Factors affecting paced exercise: how is pacing strategy influenced?

By

Andrew W. Hibbert

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Supervisor: Dr Aaron Petersen

Co-supervisor: Professor Remco C. J. Polman

Co-supervisor: Professor François Billaut

Co-supervisor: Dr Matthew C. Varley

College of Sport and Exercise Science

Institute for Health and Sport

Victoria University, Melbourne, Australia

ABSTRACT

In recent years exercise pacing research has identified numerous factors that can influence exercise intensity and improve overall performance. However, the list of factors that can influence pacing is far from comprehensive or extensively researched. Subsequently, this thesis aimed to investigate pacing factors which have not yet been empirically or functionally tested. Specifically, the following aspects were identified for investigation; the role of exercise experience, exercise-induced pain, and athlete motivation during competition. These factors were chosen for both the crucial role they play within theoretical pacing models and for the way they influence different aspects of exercise pacing (i.e. variables that are internal and external to the athlete during exercise, as well as prior to exercise). By selecting different factors, this ensured a holistic approach was taken to investigating the theoretical pacing literature.

The first factor investigated was an athlete's prior experience of the exercise, which is vital to anticipatory regulation of the task at hand and consequently, the development of a pacing strategy. Secondly, exercise-induced pain was chosen, as this a factor that is internal to the athlete during exercise. This sensation is key to the models of pacing and plays a significant role in exercise regulation. However, transcutaneous electrical nerve stimulation has not yet been fully tested as a method to reduce exercise-induced pain and how this can impact performance. Lastly, competition is an external factor during exercise, which has been known to influence pacing and performance for many years. However, the physical presence of competitors in ecologically valid circumstances, as well as interplay of social and physiological factors have not been rigorously investigated.

Study one. Exercise performance is reproducible in experienced athletes; however, less trained participants exhibit greater variability in performance and pacing.

To reduce variability, it is common practice to complete a familiarization prior to experimental testing. However, there are no clear guidelines for familiarizing novice participants to a cycling time-trial (TT), and research findings from novice populations may still be influenced by learning effects. Accordingly, the aims of this study were to establish the variability between TTs after administering differing familiarization protocols (duration or type) and to establish the number of familiarization trials required to limit variability over multiple trials.

Thirty recreationally active participants, with no prior experience of a TT, performed a 20-km cycling TT on five separate occasions, after completing either a full (FF, 20-km TT, n=10), a half (HF, 10-km TT, n=10) or an equipment familiarization (EF, 5-min cycling, n=10).

Variability of TT duration across five TTs was the lowest after completing FF ($P = 0.69$, $\eta p2 = 0.05$) compared to HF ($P = 0.08$, $\eta p2 = 0.26$) and EF ($P = 0.07$, $\eta p2 = 0.21$). In the FF group after TT2, the effect size for changes in TT duration was small ($d < 0.49$). There were large differences between later TTs in HF ($d = 1.02$, TT3-TT4) and EF ($d = 1.12$, TT4-TT5). The variability in mean power output profiles between trials was lowest within FF, with a similar pacing profile reproduced between TT3-TT5.

Familiarization of the exercise protocol influenced the reproducibility of pacing and performance over multiple, maximal TTs, with best results obtained after a full experience of the exercise compared to HF and EF. The difference of TT1 to later TTs indicates that one familiarization is not adequate in reducing the variability of performance for novice participants. After the FF and an additional TT, performance changes between TTs were small. However, a reproducible pacing profile was not developed until after the FF and two additional TTs. These findings indicate that a

minimum of three full familiarizations are necessary for novice participants to limit systematic error before experimental testing.

Study two. Afferent information from exercising muscle contributes to the sensation of exercise-induced muscle pain. Transcutaneous electrical nerve stimulation (TENS) delivers low–voltage electrical currents to the skin, inhibiting nociceptive afferent information. The use of TENS in reducing perceptions of exercise-induced pain has not yet been fully explored. This study aimed to investigate the effect of TENS on exercise-induced muscle pain, pacing strategy and performance during a 5-km cycling time trial (TT).

On three separate occasions, in a single-blind, randomized and crossover design, 13 recreationally active participants underwent a 30-min TENS protocol, before performing a 5-km cycling TT. TENS was applied to the quadriceps prior to exercise under the following conditions; control (CONT), placebo with sham TENS application (PLAC), and an experimental condition with TENS application (TENS). Quadriceps fatigue was assessed with magnetic femoral nerve stimulation assessing changes in potentiated quadriceps twitch force at baseline, pre and post exercise. Subjective scores of exertion, affect, and pain were taken every 1-km.

During TTs, application of TENS did not influence pain perceptions ($P = 0.68$, $\eta p2 = 0.03$). There was no significant change in mean power ($P = 0.16$, $\eta p2 = 0.16$) or TT duration ($P = 0.17$, $\eta p2 = 0.14$), although effect sizes were large for these two variables. Changes in power output were not significant but showed moderate effect sizes at 500-m ($\eta p2 = 0.10$) and 750-m ($\eta p2 = 0.10$). Muscle recruitment as inferred by electromyography data was not significant but showed large effect sizes at 250-m ($\eta p2 = 0.16$), 500-m ($\eta p2 = 0.15$) and 750-m ($\eta p2 = 0.14$). This indicates a possible effect for TENS influencing performance up to 1-km.

