagement in any form of prolonged motor tasks necessitates the individual to regulate their behaviour and inner states in accord with task and environmental demands for successful attainment of goals (Englert et al., 2021; McCormick et al., 2019).

However, in the present thesis, researchers flipped the task paradigm and instead of using a task where resource demand would change (e.g., time-trial), instead they implemented a unique fixed perceived effort cycling task lasting 30 minutes. In which, *perceived* resource demand is expected to remain constant and concomitantly, perceived effort should also remain constant (O'Malley et al., 2023). Using this approach, any changes in behaviour like power output, or activation of cognitive strategies like reappraisal or self-talk would represent a self-regulation of the individual to maintain the required perceived effort.

Successively, this thesis found that to maintain a constant perception of effort during 30-minutes of cycling, individuals would alter their power output (usually reductions) and activate cognitive strategies like self-talk. Specifically, a higher intensity of fixed perceived effort (e.g., *15 – hard*) often initiated steeper and greater decreases in power output over time than lower intensity fixed perceived effort exercise (e.g., *13 – somewhat hard*). Furthermore, the changes in behaviour indexed by power output also showed greater declines after an intervention of hypertonic saline which elevated perceptions of muscle pain but without any differences in cardiorespiratory indices. In addition, this thesis unexpectedly observed no significant differences in behavioural self-regulation (i.e., changes in power output over time) of perceived effort between experience levels.

As for cognitive strategies, in a two-part study (Study 2, Part B), this thesis found that individuals activated more cognitive self-regulatory strategies during cycling exercise at higher than lower perceived effort intensities. In part, this may have been due to the differences in attentional focus towards interoceptive cues (Ekkekakis, 2003) which were more prevalent during higher perceived effort exercise than lower perceived effort exercise. Further assessment of the primary themes relating to self-regulation also indicated that experienced individuals use cognitive self-regulatory strategies like reappraisal and imagery more than experienced counterparts and may implement some of these strategies (e.g., imagery) more at the start of fixed perceived effort tasks whereas inexperienced gradually implement more self-regulatory strategies as exercise progresses. In association with this study, a final study discerned that in the presence of elevated muscle pain, there may be a greater activation of brain regions associated with executive control as indexed by a greater change in deoxyhaemoglobin from a resting baseline via fNIRS.

Working periodically through these results, references to existing models such as the psychobiological model (Marcora, 2008) and cybernetics control theory (Carver & Scheier, 1982) are made to rationalise the decision-making processes that guide individuals to self-regulate perceived effort. Chiefly, according to the psychobiological model the self-regulation of perceived effort during a task which requires participants to maintain a constant perception of effort rating can operate via three main routes: (1) to reduce the corollary discharge production from central motor commands; (2) to alter the neuronal processing of corollary discharge; or (3) to enhance motivational intensity so that actual effort is lower *in relation to* potential motivation than before motivational intensity was enhanced (Figure 2) (Barwood et al., 2015; Marcora, 2019; McCormick et al., 2015, 2019; Pageaux, 2014b, 2016).

The studies within this thesis provide some evidence of the third option as it seems likely that self-talk with a motivational element (see Table 4) was used regularly by participants. Prior studies using other exercise trials have observed similar effects of self-talk to afford athletes to exercise at a higher intensity for a given perception of effort (Barwood et al., 2008, 2015) or for a longer time at a fixed intensity (Blanchfield et al., 2014) likely to due to the upregulation of motivation. Yet, as motivation was not assessed as part of this thesis, this may not be certain. However, the findings from Study 2 and previous studies do provide evidence that participants seem to identify with using self-talk as a useful strategy to optimise performance on exercise tasks (Robinson et al., 2021; Whitehead et al., 2018) and several models of exercise regulation provide a logical explanation to how self-talk enhances performance via motivational changes (e.g., Marcora, 2008, 2019; Tucker, 2009).

Tentatively, some support for the second option may exist in the findings of this thesis. To clarify, studies examining reappraisal (a strategy used particularly by experienced cyclists during the trials) have suggested that as part of the process for reframing the perception of a current situation (Lazarus, 1991), reappraisal also causes an underlying change to the activation and neuronal processing within cerebral centres associated with emotion and cognition such as the amygdala and pre-frontal cortex (Gross, 2013, 2015). Therefore, it may be that individuals activated self-regulatory strategies like reappraisal as it operates across neuro-psychophysiological pathways which have a close relation to the generation of perceived effort (Williamson et al., 2001). However, again this thesis did not assess the neuronal processing of corollaries and therefore a firm conclusion cannot be made. That being said, there is a reasonable body of evidence that indicates reappraisal affects exercise-related phenomena such as the perception of effort (e.g., Arthur et al., 2019; Giles et al., 2018; Grandjean da Costa et al., 2022; Troy et al., 2018) which is likely to have a neurological underpinning (Gross, 2002, 2013). Subsequently, future areas of research may be interested in investigating the underlying neurological changes when using cognitive self-regulatory strategies like reappraisal and its potential link to altering neuronal processes that impact effort perceptions.

These findings so far have been related to how the psychobiological model may provide an explanation to how and why one regulates the self during fixed perceived effort exercise. However, alone the psychobiological model does not fully explain how decision-making processes operate to self-regulate the self during fixed perceived effort exercise. Therefore, self-regulatory theory and its theories pertaining to its lower order strategies like self-control (Figure 10a/b), can provide more clarity into how an individual adapts their psychophysiological state and behaviour during fixed perceived effort trials to maintain a given RPE. As such, the ensuing sections will relate the findings of this thesis with regard to self-regulatory theory and other existing decision-making models.

7.2.1. BEHAVIOURAL SELF-REGULATORY STRATEGIES

When considering the differences in power output changes and trajectories in these studies (Study 1 and 2), data from prior studies demonstrate how exercise within different intensity domains precipitates varying degrees of fatigue to effect changes on perceived effort and subsequent behaviour (Aboodarda et al., 2020; Azevedo de Almeida et al., 2022; Brownstein et al., 2022; Iannetta et al., 2022). Principally, GET demarcates the boundary between the moderate and heavy intensity domains (Burnley & Jones, 2007, 2018; Gaesser & Poole, 1996; Iannetta et al., 2020). As such, exercise at RPE_{GET} is expected to occur almost exclusively within the moderate intensity domain whilst exercise at $RPE_{+15\%GET}$ is expected to bridge the heavy and moderate intensity domains (Cochrane et al., 2015a, b; Cochrane-Snyman et al., 2016). A recent study by Brownstein et al. (2022) demonstrated that there is a greater degree of neuromuscular fatigue when exercising above the GET compared to below the GET. Moreover, Iannetta et al. (2022) also established that fatigue is highly dependent on the intensity domain which exercise takes place in. Particularly, peripheral fatigue (i.e., reduced muscle contractile capacity) is affected by higher intensity exercise more so than central (e.g., suboptimal motoneuronal drive) fatigue components (Iannetta et al., 2022). Therefore, as symptoms of fatigue are more present during higher intensity exercise like that undertaken in the $RPE_{+15\%GET}$ versus the RPE_{GET} condition (Cochrane et al., 2015a, b; Cochrane-Snyman et al.,2016), greater declines in power output are expected because of the effects on central motor command towards working muscles (Behrens et al., 2023; Pageaux, 2016).

However, it must also be noted that an increase in central motor command is not always directly linked to a linear increase in perceived effort and its rating (Amann et al., 2022; de Morree et al., 2014; Marcora, 2019). Most recent studies insist upon a sum of several perceptions that lead to a change in intensity of exercise or task failure (Aboodarda et al., 2020; Behrens et al., 2023; Iannetta et al., 2022). At the centre of the corollary discharge model is the proposition that it is not only the *volume* of corollaries that affect perceived effort intensity and its rating, but that other psychosocial factors can impact *how* those corollaries are neuronally processed (Williamson, 2006; Williamson et al., 2001, 2002). Therefore, not only can measurable indices of neuromuscular fatigue (e.g., % of voluntary activation, twitch potentials) indicate ways that fatigue impacts perceived effort (Enoka & Duchateau, 2016) but also how perceptions of fatigue can be impactful to perceived effort too (Behrens et al., 2023). Therefore, changes to physical and cognitive outputs towards a task are likely dependent on an interplay between psychological alongside neurophysiological factors as best highlighted by the psychobiological model of exercise (Marcora, 2008).

Reiterating that power output showed a gradual decline across all intensities and conditions of fixed perceived effort exercise, seemingly there are effects on the neuronal processing of corollary discharge due to this decline too. In association with reductions in power output, a lowering of exercise intensity would also be expected to provoke less negative and intense psychophysiological sensory signals through the central nervous system (Venhorst et al., 2018b). Consequently, leading to reduced presence of negatively-valenced sensation/perceptions which would alter the neuronal processing of corollaries to also reduce perceptions of effort (Pageaux, 2016; Smirmaul, 2012). However, the studies in this thesis demonstrated a less positive/more negative affective valence even when power output was reduced. Therefore, other cognitive strategies may have been used to alter the neuronal processing of corollary discharge to effect changes on perceived effort (section 7.3.2).

In addition, due to the nature of the task that this thesis used (a fixed perceived effort task), this may have painted a different picture of how perceived effort is self-regulated behaviourally compared to other tasks like time-trials or time-to-exhaustion tests. To illustrate, fixed perceived effort exercise occurred without any added performance demands from the task as well as participants being blinded from data concerning performance, time, or biofeedback (O’Malley et al., 2023). Alternatively, events like time-trials do impose performance-based demands such as beating opponents or acceding towards certain task outputs (McCormick et al., 2018). In typical performance-based studies, the downregulation of power output is viewed as a sub-optimal self-regulatory technique because whilst it may be effective for reducing perceived effort it does compromise task goals such as finishing a time-trial as fast as possible (Abbiss & Laursen, 2008; Edwards & Polman, 2012; Englert et al., 2021). Alternatively, during a fixed perceived effort trial there is no imposed performance demand with participants ultimately being required to maintain a fixed perceived effort (O’Malley et al., 2023) according to a set value on the Borg 15-point scale (Borg, 1970). Therefore, participants may have been more inclined to reduce power output during this type of task as the effectiveness of this strategy to assimilate perceived effort back into its required intensity is highly effective without compromising any form of performance (Englert et al., 2021; Evans et al., 2016).

7.2.2. COGNITIVE SELF-REGULATORY STRATEGIES

Some viewpoints concerning exercise performance (e.g., Amann & Secher, 2010; Amann et al., 2015; Burnley & Jones, 2018; Hureau, Romer, et al., 2018) and the inherent self-regulation as part of exercise pursuits seem to negate the role of the brain for enacting conscious decisions towards the selected behaviours for the task (Marcora, 2010a; Noakes, 2004). Since, numerous studies have directly refuted the afferent feedback model and rationalised the role of the conscious brain in affecting changes to behavioural outputs (e.g., power output) during endurance-type exercise via the self-regulation of perceived effort (Barwood et al., 2008, 2015; Blanchfield et al., 2014a, b; de Koning et al., 2011; de Morree et al., 2012; Jacquet et al., 2021; Marcora & Staiano, 2010; Marcora et al., 2009). The findings from this thesis add to this body of literature as it appears participants also activate cognitive self-regulatory strategies during fixed perceived effort exercise, thereby individuals do not always resort to a behavioural adaptation to ensure perceived effort remained constant. In addition, Study 2, Part B also provided an interesting insight in which experienced cyclists seemed to have a heightened focus on their psychological state compared to inexperienced cyclists. Consequently, whilst individuals may have a natural tendency to focus on the physiological sensations associated with exercise (Brick, MacIntrye, et al., 2016) like pain (Mauger, 2014), breathing (Laviolette & Laveneziana, 2014), temperature (Brotherhood, 2008), or fatigue (Behrens et al., 2023), cognitive factors appear to also be important as participants accounted their psychological state as part of the self-regulatory process.

Within Study 3, this thesis also provides a possible explanation that participants also activate more cognitive self-regulatory strategies to regulate perceived effort when in the presence of elevated sensory feedback such as nociception via hypertonic saline injection. Potentially, at times, instead of lowering power output, individuals opted to use cognitive strategies to ensure perceived effort did not exceed the requirement for the task without compromising exercise intensity. To evidence, Study 2 discerned that participants activated cognitive self-regulatory strategies more often during $RPE_{+15\%GET}$ than RPE_{GET} exercise whereby more instances of self-talk, a focus on technique/form, and imagery were disclosed.

Moreover, Study 2 exhibited that experienced cyclists appeared to use reappraisal strategies more often than inexperienced counterparts. Successively, Study 3 also found a higher change in deoxyhaemoglobin levels during the hypertonic condition which had elevated muscle pain compared to an isotonic condition. Thus, inferring that in the presence of elevated muscle pain stimulated individuals to activate more cognitive self-regulatory strategies to moderate their psychophysiological state during effortful exercise compared to a placebo-controlled condition without elevated muscle pain.(Brick et al., 2014; Brick, MacIntyre, et al., 2016; Carver & Scheier, 1982, 2000; McCormick et al., 2019).

7.2.2.1. REAPPRAISAL

Reappraisal is theorised to cause an altered integration of effort-driving signals (Lazarus, 1991, 2000; Smith & Lazarus, 1983). A selection of studies has previously found that reappraisal engenders a more positive affective and emotional state compared to control conditions (Gross, 2002; Jamieson et al., 2012). Interestingly, reappraisal also has clear physiological impacts which causes more adaptive cardiovascular stress responses when an individual is engaged in a motivationally meaningful and emotionally charged situation (Jamieson et al., 2012; Urry, 2009). Combined, studies have then translated these findings into the field of exercise science and found that cognitive reappraisal can also act to reduce perceptions of effort during endurance activity (Giles et al., 2018; Sammy et al., 2017). It is thought that as reappraisal involves a manipulation of the emotional state to become more positive that this would alter the affective disposition of the individual (Grandjean da Costa et al., 2022; Gross, 2013; McRae et al., 2012). As a result, if an individual feels that the hedonic experience of the exercise is becoming more positive/less negative, this is likely to alter the neuronal processing of corollaries in a way which would reduce perceptions of effort (Brand & Ekkekakis, 2021; Ekkekakis & Brand, 2019; Lind et al., 2009; Pageaux, 2016).

Though this thesis so far has highlighted that experienced individuals seemed to identify with cognitive reappraisal strategies more than inexperienced counterparts, it is worth emphasising that inexperienced cyclists did still use reappraisal techniques during the fixed perceived effort task too (Table 4). Therefore, regardless of experience level, findings suggest that reappraisal is a useful strategy for individuals to employ to help cope with the natural vicissitudes of effortful exercise (Lazarus, 1991). Specifically, prior research has indicated that reappraisal may be particularly functional during effortful tasks as it could affect the surrounding factors that can affect the perception of effort such as affective valence (Giles et al., 2018; Grandjean da Costa et al., 2022). Or that reappraisal might enact direct changes to the activation of brain regions associated with generating effort perceptions during exercise (Gross, 2013). However, the nature of the studies in this thesis can only conjecture that reappraisal could have an effect on these areas but more studies are required to get a better sense of how reappraisal affects effort perceptions.

What this thesis can surmise though, is that it experienced cyclists have a more natural tendency to utilise reappraisal strategies to self-regulate compared to inexperienced counterparts. The reason for this may be that there are some caveats to using reappraisal as a cognitive technique. Troy et al. (2018) detail that using reappraisal techniques can be challenging for individuals, particularly those who are less experienced. As a result, reappraisal itself can become effortful for those who have less experience in using appraisal techniques (Troy et al., 2018; Giles et al., 2018) compared to those who have regularly practiced reappraisal so that it is now an ingrained, automatic, and therefore effortless strategy (Cos, 2017; Gross, 2015). In a context where a transitory increase in cognitive effort could be applied for a more effective long-term decrease in overall effort for a task (e.g., using reappraisal during the start of a marathon to make it feel less aversive for the remainder of the race), reappraisal is known to be effective for changing subjective experiences (Troy et al., 2018; Urry, 2009) as well as enhancing performance (Giles et al., 2018). However, in the context of a fixed perceived effort exercise, reappraisal may not always serve an individual in a functional way if it requires cognitive effort to implement it as this will likely cause the individual to change their perceived effort and subsequently deviate from the purpose of the task.

Whilst this may seem a drawback in using reappraisal studies to explain how perceived effort can be regulated, instead it poses an exciting prospect for future research. Strangely, no research to date has looked at the learning effects on motor and cognitive strategies. In turn, research is unaware of the impacts learning effects have on the required effort to activate self-regulatory skills to regulate perceived effort or other exercise-related phenomena. As part of learning, it is theorised that previously effortful strategies become automatic and therefore effortless (Cos, 2017). Indeed, within the Giles et al. (2018) study, a group of experienced athletes demonstrated no changes in cerebral oxygenation markers. These cerebral oxygenation markers are evidenced to be closely linked to the delivery of cognitive resources (effort) at cerebral sites involved with reappraisal, emotional regulation, and executive function such as the prefrontal cortex (Cui et al., 2011; Friedman & Robbins, 2021; Ishii et al., 2016). As a result, Giles et al. (2018) observation of no changes in cerebral oxygenation markers despite clear engagement in cognitive reappraisal indicates that this group of experienced athletes require less cerebral resources (effort) to activate cognitive strategies like reappraisal. Therefore, after a period of learning, an individual becomes equipped with a skill that to others (i.e., inexperienced individuals) is mentally effortful. Consequently, future studies may wish to investigate the long-term learning effects for cognitive self-regulatory strategies and the relative changes in effort that are required to activate them according to the learning process.

7.2.2.2. SELF-TALK

Besides reappraisal, other cognitive strategies may be adopted such as self-talk. Within Study 2, self-talk was regularly observed across the entire cohort. Particularly, the type of self-talk that was disclosed appeared to be predominantly motivational in nature (Table 4). Thus, it could be argued that when individuals engaged in self-talk, they were aiming to enhance their motivational intensity (McCormick et al., 2015). Three main studies have regularly been related throughout this thesis which exemplify how motivational self-talk alters the perception of effort, possibly via changes in potential motivation (Barwood et al., 2008, 2015; Blanchfield et al., 2014a). Blanchfield et al. (2014a) demonstrated that during a fixed power output task, participants were able to prolong their time-to-exhaustion when engaging in motivational self-talk compared to when no self-talk was used. Barwood et al. (2015) then showed that motivational self-talk caused participants to provide similar RPE responses but at a higher exercise intensity compared to neutral self-talk. Therefore, for a given exercise intensity, RPE responses were lower when conducting motivational self-talk than when it was not. A clear benefit for exercise performance (Abbiss & Laursen, 2008; Edwards & Polman, 2012).

The mechanism(s) behind motivational self-talk have not been fully discussed in any previous studies in relation to the psychobiological model (Marcora, 2008). As such, this discussion provides some potential explanations. First, self-talk appears to enhance the subjective benefit of the task thereby increasing the potential motivation of an individual (Blanchfield et al., 2014a; Richter, 2013). To recap, potential motivation relates to the maximum level of effort an individual is willing to invest towards a task (Wright, 1996). Throughout a fixed perceived effort task, a constant perception of effort is expected but an individual's potential motivation or actual effort (i.e., resources applied towards the task) could change (Figure 2). One perspective of Marcora's psychobiological model (Figure 2), portrays how when potential motivation is changed, this can affect the actual effort (i.e., resources applied to the task) that is applied despite remaining at the same perception of effort. The situation could also be flipped to suggest that when potential motivation is changed, the same level of actual effort is applied to the task, but this means an individual perceives their effort as being lower due to the lower relational value of effort to potential motivation. Thus, the relational value could change due to the linear scaling of the Borg (1970) 15-point scale (Halperin & Emanuel, 2020).

Though this hypothesis has not been directly investigated, numerous data across studies support its ideas. To begin, potential motivation – the maximum conceived intensity an individual is willing to invest – is susceptible to change (Richter et al., 2016). Regularly studies involving monetary reward and other psychosocial factors have demonstrated tangible task performance improvements due to changes in potential motivation (Apps et al., 2015; Manohar et al., 2015; Pessiglione et al., 2007). Moreover, a recent study by Malleron et al. (2023) neatly expressed that when individuals had different notions of a maximal conceived effort through imposed or self-imposed anchors, RPE responses varied greatly at task exhaustion. Therefore, for this study/thesis, instead of concluding that self-talk changing the neuronal processing of effort signals to reduce its perception of intensity and rating, it may be that self-talk changed the motivational disposition of the athlete (Inzlicht et al., 2014; Müller & Apps, 2019).

Crucially, during submaximal exercise, when motivation for the task is greater or equal to the required effort (both physical and mental), the task will continue at the same intensity (Marcora, 2008, 2010a; Richter, 2013; Richter et al., 2016). In contrast, when the motivation for the task is lower than the required effort, the task will either be reduced in intensity until an equilibrium between motivational intensity and effort is re-established (Richter, 2013) or completely discontinued (Inzlicht & Marcora, 2016). Individuals who partook in these studies showed regular engagement in self-talk presumably to enhance their motivational intensity so that it remained equal to or exceeded the required effort (Marcora, 2010a). In doing so, individuals forestalled any decreases in exercise intensity (Inzlicht & Marcora, 2016; Marcora, 2010a; Richter et al., 2008) but it would be expected that this would mean a greater intensity of effort is required for the task as motivational intensity has also increased.

7.2.2.3. FURTHER DISCUSSION ON BEHAVIOURAL AND COGNITIVE SELF-REGULATION

Moving on from theoretical debates and returning to the specific findings of this thesis concerning self-regulation of perceived effort. One interesting finding to note was that Study 2, Part B did not show any differences in behavioural or cognitive self-regulatory strategies between experienced and inexperienced cyclists despite previous studies had found a difference between the two subpopulations (Samson et al., 2017; Whitehead et al., 2018, 2019). Conceptually, a difference in self-regulatory strategies, particularly cognitive strategies were expected. Within this literature, it is suggested that self-control – a component of self-regulation – involves a purposeful selection of less dominant/impulsive but more facilitative strategies to achieve goal (Baumeister et al. 1994; Inzlicht et al., 2014). In the context of a fixed perceived effort task, the goal was to maintain a constant perceived effort. The overriding dominant response may be to reduce power output as a form of behavioural self-regulation (Carver & Scheier, 2000). In connection with this, cognitive strategies may be seen as a less dominant response to maintain a constant perceived effort during exercise. Therefore, those that are more trained/experienced could be more likely to autonomously self-regulate as experience has provided those individuals with a wider set of self-regulatory schema to activate to effectively self-regulate perceived effort (Elferink-Gemser & Hettinga, 2017).