Yet, overall, these findings do not support the use of TENS to improve 5-km TT performance.

Study three. The aim of this study was to investigate time-trial (TT) performance in the presence of one competitor and in a group with competitors of various abilities.

In a randomized order, 24 participants performed a 5-km cycling TT individually (IND), with one similarly matched participant (1v1), and in a group of four participants (GRP). For the GRP session, two pairs of matched participants from the 1v1 session were used. Pairs were selected so that TT duration was considered either inferior (INF) or superior (SUP) compared to the other pair of participants.

Overall, TT duration ($P = 0.86$, $\eta p2 < 0.01$) was not different between conditions, whilst heart rate (HR) was significantly greater in GRP compared to IND ($P < 0.01$, $\eta p2 = 0.16$). For INF, a large effect size for both mean power ($P = 0.07$, $\eta p2 = 0.15$) and HR ($P = 0.05$, $\eta p2 = 0.16$), indicates greatest effort in GRP. Pacing behaviour was affected by competition but similar in 1v1 and GRP for SUP, whilst large effect sizes indicate an increased power output in the initial 750-m for INF in GRP. Additionally, for INF, there was a significant correlation with ego orientation for an increase in TT duration between the GRP session and both the IND ($r = 0.43$, $P = 0.04$) and 1v1 ($r = 0.54$, $P = 0.01$) sessions. For INF participants, the intensity was increased when competing in GRP. Yet, the presence of the SUP competitors resulted in lesser performance improvements for ego oriented INF participants.

These findings demonstrate that consideration should be given to the ability of competitors in a group setting to provide adequate motivation.

Overall this thesis provides novel insight into pacing factors that have previously not been fully understood. This research is of importance as a greater understanding of how exercise is self-regulated is crucial to unlocking the potential for increased exercise

performance. The main results and conclusions of this thesis shed light on the highlighted pacing factors of experience, exercise-induced pain and competition, and how these can impact on performance during self-paced cycling time-trials. Accordingly, these findings provide information to benefit the development of sound experimental protocols as well as providing a mechanistic understanding of the development of exercise scenarios and interventions that can be beneficial to performance outcomes.

STUDENT DECLARATION

"I, Andrew W. Hibbert, declare that the PhD thesis entitled "Factors affecting paced exercise: How is pacing strategy influenced?" is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

Signature:  Date: 22 November 2018

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PUBLICATIONS AND PRESENTATIONS

This thesis is supported by the following publications and conference presentations:

Publications

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(Chapter 3. Study 1)

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(Chapter 5. Study 3)

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Polman, R.C.J. **Hibbert, A.W.**, Billaut, F., Varley, M.C. Role of competitors and motivational orientation on 5 km time trial performance and pacing strategy. Oral presentation. *European Congress of Sports Science (ECSS) Conference*. Dublin, Ireland, July 2018

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LIST OF ABBREVIATIONS

1v1	Time-trial with another participant
ANOVA	Analysis of variance
BASE	Baseline measurement
CAR	Central activation ratio
CGM	Central governor model
cm	Centimetre
CNS	Central nervous system
CONT	Control condition
CV	Coefficient of variation
EF	Equipment familiarisation protocol
EMG	Electromyography
ES	Effect size
FAM	Familiarisation
FF	Full familiarisation protocol
FS	Feeling scale
GRP	Time-trial with three other participants
HF	Half familiarisation protocol
HR	Heart rate
IND	Individual time-trial
INF	Inferior competitor
kg	Kilograms
km	Kilometres
m	Metres
min	Minutes
MVC	Maximal voluntary contraction
η_p^2	Partial eta squared
PLAC	Placebo condition
POST	Post-exercise measurement

PO	Power output
PPO	Peak power output
PPT	Pressure pain threshold
PRE	Prior to exercise measurement
$Q_{tw,pot}$	Potentiated quadriceps twitch
RMS	Root mean square
RMS_{sum}	Summed root mean square
RPE	Rate of perceived exertion
RPM	Revolutions per minute
s	Second
SD	Standard deviation
SUP	Superior competitor
TENS	Transcutaneous electrical nerve stimulation
TT	Time-trial
VO_2	Oxygen uptake
VO_{2peak}	Peak oxygen uptake
W	Watts
W/kg	Watts divided by kilograms
W/PPO	Watts divided by peak power

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CHAPTER 1. INTRODUCTION

In many endurance events, success is often defined as the ability to complete the required distance as quickly as possible. Consequently, the ability of the athlete to manage intensity and fatigue throughout the exercise is an essential factor in performance (Mauger, 2013). This regulation of intensity throughout exercise is termed 'pacing'. Pacing has recently been defined as "The goal directed distribution and management of effort across the duration of an exercise bout" (Edwards & Polman, 2012). Overall, the purpose of pacing is to manage levels of fatigue to maximise goal achievement but also to prevent the occurrence of bodily harm (Edwards & Polman, 2013). To appropriately pace an exercise, information related to the known demands of the exercise and associated metabolic consequences are considered. Decisions are then made regarding the best way to manage energy expenditure to minimise the possibility of premature fatigue (Edwards & Polman, 2013; Lambert, St Clair Gibson, & Noakes, 2005). While pacing relates to changes in intensity, during an exercise, an athlete will likely plan how they will approach the task; this deliberate planning is considered a pacing strategy (Abbiss & Laursen, 2008). Together, pacing and pacing strategies have received considerable attention in the scientific literature in recent years, as previously fatigue was only seen from a physiological perspective. However, it is now clear that pacing is influenced by both physiological and psychological factors (Edwards & Polman, 2013).