Another perspective which also argues that differences between experienced and inexperienced cyclists should have been present relates to the individualised preferences that individuals may have for investing specific types of effort (e.g., physical, or mental). According to neuroeconomic models of effort-based decision-making (e.g., Westbrook & Beaver 2015), data suggests that cognitive self-regulatory strategies may be implemented in favour of behavioural self-regulatory strategies due to the subjective valuations that are made. As such, whether a quantum of physical *or* mental effort is applied depends on previous experience and personal preferences (Chong et al., 2017, 2018). To illustrate, experienced individuals naturally inure themselves to physical effort over time through training and engagement in exercise (Cos, 2017; McCormick et al., 2018; Siddle, 1991). As a result, the application of physical effort becomes less aversive, and individuals may feel more efficacious at regulating this form of effort (Anstiss et al., 2018; Chong et al., 2017; McCormick et al., 2019). Alternatively, inexperienced individuals may be less accustomed to physical effort compared to experienced counterparts (McCormick et al., 2016). Consequently, investing physical effort is less appealing (Chong et al., 2017; McCormick et al., 2016). In practice, this may mean that experienced individuals would opt to maintain physical outputs (i.e., maintain the same level of physical resources) and choose to activate cognitive strategies to moderate their perceived effort (Chong et al., 2018). On the other hand, inexperienced individuals who are more averse to investing physical effort may opt to reduce physical outputs to regulate their perceived effort instead of choosing to maintain their investment of physical resources and change perceived effort via cognitive strategies (Chong et al., 2018). Notably, this line of thought has not been explored in any sense within the field of exercise science. Specifically, most other models of decision-making infer that participants make logical or predictive decisions to regulate their effort during exercise (McCormick et al., 2019; Renfree et al., 2014). In contrast, there is less acknowledgement of aberrant models of decision-making where participants have personal preferences to the type of effort they are willing to invest and what that means for how they self-regulate their perceived effort and other inner states during exercise (Chong et al., 2017).

In part, findings from Study 2 do evince some ideas that experienced individuals are more likely to invest cognitive effort at earlier phases of a task. Particularly, it was observed that some cognitive strategies like reappraisal which are taxing on cognitive resources were activated more by experienced cyclists in early stages of the fixed perceived effort task than inexperienced counterparts, however, this finding was not significant (i.e., no condition × time interaction). Moreover, there is also the suggestion that there are no differences in preferences for physical effort as both subgroups exhibited similar changes in power output and no differences in psychophysiological state also.

Finally, after discussing the personal differences that may influence which self-regulatory strategies are activated, revisiting findings from Study 3 suggests that context, exercise intensity, and specific psychophysiological states may also play a role in how perceived effort is self-regulated and the type of effort individuals are impelled/choose to invest. To recap, Study 3 found a condition × time interaction on power output as well as increased change in deoxyhaemoglobin from baseline in the presence of elevated pain perceptions versus a placebo-control not involving elevated pain perceptions. As a result, it appears that due to the presence of elevated pain perceptions, individuals self-regulated the fixed perceived effort exercise in a slightly different manner than when elevated pain perceptions are absent. It appears that individuals could apply more mental effort in the presence of elevated pain perceptions to cope (Venhorst et al., 2018b).

Data from previous studies across kinesiology, neuroscience, and psychology reason that this is because elevated pain imposes increased demands that are twofold (Aboodarda et al., 2020; Martinez-Valdez et al., 2020; Norbury et al., 2022a, b; Rainville et al., 1997). On one hand, pain stimulates subconscious changes to muscle activation whereby fatigue prone fibres increase in excitability (Burns et al., 2016; Falla & Farina, 2008) whereas fatigue resistant fibres useful to endurance performance become inhibited (Farina et al., 2004, 2005; Martinez-Valdez et al., 2020). To add, increased corticospinal inhibition and decreased corticospinal excitability result in an impeded central drive conductance along corticospinal pathways to innervate muscle fibres (Chowdhury et al., 20221; Sanderson et al., 2021). Therefore, it is anticipated that more central drive is required and therefore greater neuronal processing of corollary discharge production occurs, resulting in an increased perception of effort for a given exercise intensity (Norbury et al., 2022a, b; Pageaux, 2016; Smith et al., 2020).

Meanwhile pain is also believed to elicit negative psychological states which are thought to perpetuate cognitive effort demands and other affective-cognitive states that are associated with increased effort perceptions for a set physical intensity (Venhorst et al., 2018a, b).By definition, pain signals the presence of potential or actual tissue damage (Raja et al., 2020) thereby creating an impulsive protective response that motivates the individual to alter their behaviour to reduce the potential damage (Vadivelu et al., 2009). However, during most forms of exercise tasks like time-trials, individuals can *"ignore"* these signals in aim of acceding towards better task performance (Mauger, 2013). A similar *"disregard"* of sensory nociceptive signals has also been found in cognitive tasks when experimental pain has been implemented (Vogel et al., 2021). Therefore, data implies that whilst pain perceptions may predispose individuals to reduce their task outputs in aim of alleviating the negative impacts of pain (Mauger, 2013), individuals decision-making processes can actively prioritise other aspects of the task more than pain (Vogel et al., 2021). As a result, this requires individuals to engage in the active quelling of dominant impulses, known as response inhibition (Mostofsky & Simmonds, 2007) which has been highlighted as taxing on cognitive resources (Englert, 2016; Evans et al., 2016; Hagger & Chatzisarantis, 2007; Marcora & Staiano, 2010; Mostofsky & Simmonds, 2007; Pageaux, Angius, et al., 2015). Data from fMRI studies also highlight that pain does index an increased activity across supplementary motor areas, the anterior cingulate cortex and anterior insula, further proving that pain elicits some form of mental demand as these areas of the brain are also closely involved with effort (Misra & Coombes, 2015).

Therefore, in short, pain imposes added physical *and* mental demands on individuals during goal-directed tasks. Consequently, pain necessitates greater resources for physical and mental aspects of an exercise task wherein a greater resource demand infers greater effort and therefore a higher perception of effort. Applied to a fixed perceived effort task, if an individual is exercising in the presence of higher pain perceptions, logically exercise intensity will be lower for a set intensity of perceived effort. As was seen in Study 3, power output was lower in the presence of elevated pain perceptions (hypertonic) than lower pain perceptions (isotonic). However, whilst the negative implications of pain on task performance seem certain, some data suggest that pain is not always a negative influence on task performance as it may be possible to reduce perceived effort in the presence of pain (Brick et al., 2014; Crombez et al., 2013; Legrain et al., 2009; Van Damme et al., 2010).

To start with this counterargument, studies by Koltyn (2000, 2002) highlighted that exercise (i.e., effort input) could create an exercise-induced hypoalgesia during and after engagement in some form of exercise. Particularly, pain threshold measures were taken before and after an aerobic and resistance exercise bouts in which pain threshold was observed to be significantly lower after exercise (Koltyn, 2000, 2002; Koltyn & Arbogast, 1998; Koltyn et al., 1996). This hypoalgesic effect (i.e., lower pain due to current/prior effort) was believed to stem from increased circulation of endocannabinoids after exercise (Koltyn et al., 2014). However, the concept could be reversed in which exposure to pain during exercise could reduce perceived effort in a somewhat similar manner by capturing attention and displacing effort-driving signals from being processed and therefore perceived (Brick et al., 2014; Koster et al., 2004).

Koster et al. (2004) suggest that threat-oriented phenomena, like pain, captures and holds attention during behavioural tasks. Next, Van Damme et al. (2010) then evidenced that when presented with a task goal, pain acquires the most attention even if the pain is irrelevant to the task. As a result, using a similar premise as shown by Terry et al. (2020) concerning music and finite bandwidths to process information, if a given level of nociceptive signals are presented during effortful exercise, it is conceivable that nociceptive signals prevent as much neuronal processing of corollary discharge from central drive (Brick et al., 2014). Therefore, decreased effort perceptions during detectable nociceptive stimulation could result from the limited attentive capacity of individuals shared between the effort and pain neural circuits (Buhle & Wager, 2010; Misra & Coombes, 2015) in the cingulate cortices, anterior insula, and supplementary motor areas (Zénon et al., 2015).

Indeed, three studies have showed that in the presence of pain, effort can remain unhindered when being applied towards the task. First, a study by Buhle and Wager (2010), found that the effect of pain on working memory task performance was not always linearly related. Mainly, there is a varied response according to the intensity of pain and the subsequent task performance (Buhle & Wager, 2010). Next, Vogel et al. (2021) summarised that pain and effort may not share the same basic influences. Therefore, whilst pain and effort may both be seen as aversive, decisions towards an exercise or a cognitive task in the presence of pain and/or effort vary because of how pain and effort are valued. Thus, for a cognitive task, participants can still feel that it is worth investing the effort irrespective of the pain that is present or anticipated as part of their future actions. Finally, Seminowicz and Davis (2007b) identified that even when pain is present, individual's attention towards a task is maintained and they can overcome the pain that is being applied without changes in perceived effort.

A second argument is that pain perceptions may be associated with a negative hedonic experience causing displeasure (Ekkekakis et al., 2011; Mauger, 2013). Nevertheless, pain perceptions could still enhance the affective experience via motivational changes (Koltyn, 2000; Zenko et al., 2016). For instance, the perception of pain involves metacognitive awareness that the individual is exercising at a certain intensity that is high enough to elicit psychophysiological changes (Brick et al., 2014). In turn, this indicates that the individual is exercising at a high intensity which is usually good for task outcomes (Graven-Nielsen, 2006). Terms such as "*no pain, no gain*" have become commonplace amongst exercisers suggesting an altered appraisal of pain perceptions which can be used to motivate the individual (Van Damme et al., 2008). Likewise, during events like a time-trial, if an individual thinks that they are exercising at a high intensity then the individual may also acknowledge that this means they are going at a high enough intensity to outvie their opponents (Lasnier & Durand-Bush, 2022). Therefore, enhancing the affective experience may cause altered neuronal processing of effort-driving signals to reduce perceived effort (Pageaux, 2016).

However, akin to most research concerning pain and exercise, this notion is yet to be explored within research. It is interesting to think how the intensity of pain may play a role in reducing effort perceptions. Furthermore, based on what has been related, there could also be an investigation of a "*critical intensity hypothesis*" of pain. To illustrate, below this *critical intensity*, pain perceptions operate to reduce attention to effort driving signals and help promote motivational intensity due to metacognitive inferences that pain presence indicates a high intensity of exercise (Buhle & Wager, 2010; Legrain et al., 2009; Valet et al., 2004; Van

Damme et al., 2008, 2010; Verhoeven et al., 2010). Importantly, when below this *critical intensity*, it may be that the positive effects of pain like reduced attention or improved motivation outweigh the negative impacts of pain such as reduced corticospinal efficiency in conducting central drive to muscles or increased cognitive demand due to response inhibition of pain experience. Overall, resulting in superior task performance. However, at the point of reaching or exceeding this *critical intensity* of pain, it could be argued that the negative impacts of pain then outweigh its positives and causes inferior task performance. Again, an exciting hypothesis and line of research that hitherto has been totally unexplored.

7.3. MAIN IMPLICATIONS

After a discussion of the major findings of this study and possible mechanistic explanations of these findings, some main implications can be garnered. First, this thesis found that the use of a novel fixed perceived effort task which corresponded RPE to known physiological thresholds was a reliable task. In the real world, this does suggest that those who lack the capacity to measure intricate psychophysiological measures could resort to fixed perceived effort tasks as they are known to be able to be reliably produced over several occasions (see other studies in the area by Cochrane et al., 2015a; Cochrane-Snyman et al., 2016, 2019; Eston & Williams, 1988; O'Grady et al., 2021). Moreover, the psychophysiological responses associated with this exercise were reliably produced across numerous bouts where exertion was based solely off a set RPE. Interestingly it appears that for future research higher intensity fixed perceived effort exercise is more reliable than lower intensity fixed perceived effort exercise. This concurs with other previous findings (Eston & Williams, 1988; O'Grady et al., 2021).

Next, psychophysiological responses to fixed perceived effort exercise are perhaps dependent on the intensity of task according to a perceived effort and not according to the actual power output being exerted. Reviewing the data, it appears that changes in psychophysiological markers such as cardiorespiratory markers like heart rate, as well as some perceptual markers like affective valence are distinct from the actual effort (e.g., power output) being applied towards the task. For example, in Study 1 and 2, participants showed a continual decline in power output at a fixed perceived effort. In addition, during these studies, heart rate showed a continual increase to suggest the physiological response at a set perception of effort is not entirely linked. Similarly, in Study 3, a significant condition effect in power output was found but without any differences in physiological variables like heart rate and $\dot{V}O_2.kg^{-1}$.

Furthermore, although a significant difference in power output was observed between hypertonic and isotonic conditions, the actual difference in the latter stages of the exercise were approximately three – five Watts. Despite this, affective valence responses were more markedly different with differences of at least one point on the feeling scale (Hardy & Rejeski, 1989). Therefore, there is some evidence that supports the interpretation that different psychophysiological responses may not always paired with the intensity of exercise being conducted.

However, the purpose of the current thesis was not to determine the causes of perceived effort (see Pageaux, 2016) or whether perceived effort is the (sole) determinant of exercise behaviour (see Marcora, 2019). Instead, the thesis aimed to use a psychophysiological approach to measure the physiological and psychological indices of perceived effort to gather an insight into how individuals decide how to self-regulate their perceived effort during an exercise task. Nevertheless, further discussion on whether psychophysiological responses are *associated* with perceived effort rather than the *cause* of effort perceptions and its ratings could continue in future (Amann, 2011; Amann & Secher, 2010; Venhorst et al., 2018b).

The main implications of the present thesis relate to the self-regulation of perceived effort which drew upon theories from the field of psychology. For instance, Carver and Scheier's (1982, 2000) control theory involves two major categories of self-regulation available to individuals when exercising at a fixed perceived effort, behavioural or cognitive. This thesis demonstrated that individuals incorporated a mixture of behavioural and cognitive self-regulatory strategies over the course of the fixed perceived effort bouts that were conducted. However, it was highlighted that opting for these strategies could be dependent on the context (e.g., the type of task being completed), the previous experience that an individual has (e.g., aberrant models based on personal experience with certain strategies), and the current psychophysiological states that ought to be regulated (e.g., presence or absence of pain).

Overall, it seems that the higher the exercise intensity, the more self-regulation of perceived effort is required as indexed by larger changes to power output in some studies. Moreover, there was also evidence of different amounts of cognitive self-regulatory strategies like self-talk was used at different perceived effort intensities. However, results hint that experienced and inexperienced cyclists did not necessarily self-regulate their perceived effort more or less often than inexperienced counterparts but may have been more disposed to use certain strategies like reappraisal compared to an inexperienced cohort of cyclists. Further analysis of primary themes from the think aloud protocol also showed experienced cyclists seemed more attuned to their psychological state as well as particular physiological sensations like fatigue. Moreover, despite no differences in power output changes (i.e., trajectories of power output over the exercise) between cyclists of different levels of experience, the experienced cyclists discussed the possibility of keeping their power output constant more often and mentioned decreasing their power output fewer times than inexperienced cyclists. Meaning, that whilst the power output changes were insignificant, a case could be made that experienced cyclists may be more intent to avoid behavioural self-regulatory strategies (e.g., power output changes) and instead opt for cognitive self-regulatory strategies like reappraisal whereby task outputs can be maintained. Accordingly, it has been postulated that experienced individuals may be more inclined to enact cognitive strategies due to the aberrant decision-making processes that occur where individuals have personal preferences for physical or mental effort to be applied towards a task (Chong et al., 2017, 2018).

Finally, this thesis explored the impact of a pain intervention via a hypertonic or isotonic placebo-control on perceived effort regulation during the fixed perceived effort cycling task. It was observed that elevated perceptions of pain did cause a lower power output (i.e., a change in behavioural self-regulation) as well as more activation of cerebral regions associated with executive control such as the prefrontal cortex which possibly corroborates a greater use of cognitive strategies being used by cyclists to cope with added psychophysiological demands (Robinson et al., 2021). Generally, pain imposes increased physical and mental demand on an individual when conducting an exercise at a fixed perceived effort. As a result, more self-regulatory behaviours are thought to be required to maintain a set perception of effort. Thus, pain measures would be prudent during future studies involving perceived effort to ensure no confounding effects. Moreover, enabling individuals to draw on cognitive self-regulatory techniques may be useful to enhance exercise task performance as cognitive strategies can be used in lieu of behavioural changes that are counterproductive to exercise goals (e.g., exercising at a higher intensity for a set perception of effort) (Vogel et al., 2021). Thereby, increasing the likelihood of improved exercise performance or goal attainment across sport and exercise domains.

7.4. LIMITATIONS AND FUTURE RESEARCH

Due to the exploratory nature of this thesis, naturally more questions are created than answers. Whilst this may be viewed initially as a limitation, there are many positive aspects of this type of work as many different lines of research have been presented throughout the current discussion. Mostly, these ideas have stemmed from either a lack of data in areas to fully validate a mechanistic explanation, or from small pools of conflicting data when explaining mechanistic explanations for a particular finding.

First, there are many previous discussions on the causes of perceived effort (see Pageaux, 2016) and the relative effects of added phenomena (e.g., afferent feedback) on perceived effort and performance (see Amann et al., 2020; Marcora, 2019). After discussing the psychophysiological response to exercise at fixed perceptions of effort, it was suggested that cardiorespiratory responses dissociated from the perceived effort of the exercise. Meanwhile, the studies within this thesis suggest that the power output exerted during a fixed perceived effort cycle is also dissociated from the perception of effort rating. However, this thesis did not directly aim to test the causes and role of perceived effort in exercise performance. Therefore, *conclusive* arguments about the relative contributions of central or peripheral indices on effort perceptions cannot be made. Furthermore, a more resolute standpoint as to whether existing models of exercise regulation involving effort perceptions like the psychobiological, central governor, or afferent feedback model cannot be taken. Only some inferences to what the data suggest can be posited.

Nonetheless, to explore these points further, it has been suggested that future studies could maintain the fixed perceived effort task paradigm but implement added measures like stroke volume and electromyography to glean a more in-depth view of the cardiorespiratory responses and central motor command changes reaching the muscle. This way, more solid mechanistic explanations can be made to explain why power output, and cardiorespiratory indices change in the ways they do at fixed intensities of perceived effort. Furthermore, added interventions such as afferent nerve blockades could also shed light on the role of afferent feedback during fixed perceived effort exercise. Similarly, fixed perceived effort exercise could also be conducted at a set intensity but with different motor command manipulations such as imagined contractions (no motor command and no movement), and a hybrid of actual (motor command and movement) and electrically evoked contractions (no motor command but with movement). All of which could help to explain the relative roles that afferent feedback (peripheral) or central motor command (central) mechanisms may or may not play in the perception of effort.

Subsequently, this thesis moved onto discussing the possible decision-making processes that guide self-regulatory responses that were shown as part of a fixed perceived effort exercise. Within this section numerous lines of future research were proposed. One of which was a further investigation in the context dependent changes in self-regulation. For example, it was discussed how the present thesis may have a biased picture of how forms of behavioural (i.e., changes in power output) or cognitive (i.e., mental strategies like self-talk) may be utilised according to the task being a fixed perceived effort task. As part of a fixed perceived effort task, there are no imposed performance demands on the participants besides the requirement to maintain a fixed perception of effort rating throughout a 30-minute cycling task (Cochrane et al., 2015a). Furthermore, no form of performance (e.g., Watts, distance), time, or biofeedback (e.g., heart rate, ventilation) were displayed to participants during this type of task (Cochrane-Snyman et al., 2016). In contrast, typical motor tasks like time-trials involve performance demands being imposed on participants with data concerning performance, time, and psychophysiological state being readily available (Abbiss & Laursen, 2008). Primarily, as tasks like time-trials are centred on besting opponents or acceding towards the best performance possible, the likelihood to regulate perceived effort by downregulating physical outputs (e.g., lowering power output) is highly unlikely unless deemed unavoidable (Foster et al., 2004). Alternatively, participants may enlist cognitive strategies to regulate their perceived effort whilst completing the exercise to their best capacity by maintaining physical outputs and enhance task performance (Brick, MacIntyre, et al., 2016. However, during a fixed perceived effort task like that used in this thesis, there are no performance demands (Cochrane-Snyman et al., 2016). Therefore, participants are aware that there are no drawbacks to lowering physical outputs (Cochrane et al., 2015a). Resultantly, as lowering power output is a direct and effective way at reducing central drive and therefore perceived effort, participants may have opted for behavioural self-regulatory strategies more often than what would occur in performance-based motor tasks like time-trials.

Naturally, this is difficult barrier to overcome but it does appear that despite participants knowing that the task was fixed perceived effort, the activation of cognitive resources did occur across all studies (particularly Study 2 and 3). Regardless, future work on fixed perceived effort exercise must remain conscious that the demands of the task do endear athletes to change their self-regulatory strategies. A feasible way to address this is by requiring athletes to complete different types of tasks with and without performance demands and track the self-regulation of perceived effort with think-aloud protocols.

After discussion of context-dependent self-regulation, two main forms of cognitive self-regulation were discussed in depth. Namely, reappraisal and self-talk were identified as being regular strategies of self-regulation that participants used in Study 2. However, in review of the exercise science literature around both reappraisal and self-talk, a lack of studies have truly tried to measure the effects reappraisal (Giles et al., 2018; Grandjean da Costa et al., 2022; Sammy et al., 2018) or self-talk (Barwood et al., 2008, 2015; Blanchfield et al., 2014; de Matos et al., 2021) have on underpinning factors of perceived effort and effort-based decision-making. Meanwhile, the field of psychology is saturated with studies to show the positive effects reappraisal can have on emotion (e.g., Lazarus, 1991, 2000; Smith & Lazarus, 1993) and affective states (Gross, 2002) as well as self-talk's positive effects on motivation and other emotional states. Therefore, a translation of these findings from the field of psychology into the exercise science sphere is warranted.

Another discussion point regarding cognitive self-regulatory strategies concerned findings that strategies to cope with fixed perceived effort exercise like reappraisal may themselves be effortful to activate (Gross, 2013, 2015). However, there is also data which insinuates that learning effects of cognitive strategies may reduce the effort requirements for implementing cognitive strategies (Cos, 2017; Gross, 2015; Siddle, 1991). Consequently, self-regulation via cognitive strategies becomes a useful tool for performance gains on others who are untrained. Nonetheless, this area of research is totally unexplored. No extant data exists to suggest whether a learning effect takes place over time when engaging in effortful exercise and using cognitive strategies to help regulate the perception of effort. Subsequently, no data exists to also suggest whether over time the ability to implement these cognitive strategies becomes effortless and automatic. Thus, a large range of studies that are longitudinal in nature could be possible in this area.