In fact, pacing can be altered by prior experience as well as by factors that may be internal (e.g., heat accumulation, pain and mental fatigue) or external (e.g., environment and competitors) to the athlete. These factors are considered together so that decisions can be made regarding the best way to manage energy (Edwards & Polman, 2012; Noakes, 2012). Previous studies have reported results regarding the many variables that influence pacing, including the benefit for improvement of performance (Noakes, 2012).

In fact, the investigation of variables has led to the development of theoretical pacing models, including the Teleoanticpation model (Ulmer, 1996), the Central Governor Model (Noakes, 2012), the Psychobiological model (Marcora, 2008) and the conscious awareness brain regulation model (Edwards & Polman, 2013). Yet, uncertainty on the magnitude and effect on pacing still exists surrounding several variables. For this thesis to investigate pacing in a holistic fashion, factors were identified for the way they influence different aspects of exercise pacing (i.e. variables that are internal and external to the athlete during exercise, as well as prior to exercise). Specifically, the factors chosen were the role of exercise experience, exercise-induced pain, and athlete motivation during competition.

Before a task, knowledge of task demands and prior experience are considered to set an appropriate initial pace. This importance of prior experience has led to an investigation into the development of an efficient pacing strategy (Foster et al., 2009). Providing evidence that pacing is a learnt skill, school children with advanced cognitive development are more skilled at pacing (Micklewright et al., 2012), while a successful pacing strategy is reliant on experience in the task (Micklewright, Papadopoulou, Swart, & Noakes, 2010). Although prior experience is recognised as important to pacing, it is yet to be established what the most efficient process is to develop and retain a pacing strategy. This is an important issue when studying exercise in experimental settings, as variability in pacing and performance should be minimised to find the actual effect of interventions. As in any subsequent bout the individual, environmental or motivational factors may differ, which will result in an adjustment of this strategy to hopefully replicate another successful performance.

During an exercise, afferent feedback and the actions of an opponent can lead to different regulation of pace. All exercise inherently involves a level of discomfort

associated with afferent information (i.e., exercise-induced pain) (Cook, O'Connor, Eubanks, Smith, & Lee, 1997; Mauger, 2013). The conscious awareness of afferent feedback will lead to the regulation of exercise. In effect, when pain perceptions are above what an athlete is willing to endure, exercise intensity will be down-regulated. However, it is possible to minimise the afferent information through pain relief (Amann, Proctor, Sebranek, Pegelow, & Dempsey, 2009; Mauger, Jones, & Williams, 2010a). The management and reduction of exercise-induced pain via non-invasive methods have been studied previously, with exercise training effective in reducing pain over subsequent cycling trials (Micalos, Marino, & Kay, 2004). Yet, the effect of non-invasive pain relief and the impact on pacing has not been extensively investigated. Specifically, the use of transcutaneous electrical nerve stimulation, which can reduce pain non-invasively (Johnson, Paley, Howe, & Sluka, 2015), has not been thoroughly investigated for its effect on exercise-induced pain and consequently how this may influence exercise pacing.

Also within an exercise bout, the impact of a competitor has been demonstrated to influence pacing decisions (Konings, Schoenmakers, Walker, & Hettinga, 2016). However, most studies have investigated the perception of a competitor, i.e. a virtual avatar and not the presence of a competitor. Additionally, aside from one study (Tomazini et al., 2015), the investigation of pacing and competition has only utilised one competitor, while in a real competitive environment, there is likely to be more than one competitor. With the presence of multiple competitors, the goal and motivational orientation are likely to be influenced by numerous inter athlete interactions compared to exercising with only one competitor (Ryan & Deci, 2017). It is, therefore, of merit to investigate pacing in a group environment where interpersonal interactions may influence pacing decisions.

To summarise, although a vast amount of literature has identified countless factors that can influence exercise intensity, this list is far from extensive. Additionally, many of

the potential factors have not been empirically tested, or the mechanism on how it might influence pacing and performance is unclear. Subsequently, this thesis will investigate how an experience in an exercise forms a reproducible pacing strategy. This information would then be used to familiarise participants before implementing a pain relief intervention that has not yet been investigated for exercise-induced pain. Also, this thesis will investigate the impact of real competition on motivation, goal orientations and performance.