After discussing reappraisal and learning effects, discussions turned towards a theoretical narration about how self-talk may impact the perception of effort to allow individuals to continue a given intensity of exercise at a fixed perceived effort. Briefly, Figure 2 presented an alternative hypothesis of the psychobiological model to explain how self-talk may enhance potential motivation to instigate changes to the actual effort (resources) applied to a task for the same rating of perceived effort (Barwood et al., 2008, 2015). Whilst this thesis did not conduct any form of test to directly test this hypothesis, regardless, it is interesting to consider that future research may wish to explore the psychobiological model in more depth and continue to test its central tenets. In doing so, more light may be shed on the deeper explanations of how effort and motivation interact, resulting in different ratings of perceived effort as well as changes in task-directed behaviour.

Finally, discussions progressed onto the role of pain on perceived and actual effort and how Study 3 provided a neat illustration of how a context-specific intervention could influence the regulation of perceived effort. In this study, it appears that when perceptions of pain are higher (hypertonic condition), and individual lowers their power output and potentially does so at a faster rate compared to instances where pain perceptions are lower (isotonic condition). The condition and condition × time interactions that were observed in Study 3 are supportive of this interpretation. Though pain may cause changes to behaviour due to direct afferent feedback of biochemical changes in the periphery (Amann et al., 2022), prior research by Graven-Nielsen et al. (2002) indicates that hypertonic saline causes decrements to exercise performance via central mechanisms. Moreover, the discussion within Chapter 6 supposed that the pain ratings and power output data indicate that pain does affect the perception of effort and associated outputs but only when it is *experienced*. Alternatively, pain does not seem to demonstrate any *residual* effects which impact exercise behaviour at a later stage of a task when elevated muscle pain has dissipated. To add, ΔHHb was measured as a possible proxy of cognitive self-regulation by indexing activation of cerebral regions associated with executive control of behaviour. Study 3 identified that changes in ΔHHb were greater from a resting baseline in the hypertonic versus isotonic condition. The discussion has related numerous data from prior studies that supports the negative impact pain has on the neurophysiological and psychological state of an individual during exercise tasks (e.g., Chowdhury et al., 2022; Rainville et al., 1997; Sanderson et al., 2021). Understanding relative impacts of neurophysiological changes (e.g., changes in muscle fibre recruitment, corticospinal signal conductance), psychological (e.g., reduced affective valence) is not entirely possible with the data from this thesis.

However, it was also theorised that pain can sometimes have a positive effect on effort perceptions (i.e., cause reductions). This theory was based on previous findings which evidence that effortful exercise can reduce perceptions of pain (Koltyn, 2000, 2002), therefore, the flipside of this may also be true in the presence of lower pain intensity (Brick et al., 2014; Van

Damme et al., 2010). Specifically, the author posed a *critical intensity hypothesis* of pain whereby intensities of pain below this *critical intensity* could elicit attentional shifts and enhance motivational aspects of affective valence (Buhle & Wager, 2010; Legrain et al., 2009; Valet et al., 2004; Van Damme et al., 2008, 2010; Verhoeven et al., 2009). Alternatively, intensities of pain at or above this *critical intensity* would elicit overbearing inhibitive effect to corticospinal transmission of central motor command transmission and negative hedonic aspects of affective valence. Consequently, pain perceptions below this *critical intensity* could elicit reductions in perceived effort for a given exercise output and therefore improve exercise performance. In contrast, pain perceptions at or below this *critical intensity* would exacerbate perceptions of effort for a given exercise intensity and therefore inhibit exercise performance.

As such, no data exists to test the potentially positive effects of lower intensity pain on effort during any form of task. One feasible way to empirically test this idea is through quantitative sensory testing. In which, random pressures or temperatures that elicit pain perceptions can be applied to regions of the body. For instance, applications of temperatures above 40-43°C could elicit different ratings of pain intensity (Mense, 1993). Using the ratings of pain from a prior familiarisation session, random temperatures which correlate to specific pain ratings could be applied during a series of subsequent fixed perceived effort task. Based on the outputs (e.g., forces, torque, power/velocity), an intensity-output response could be identified between pain and perceived effort. Thus, providing an empirical testing procedure to test this *critical intensity hypothesis*. Alongside which, it would also be useful to incorporate measures of motivation and affect to understand the impact pain perceptions have on aspects of effort-based decision-making.

Overall, several lines of future research have been provided in response to the shortcomings of this thesis project. Whilst there are shortcomings to this present work, it has stimulated a breadth of studies that could span numerous domains of research (physiology, psychology, kinesiology, neuroscience). Furthermore, it is also exciting to consider the wide range of applications this type of future work could pose. For example, a more in depth understanding of how self-regulation of perceived effort occurs could be applied across performance areas as well as physical activity such as exercise participation and adherence programmes. Likewise, other suggestion like a more in-depth look at the pain intensity-output response could apply to clinical populations such as chronic pain. In particular, it could be better understood what the effort constraints are based on intensities of pain. Therefore, physical activity interventions could be tailored to not elicit inhibitive intensities of pain to help foster engagement and adherence to exercise programmes.

Chapter 8 - CONCLUSION

In three separate studies, this thesis conducted a progressive investigation into the reliability of a novel fixed perceived effort cycling task (Study 1). This study demonstrated that a novel fixed perceived effort trial that corresponded perceived effort ratings to a known physiological threshold was reliably produced over numerous bouts and elicited consistent psychophysiological responses. Successively, Study 1, and a following study (Study 2, Part A) also probed the psychophysiological responses associated with two intensities of fixed perceived effort. During these studies it appeared that physical outputs at a set perceived effort intensity would decrease over time to maintain the same perception of effort. Meanwhile, certain psychophysiological markers showed characteristic increases (e.g., heart rate) or decreases (e.g., affective valence) as the fixed perceived effort exercise progressed.

It was also of interest how individual's decision-making guided self-regulatory activities during fixed perceived effort exercise. In which, Study 2 utilised a think aloud protocol to understand the behavioural and cognitive self-regulatory strategies that were used by participants at different fixed perceived effort intensities (Part A) as well as any differences in self-regulation between experienced and inexperienced cyclists (Part B). Within Part A, it was found that there was a greater change in power output during the higher intensity fixed perceived effort cycle, signifying a greater amount of behavioural self-regulation. Furthermore, the activation of and attention towards self-regulatory strategies was also greater in the higher intensity fixed perceived effort cycle. When assessing differences between experience levels of participants, there were no significant differences in power output or major secondary themes of the think aloud protocol suggesting participants of any experience level may self-regulate similarly during fixed perceived effort exercise. However, there were a few significant differences in the primary themes of the think-aloud data between experience groups. Namely, experienced participants seem to focus more on certain internal states such as psychological state. In addition, experienced cyclists discussed using reappraisal and imagery strategies more often than inexperienced counterparts.

Finally, this thesis then explored any changes in self-regulation of perceived effort after an intervention of a common sensation present during endurance exercise, muscle pain. In addition, this study also incorporated the use of fNIRS to assess the activation of cognitive resources (e.g., oxy- and deoxyhaemoglobin) for cognitive self-regulation at the prefrontal cortex. It was found that the presence of elevated muscle pain due to a hypertonic injection cause a significantly lower power output than an isotonic placebo-control condition. In addition, fNIRS data showed a greater change in deoxyhaemoglobin between condition suggesting a heightened activation of cerebral centres involved with executive control and self-regulatory strategies to cope with elevated muscle pain during a fixed perceived effort task.

Overall, this thesis found a novel fixed perceived effort exercise to be reliable. Using this task paradigm, subsequent studies suggest that specific intensities of perceived effort exhibit different changes in power output and psychophysiological responses across a 30-minute exercise bout. Subsequently, data concerning the self-regulation of perceived effort shows that participants employed a mixture of behavioural (i.e., changing power output) and cognitive (i.e., implementing reappraisal and/or self-talk) strategies to ensure perceived effort stayed constant throughout the task. Potentially, experienced individuals may be inclined to use mental resources demanding self-regulatory strategies like reappraisal earlier to regulate perceived effort than inexperienced counterparts. Furthermore, there was a difference in self-regulatory strategies between conditions which involved elevated muscle pain (hypertonic injection) or a no elevated muscle pain (isotonic injection). Therefore, the self-regulation of perceived effort is likely context dependent, and influenced by which psychophysiological states are most prominent (e.g., pain). Moreover, there are also likely to be some individual preferences towards how perceived effort is self-regulated according to aberrant effort-based decision-making processes.

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Chapter 10 – APPENDICES

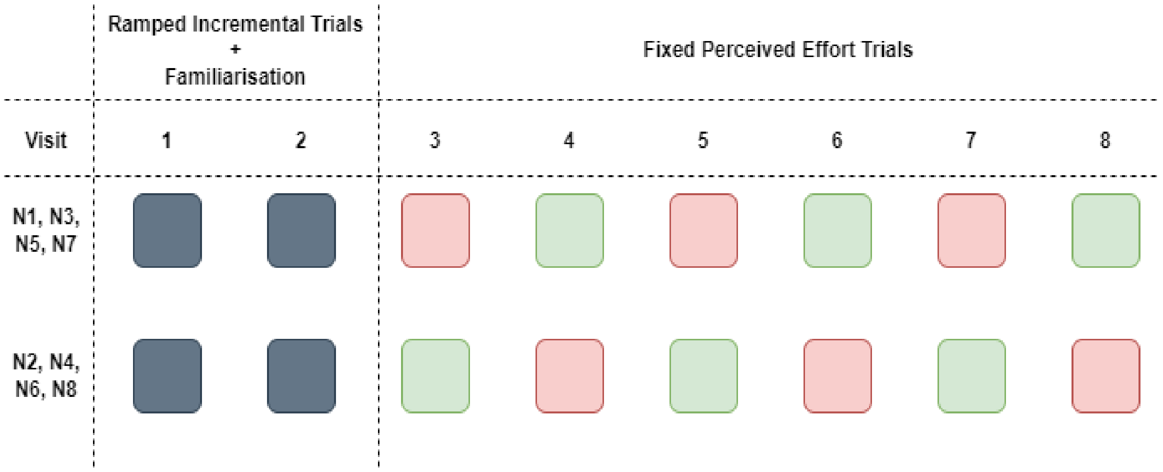

Figure 26. Appendix 1. Randomisation orders of Study 1 protocols for participants with inbuilt legend. N = participant. Grey blocks indicate ramped incremental trials and familiarisation visits. Red blocks indicate $RPE_{+15\%GET}$ fixed perceived effort visits. Green blocks indicate RPE_{GET} fixed perceived effort visits. Note - This study was truncated by Covid-19 pandemic start as the study commenced in January 2020.