CHAPTER 2. REVIEW OF LITERATURE

2.1 Defining pacing

Performance within exercise is critically defined by the way an individual distributes work output. This regulation of intensity to increase performance while managing fatigue has been termed pacing. Any exercise event is controlled by a conscious decision to initiate and cease the bout; therefore, inevitably all exercise has a beginning and an end (St Clair Gibson et al., 2006). Based on the management of exercise intensity and how the end of an exercise is determined, an exercise task can be either considered closed looped or open looped, with goal achievement differing significantly between these two classifications (Foster, Schrager, Snyder, & Thompson, 1994). Pacing occurs within exercise tasks that are considered closed looped. Examples of a closed loop exercise are distance based time-trials or competition-based events where the goal is to cover the required distance quicker than all other competitors. As closed looped tasks have a defined start and end to the exercise, precise management of intensity and fatigue occurs to maximise performance. On the other hand, open looped tasks generally have the intensity dictated by external factors, for example, exercising for as long as possible at a constant intensity. Given that intensity is dictated by external factors, open looped tasks do not allow for pacing. Accordingly, the focus of this thesis will be on tasks that are considered closed looped.

During exercise, several cues are processed to ensure goal achievement without exhausting the body's physiological systems. However, there is an almost infinite number of variables, which can affect a performer's path to achieve the desired outcome (Edwards & Polman, 2012; Noakes, 2012; Noakes, St Clair Gibson, & Lambert, 2005; Tucker & Noakes, 2009). Previously, it was assumed exercise was limited by peripheral physiological systems, without any contribution of central systems (Hill & Long, 1925).

Recently this hypothesis has been challenged with the proposition of alternative exercise regulation models that explain how the brain plays a role in determining exercise intensity (Edwards & Polman, 2013; Noakes, 2012; Pageaux, 2014).

2.2 Models to explain fatigue and pacing

Recently, composite theories have arisen to explain how exercise is managed, considering many processes and differing mechanisms (Edwards & Polman, 2013; Tucker, 2009). These include the 'teleoanticipation model' (Ulmer, 1996), 'central governor model' (Noakes, 2011; Noakes, Peltonen, & Rusko, 2001; Noakes & St Clair Gibson, 2004; Noakes et al., 2005), anticipatory model (Ansley, Robson, St Clair Gibson, & Noakes, 2004; Kay et al., 2001; Tucker, 2009; Tucker, Rauch, Harley, & Noakes, 2004), psychobiological model (Marcora, 2008; Pageaux, 2014), and the conscious awareness brain regulation model (Edwards & Polman, 2012, 2013). Fundamentally, all models suggest that exercise is regulated to manage fatigue within safe levels but also to achieve the goal of exercise. These models will be explained in the following sections.

2.2.1 Peripheral model of fatigue

Firstly, to understand how pacing has become a prominent topic in exercise science, it is important to determine how fatigue was perceived before the discovery of a central component to exercise. Before the influence of central regulation had been established, it was believed that fatigue in exercise originated solely from peripheral mechanisms. These beliefs arose from the observations that lactic acid would increase in skeletal muscle during fatigue, with the reduction of lactic acid restoring muscle function (Hill & Long, 1925). The primary component of this exercise model is that exhaustion during exercise was due to the limitation of the body's aerobic system. Effectively, once the body is no longer able to oxidate lactate, exercise requires termination (Hill & Long, 1925). In fact, as part of this understanding, a controller was proposed that regulated

oxygen delivery to the heart. It was considered that the controller prevented the development of myocardial ischemia during maximal exercise rather than reducing fatigue (Hill, Long, & Lupton, 1924). The downfall of this viewpoint is that any exercise will be conducted at a constant intensity and will cease at an absolute endpoint, and can only be restarted after a period of rest, in which the fatiguing aspects of exercise are reversed (St Clair Gibson & Noakes, 2004).

This simple notion of exercise fatigue was considered for many years, with much of the subsequent research explaining fatigue through the same cause and effect models. However, it is now known that the cause of fatigue is not only due to the regulation of oxygen delivery. Instead, the current findings of multiple pacing strategies, muscle activation properties and the presence of end spurts are all evidence for a central component to exercise regulation (St Clair Gibson & Noakes, 2004).

2.2.2 Teleoanticipation

The basis of the current understanding of the central regulation of exercise was first described in the investigation of "teleoanticipation" (Ulmer, 1996). It was found that the current simple feedback loop of motor control could not explain all the phenomena exhibited in maximal exercise (i.e., the regulation of intensity) (see Figure 2-1).

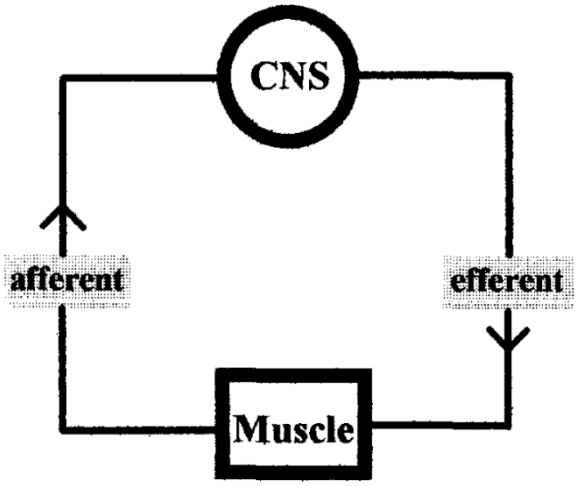

Figure 2-1: Principle of feedback control in the motor system (Ulmer, 1996).

Specifically, if athletes run too quickly, they will not finish because of early fatigue, but if they run too slowly, they will not reach their aim (Ulmer, 1996). Consequently, the limits of the regulation loop of feedback for biomechanical control was the initiation to first investigate the concept of extracellular regulation by psychophysiological feedback (Ulmer, 1996).

With the intention of explaining how individuals would limit work rate in the occasion of exercise being longer in duration or more demanding than expected, a new model for exercise intensity regulation was proposed (see Figure 2-2) (Ulmer, 1996). The proposed theory contended that afferent information on the current metabolic rate is transmitted together with the anticipation of the work required to complete the movement patterns. This idea stemmed from the situation where work rate would be limited even with an absence of afferent information, i.e. before exercise has started. As demonstrated by varying the exercise distance which resulted in pre-set intensities and rates of perceived exertion (RPE) (Faulkner, Parfitt, & Eston, 2008; Ulmer, 1996). Therefore, the knowledge of the exercise duration is a reference point to regulate intensity. Additionally, for the feedback, feedforward and anticipatory mechanisms to work effectively, prior experience of similar exercise is also considered. Knowledge of the endpoint and experience provide the information to optimise intensity prior to the exercise and compare current intensity against past successes and failures during exercise (Ulmer, 1996). Subsequently, pacing strategies are selected based on the length of the exercise (Abbiss & Laursen, 2008; Wittekind, Micklewright, & Beneke, 2011). Because of this initial observation, it was proposed that there must be a component of the body's feedback system that acts to access exercise information. Consequently, a hypothetical programmer was proposed to be located somewhere in the central nervous system (CNS), which acts as a black box to process information, which then distributes signals to alter the exercise

intensity and optimise performance (see Figure 2-2) (Ulmer, 1996). This model of control (see Figure 2-2) regulates performance with a controller that receives feedback on the levels of exertion from the exercising muscle and other body systems. Once this feedback is interpreted by the controller, afferent signals are sent back to the periphery so that intensity can be adjusted appropriately (Ulmer, 1996). However, this concept was never comprehensively tested by the authors.

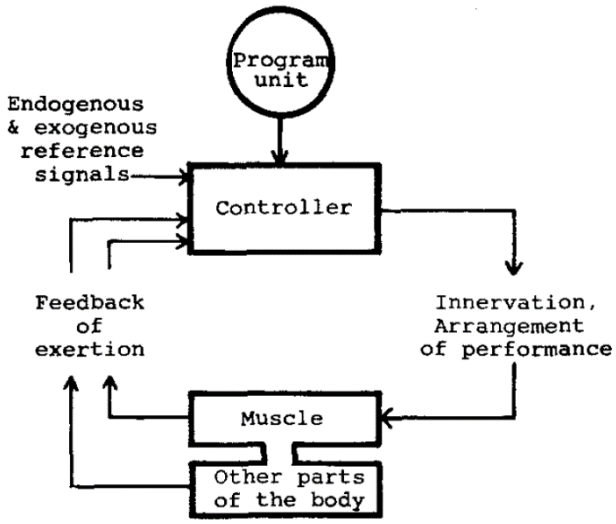

Figure 2-2: Proposed model of a control system for optimal adjustment of intensity during exercise (Ulmer, 1996).

2.2.3 Central Governor Model

Expanding on the concept of central programmer as described by Ulmer (1996), a new model, termed the Central Governor Model (CGM) (Figure 2-3) was proposed and is perhaps the first pacing model to describe the role of the brain in exercise (Lambert et al., 2005; Noakes, 2000; Noakes et al., 2001; Noakes & St Clair Gibson, 2004; Noakes et al., 2005; St Clair Gibson & Noakes, 2004). The CGM was developed from observations of suboptimal muscle recruitment (Noakes, 2004) and that changes in pace during exercise occur to maintain an exercise reserve (Swart et al., 2009). These observations

led to the proposal of the model that works with feed-forward control to initially determine the exercise intensity, while afferent feedback provides information within the exercise, so that muscle recruitment can be regulated to preserve homeostasis (Noakes & St Clair Gibson, 2004).