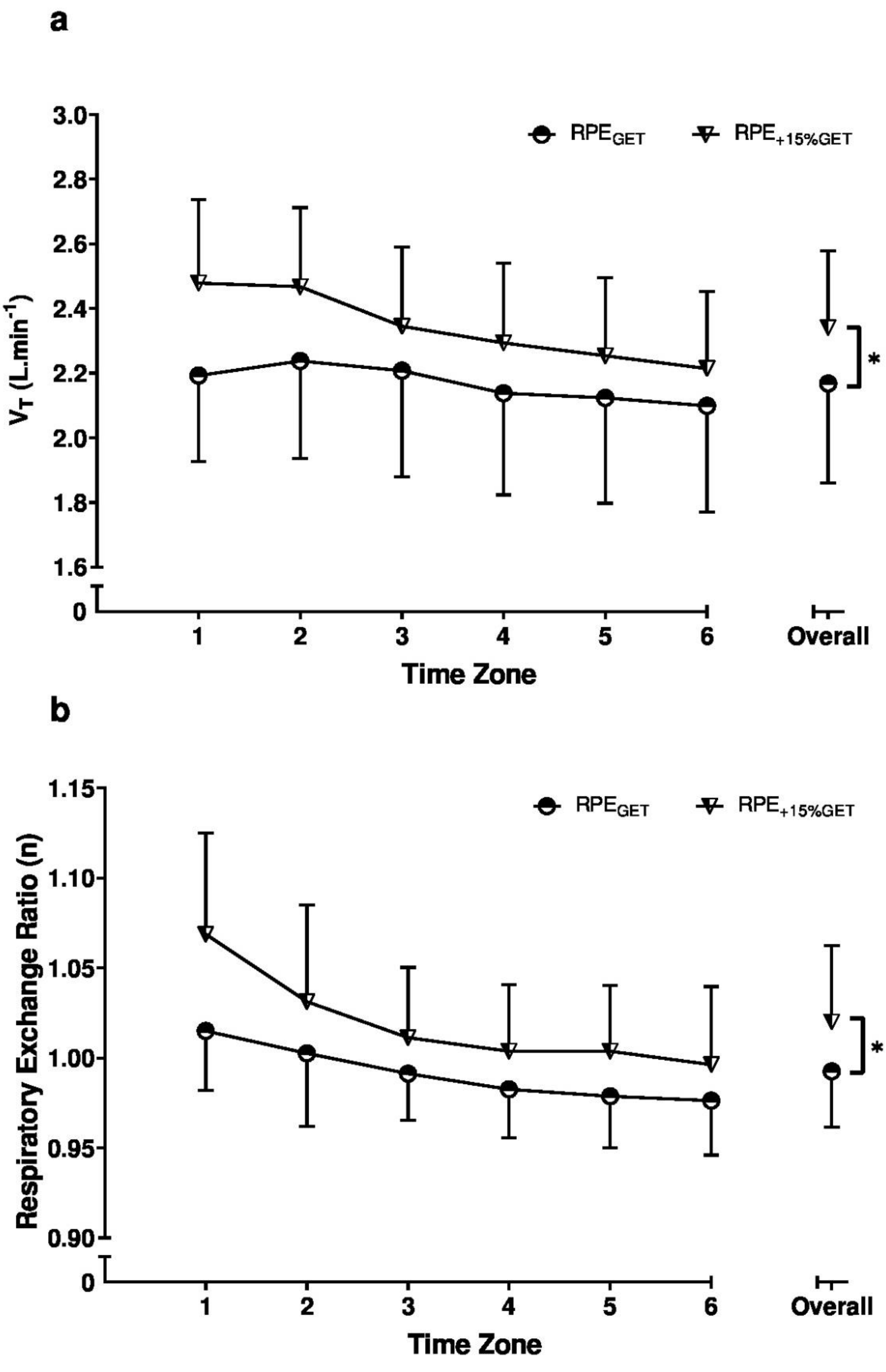

Figure 27. Appendix 2. Mean group (a) tidal volume ($\dot{V}_T$), (b) respiratory exchange ratio responses during fixed perceived effort trials in Study 1. Significant condition (∗), time (§), and condition × time (†) effects illustrated.

University of Kent

Participant Information Sheet

Think Aloud Protocols, Instructions & Practice

Introduction and Background

In recent years, a strategy called 'Think Aloud' has been employed whereby athletes are asked to vocalise their thoughts and feelings during an athletic event. In doing so, this gives researchers an idea of an athlete's cognitions and how these may be impacting performance.

Practicing Think Aloud

Below are a series of instructions/tasks to help you practice think aloud in the time leading up to your first data collection session.

1. Complete the following tasks at first on their own and then try to practice these whilst doing another activity such as unpacking your shopping, walking to the bus stop, on a leisurely cycle or when at the gym:

(1a) Math Problem

I would like you to please think aloud as you multiply 19 times 6 in your head.

(1b) Anagram

Now I would like you to please solve an anagram. It is your task to find an English word that consists of all the presented letters. For example, if the scrambled letters are KORO, you may see that these letters spell ROOK.

Please think-aloud while you solve the following anagrams:

<TAAD> <NPHEPA> <YLICCNG>

You can get a friend or relative to create other anagrams to help you practice.

(1c) Naming/free association task

Now I would like you to think aloud as you name 20 different animals. Simply verbalize what passes through your mind as you name them.

2. Finally, please take time to practice the think aloud protocol that will be used in this study. To prepare, the researcher will be reciting the following sentences *verbatim* during this study's data collection:

"Please verbalise how you are feeling throughout the cycling trial. You do not need to try to explain your feelings and you should speak as often as you feel comfortable in doing so".

It is recommended that you practice all these tasks before visiting the laboratory. We recommend you practicing the tasks alone and progress by doing think aloud alongside others. If you have any concerns, please do not hesitate to contact the lead researcher.

Figure 28. Appendix 3. Think aloud practice sheet provided to participants as part of the familiarisation and guidelines to ensure quality data disclosure in experimental visits.

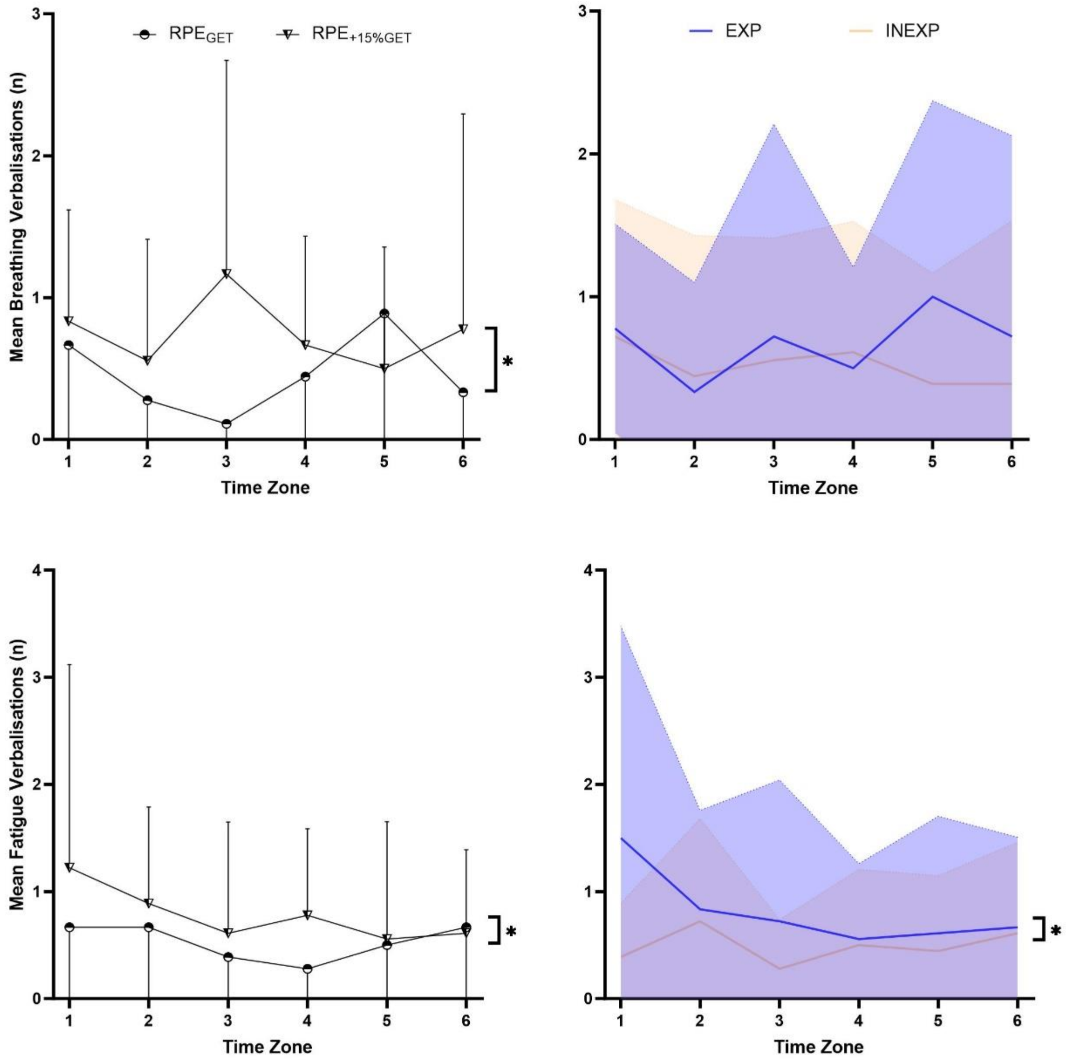

Figure 29. Appendix 4. Mean internal sensory monitoring of (a) breathing and (b) fatigue responses for fixed perceived effort trials during Study 2. Significant condition (✱), time (§), and condition × time (†) effects illustrated.

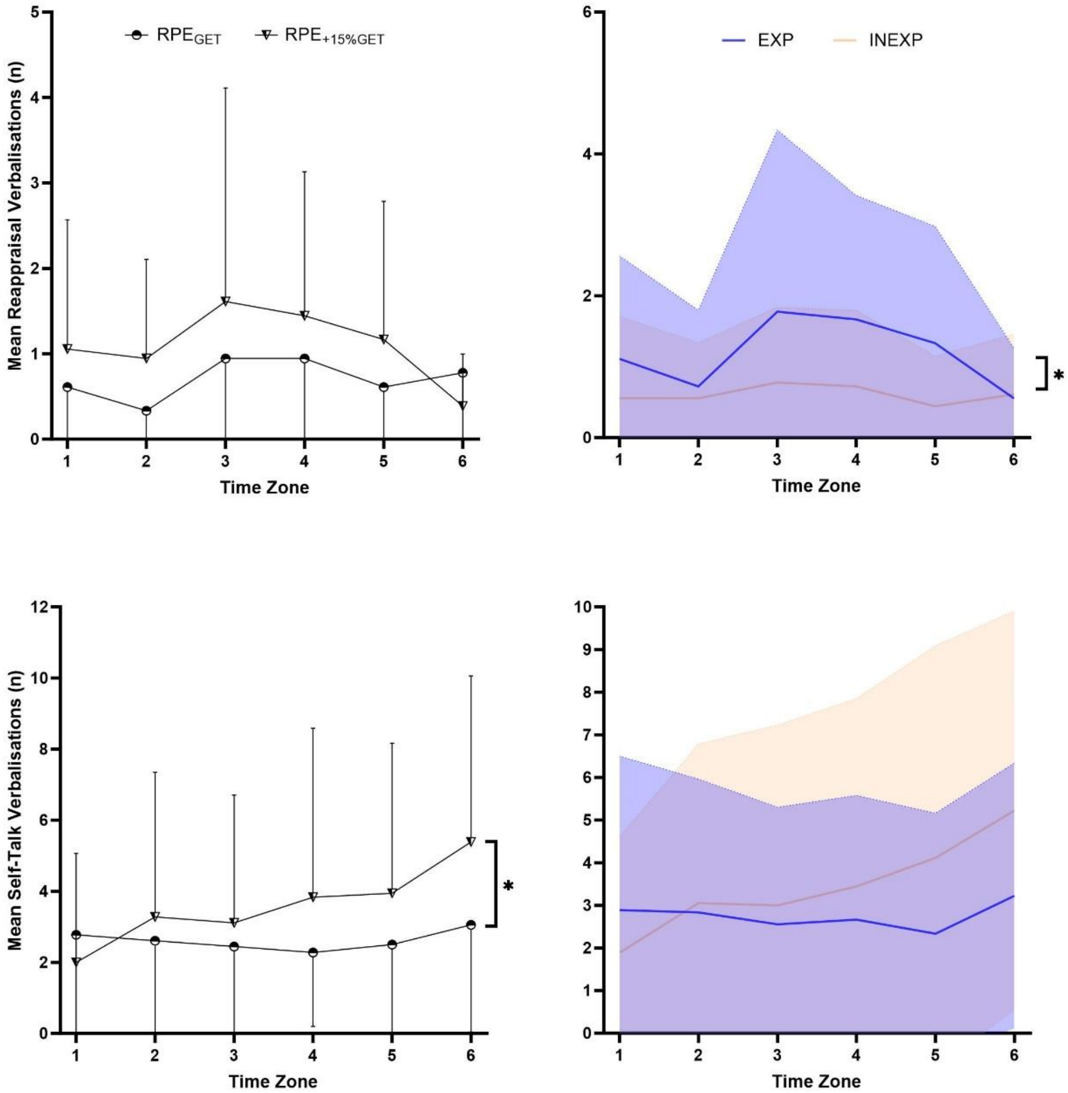

Figure 30. Appendix 5. Mean group responses for primary themes of active self-regulation including (a) reappraisal, (b) self-talk during fixed perceived effort trials in Study 2. Significant condition (∗), time (§), and condition × time (†) effects illustrated.