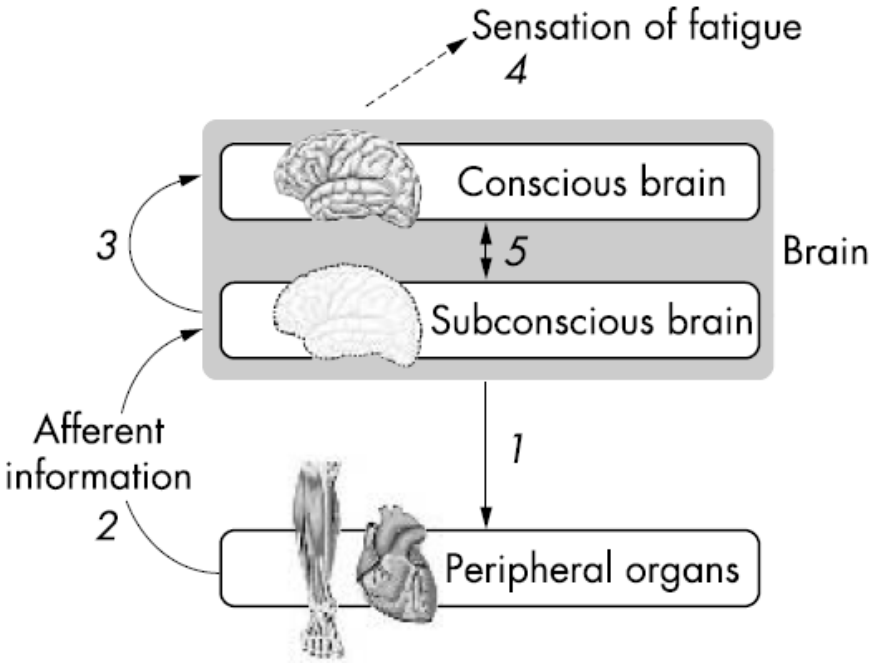

Figure 2-3: The central governor model. This model proposes that: 1. The subconscious brain sets the exercise intensity by determining the number of skeletal muscle motor units that are activated throughout the exercise. 2. The extent of skeletal muscle motor unit recruitment can then be influenced by sensory feedback from a variety of peripheral organs. 3. The subconscious brain informs the conscious brain of an increasing neural effort, perhaps related to an increased difficulty in maintaining homoeostasis at that exercise intensity 4. This is interpreted by the brain as the increased sensation of fatigue. 5. The sensation of fatigue may itself control further subconscious brain control processes (St Clair Gibson & Noakes, 2004).

Teleoanticipation is a crucial concept of the CGM, with pace determined by feed-forward controls prior to exercise (see Figure 2-3). The knowledge of the exercise endpoint plays a vital role in this process so that an appropriate pace can be selected and modified (Lambert et al., 2005; Noakes & St Clair Gibson, 2004). In addition to knowledge of the exercise endpoint, many internal cues are considered, including metabolic fuel reserves and oxygen saturation to set the initial pace (Noakes et al., 2005). These internal cues are then referenced against the relevant external cues such as the environmental conditions (Tucker et al., 2004), presence of competitors (Corbett,

Barwood, Ouzounoglou, Thelwell, & Dicks, 2012) and any previous experience in the task (Paterson & Marino, 2004) (see Figure 2-3). To effectively pace the task, the CGM will then interpret these cues in the subconscious and accordingly adjust the magnitude of the efferent neural drive.

During the task, afferent information is important in ensuring that the intensity is maintained to prevent severe threats to homeostasis or premature fatigue. Afferent information is transmitted from all body systems, but especially the exercising muscle via the metaboreceptors, nociceptors and thermoreceptors, back to the CGM to determine if the current intensity is appropriate (Lambert et al., 2005). If the intensity is too vigorous, changes in the afferent information are interpreted so that intensity is down-regulated. Conversely, if the magnitude of afferent information is not as high as expected, exercise intensity will be increased (Lambert et al., 2005; Rauch, Schonbachler, & Noakes, 2013). Crucial to this management of intensity, the conscious perception of afferent information is represented as a 'sensation' or 'emotion' of fatigue (Lambert et al., 2005; St Clair Gibson et al., 2003). Consequently, the way exercise is perceived is vital in the regulation of exercise.

The measure of the sensation of fatigue is known as the rate of perceived exertion (RPE) (Borg, 1982). Adjustment of intensity during exercise of varying lengths supports the notion that the RPE plays a significant role in the feedback loop for the optimal intensity (Tucker, 2009). The perceived exertion is used as a mediator between what an expected sensation of exercise will be and intensity across a task will subsequently be regulated to match this (Tucker, 2009). Additionally, it has been observed that RPE rises in a linear function in relation to the duration of exercise and will only reach the maximum value at the termination of exercise (Tucker, 2009). Because of this, it is suggested RPE is set in the initial stages or before exercise, with this finding leading to the development

of the anticipatory exercise regulation (Tucker, 2009). Therefore, a 'template RPE' is set in anticipation based on the expected duration of the bout and previous experience in similar bouts. Any discrepancy between the RPE template and the experienced RPE will result in a modification of intensity to restore an appropriate RPE trajectory (Joseph et al., 2008; Tucker, 2009; Tucker, Marle, Lambert, & Noakes, 2006). The effect of this regulation is that exercise intensity is set in anticipation of the task, so that the increase in RPE stays the same, even in different exercise conditions (Joseph et al., 2008; Tucker et al., 2006).

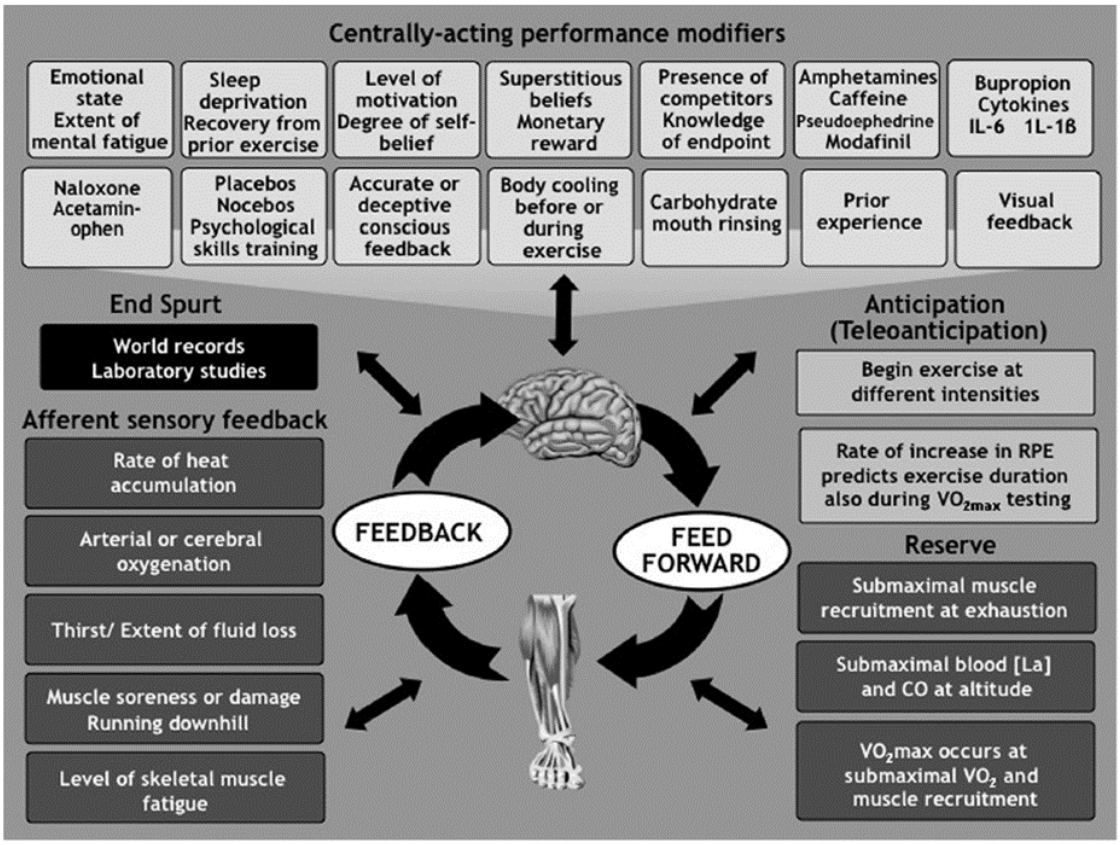

Figure 2-4: Factors that affect pacing and support the central governor model (Noakes, 2012).

After being proposed initially as a simple control mechanism (see Figure 2-3), the CGM has since evolved to encompass a multitude of exercise regulation scenarios (see Figure 2-4). However, although this model has been used to explain exercise phenomena that were previously unsolved, an oversight of this central regulatory model is that the

presence of a governor or a specific processing centre within the body is unlikely. Rather than a specific governor, it is considered that central regulation is more likely to be controlled by the brain (Edwards & Polman, 2013). Additionally, critics have noted that the original CGM (see Figure 2-3) paid no attention to the role of motivation and mental effort to influence exercise performance (Inzlicht & Marcora, 2016). This is important as motivation can influence performance and perceptions of effort (Blanchfield, Hardy, de Morree, Staiano, & Marcora, 2013). This oversight has been addressed in the evolution of the model (see Figure 2-4), but as the primary role of the central governor is to maintain homeostasis, the introduction of variables that may override this function, question the foundation of the model (Inzlicht & Marcora, 2016). In fact, by incorporating many factors into the CGM, the complexity of the model has been increased, which has consequently made the model unable to be tested and therefore unable to be falsified (Inzlicht & Marcora, 2016). Based on these limitations, the validity of the CGM has been questioned with some alternative models proposed which address mental constructs (Marcora, 2008) and attribute exercise regulation to a conscious process controlled by the brain (Edwards & Polman, 2013).

2.2.4 Psychobiological model

The psychobiological model proposed by Marcora (2008); see also Pageaux (2014), contends that regulation of intensity is a conscious process that is determined by five factors; perception of effort, potential motivation, knowledge of the distance/time to cover, knowledge of the distance/time remaining, and previous experience/memory of perception of effort during exercise of varying intensity and duration (Pageaux, 2014). This model has been based on the motivational intensity theory (Wright, 1996), with conscious regulation primarily determined by the participant's perception of effort in relation to their level of motivation. Therefore, exercise intensity will be regulated to the

maximum level of effort an individual is willing to exert. This level of effort may be affected by muscle and mental fatigue which will result in conscious downregulation of intensity to maintain the desired perception of effort (de Morree & Marcora, 2013; Pageaux, 2014). Conversely, the presence of external factors (e.g. competitors or spectators) may also increase the effort an athlete is willing to exert (Pageaux, 2014). Compared to the CGM, the psychobiological model attributes exercise regulation to a conscious process rather than a subconscious process, thus removing the need for a specific processing centre. Also differing from the CGM, this model proposed that perceived exertion is independent of afferent feedback but rather a consequence of an increase in central motor command which produces internal signals which are sent between the motor and sensory areas of the brain (de Morree, Klein, & Marcora, 2012; Marcora, 2009). However, it is this distinction of the model that has been criticised. The rate of increase of RPE has been shown to predict the duration of exercise, even under differing exercise conditions (Crewe, Tucker, & Noakes, 2008). Therefore, it is considered that afferent feedback must be accounted for so that termination does not occur prematurely (i.e. afferent information is essential for the sensing levels of fatigue that may threaten homeostasis) (Noakes & Tucker, 2008; Tucker et al., 2004). Consequently, by not accounting for the role of sensory information, the psychobiological model is not able to explain exercise regulation in all scenarios. However, regardless of the origin of perceptions of exertion, both the central governor and the psychobiological model consider this an important variable in the regulation of exercise intensity.