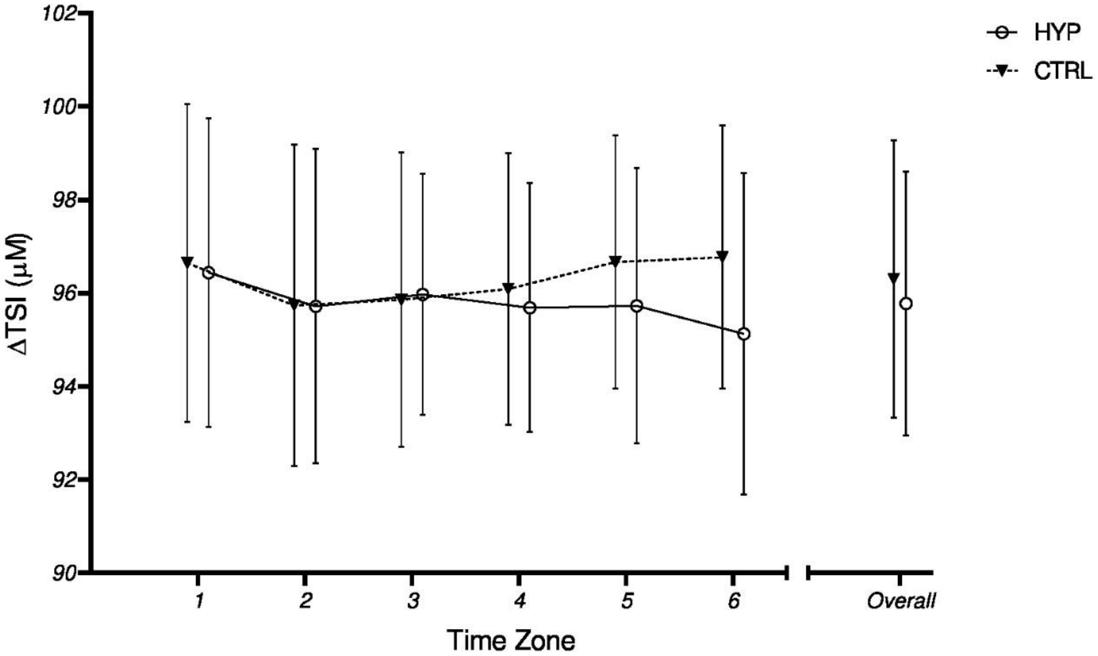

Figure 31. Appendix 6. Mean group responses for changes in tissue saturation index (ΔTSI) during the fixed perceived effort trials in Study 4. Significant condition (✱), time (§), and condition × time (†) effects illustrated. HYP refers to the hypertonic (painful condition) whereas CTRL refers to the isotonic (non-painful condition).

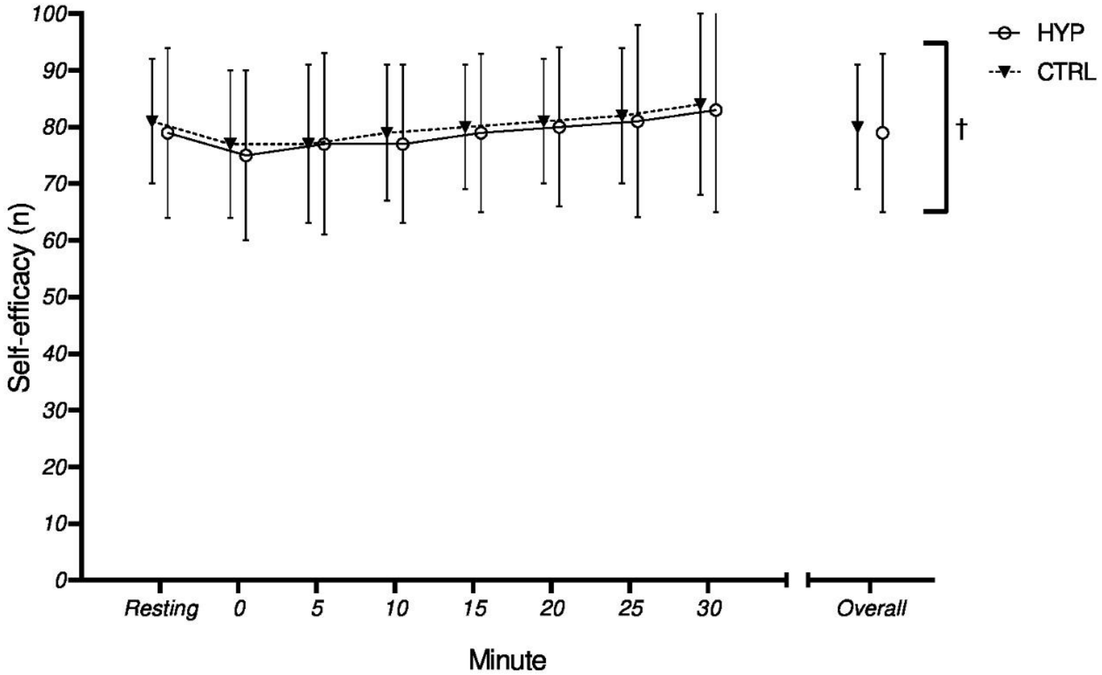

Figure 32. Appendix 7. Mean group self-efficacy responses during fixed perceived effort trials in Study 4. HYP – hypertonic, CTRL – isotonic. Significant condition (✱), time (§), and condition × time (†) effects illustrated.

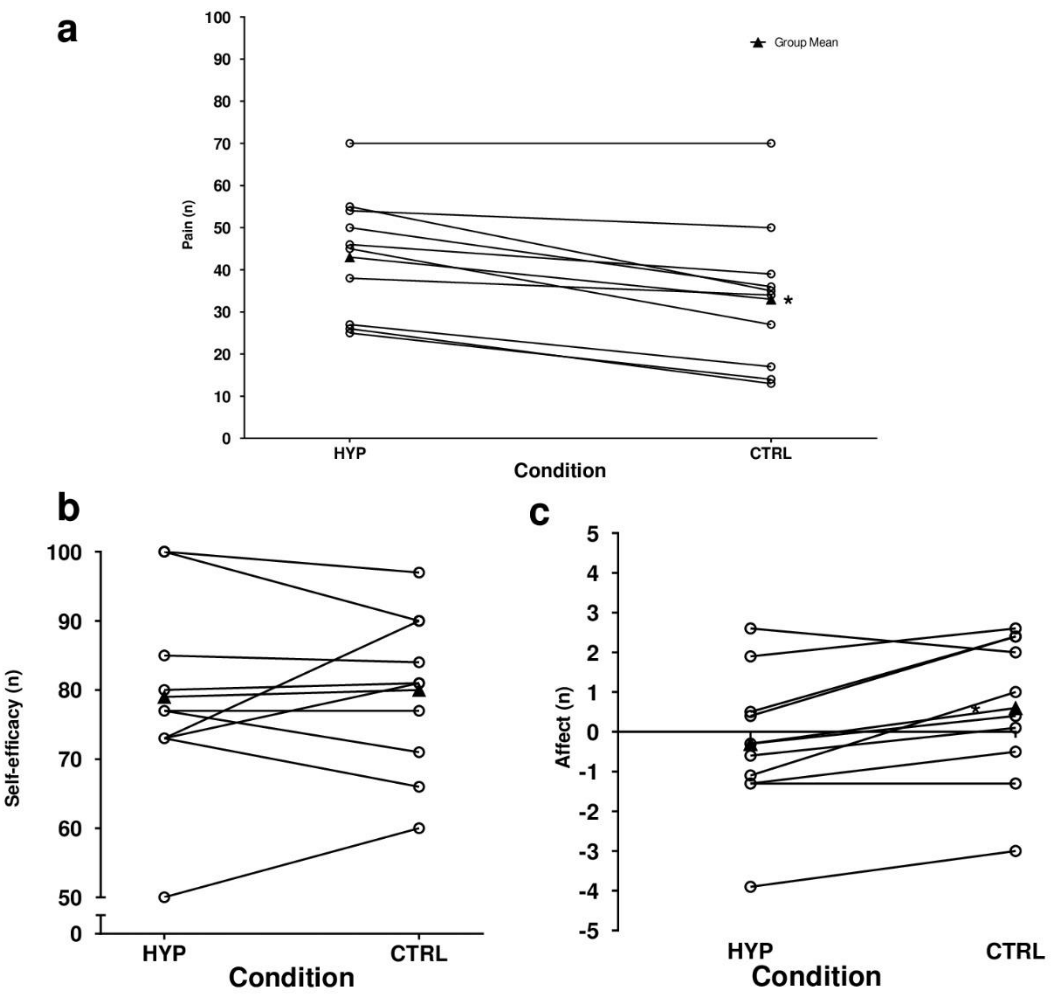

Figure 33. Appendix 8. Overall (30-minute average) individual (a) pain intensity, (b) self-efficacy, (c) affective valence changes and group mean response during fixed perceived effort trials in Study 4. HYP – hypertonic, CTRL – isotonic. Significant condition (∗) effects illustrated.

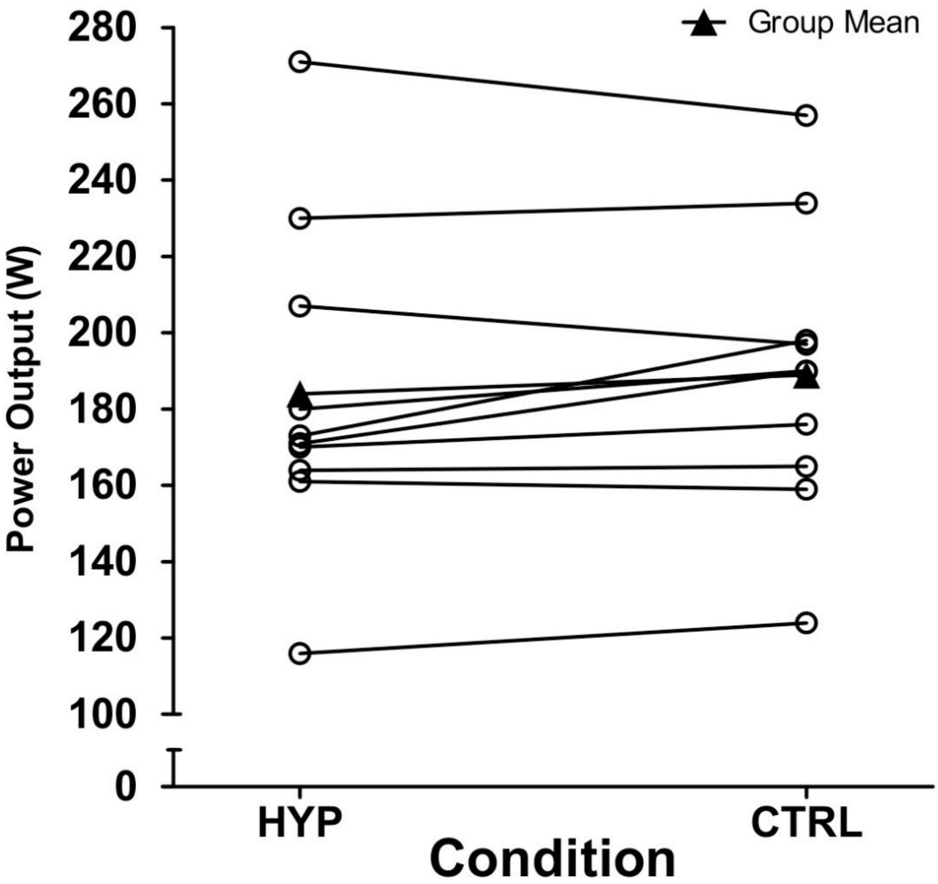

Figure 34. Appendix 9. Overall (30-minute average) individual power output changes and group mean response during fixed perceived effort trials in Study 4. HYP – hypertonic, CTRL – isotonic. Significant condition (∗) effects illustrated.

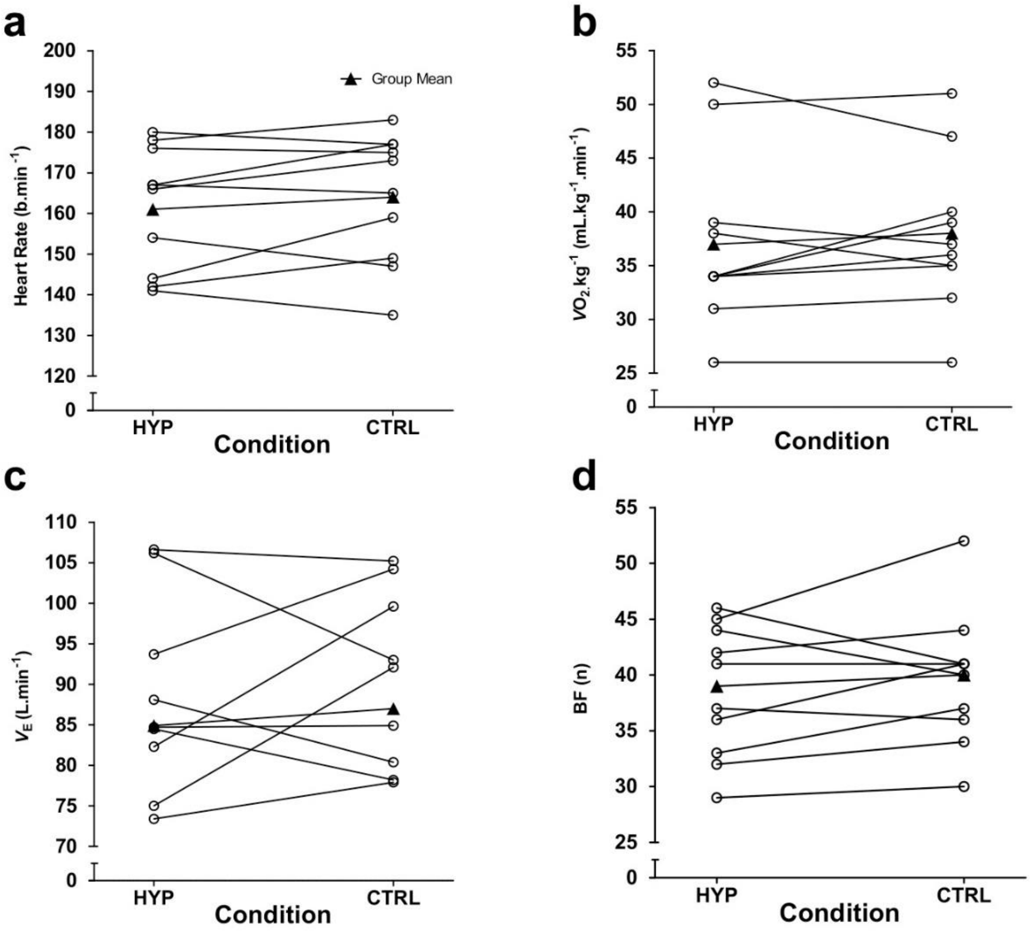

Figure 35. Appendix 10. Overall (30-minute average) individual (a) heart rate, (b) relative oxygen uptake ($\dot{V}O_2.kg^{-1}$), (c) minute ventilation ($\dot{V}_E$), (d) breathing frequency (BF) changes and group mean response during fixed effort trials in Study 4. HYP – hypertonic, CTRL – isotonic. Significant condition (∗) effects illustrated.

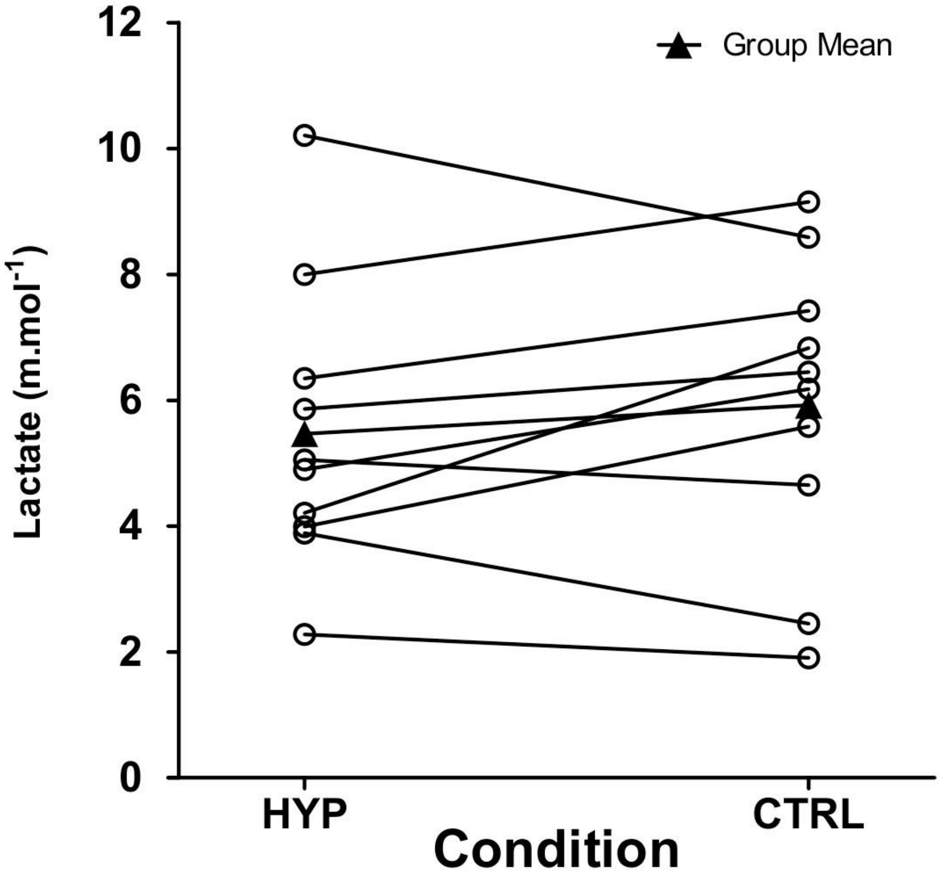

Figure 36. Appendix 11. Overall (30-minute average) individual blood lactate changes and group mean response during fixed perceived effort trials in Study 4. HYP – hypertonic, CTRL – isotonic. Significant condition (∗) effects illustrated.

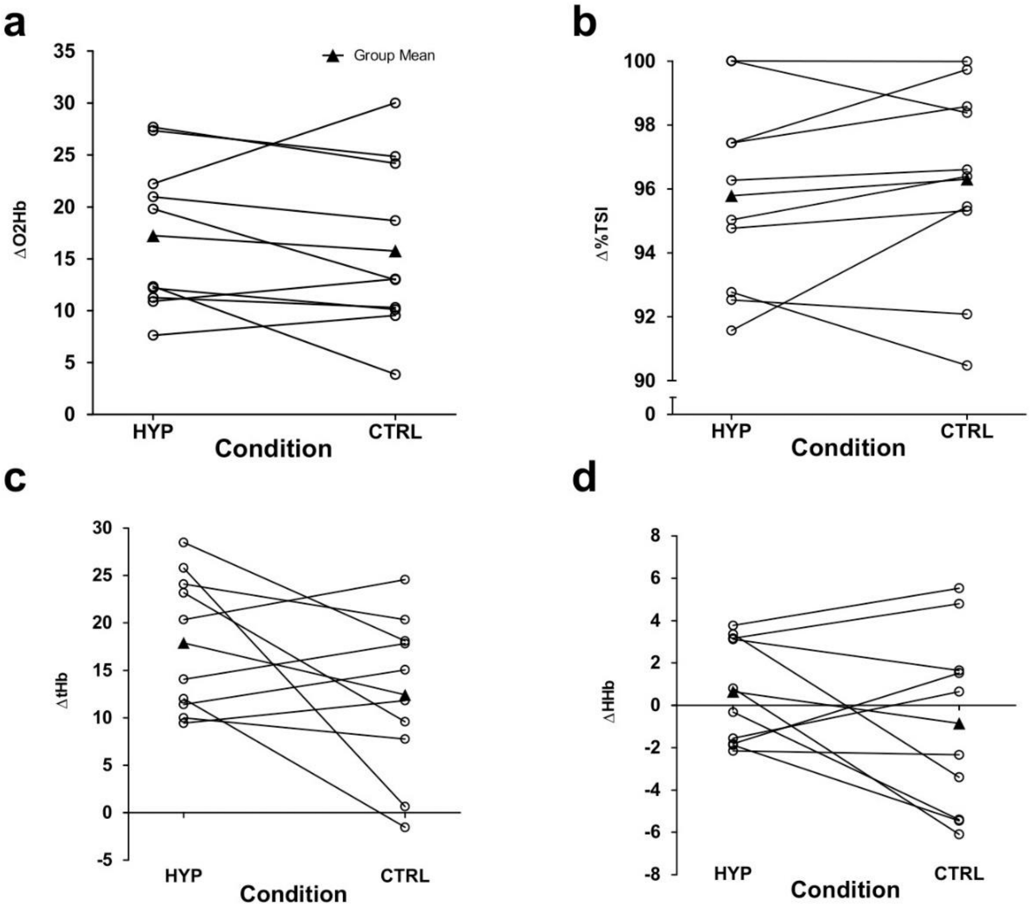

Figure 37. Appendix 12. Overall (30-minute average) individual (a) oxyhaemoglobin (ΔO_2Hb), (b) tissue saturation index (ΔTSI), (c) total haemoglobin (ΔtHb), (d) deoxyhaemoglobin (ΔHHb) changes and group mean response during fixed perceived effort trials in Study 4. HYP – hypertonic, CTRL – isotonic. Significant condition (∗) effects illustrated.

PERMISSIONS