2.2.5 Conscious awareness brain regulation model

Similar to the other models outlined in this literature review, the conscious awareness brain regulation model proposes that exercise is regulated using the athlete's prior experience, knowledge of the exercise endpoint and afferent feedback (Edwards &

Polman, 2013). However, differing to the other models, this model is built on the theoretical basis of brain regulatory control and attributes the pacing to be a decision-making process (see Figure 2-5).

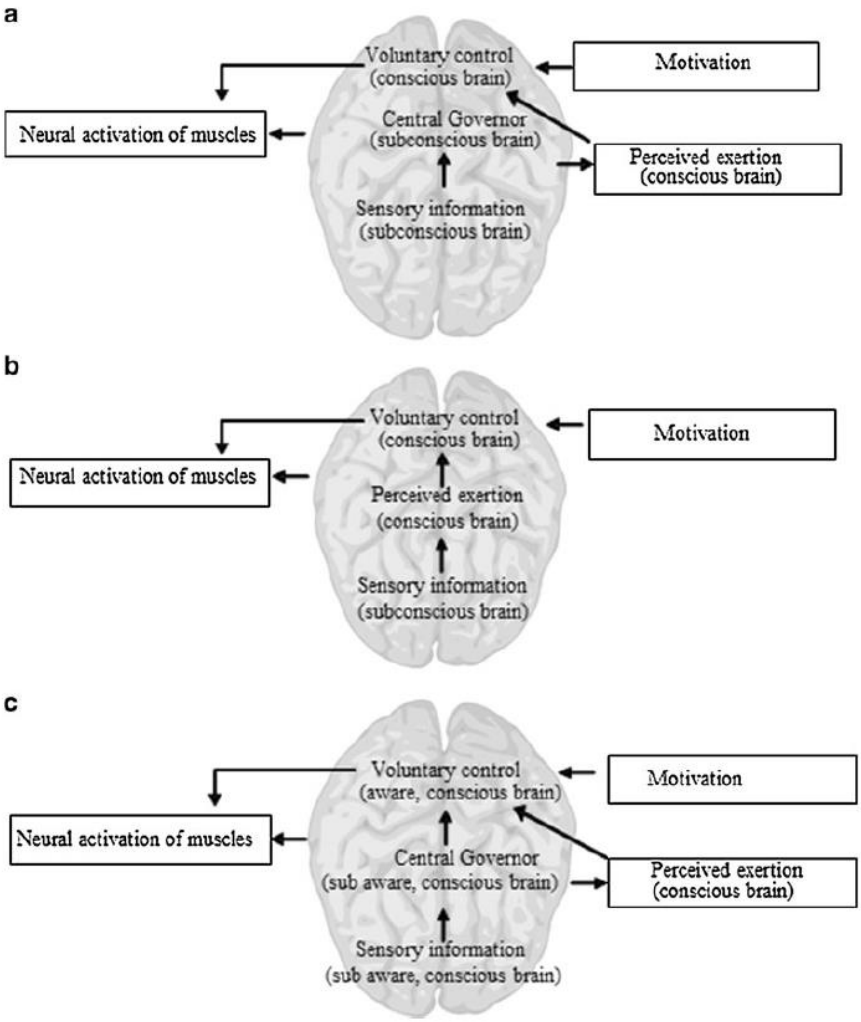

Figure 2-5: A comparison of brain regulation models of human movement: (a) central governor model; (b) psychobiological model; (c) conscious awareness brain regulation model (Edwards & Polman, 2013).

This model states that sensory information which does not threaten homeostasis is not transmitted to higher level neural processing centres (Edwards & Polman, 2013). Therefore, regulation of this low-level exercise is considered to occur in a sub-awareness state, albeit still maintained by the brain (see Figure 2-5), these tasks are regulated with a certain level of automaticity (i.e., based on prior experience or expectations of the exercise requirements) (Edwards & Polman, 2013). The individual only gains awareness,

requiring conscious regulations when task demands increase and consequently the magnitude of sensory information (see Figure 2-5) (Noakes, 2012; Swart, Lindsay, Lambert, Brown, & Noakes, 2012). For example, during high-intensity exercise metabolic disturbances are likely to be substantial, which in turn will increase afferent sensations that trigger conscious awareness to change behaviour (Edwards & Polman, 2013; Swart et al., 2012). The conscious attention proposed by the conscious awareness brain regulation model has since been extended to explain pacing as a decision-making process (Renfree, Martin, Micklewright, & St Clair Gibson, 2014). Decision making relates to the ability to select practical actions to achieve a specific task from several possibilities (Smits, Pepping, & Hettinga, 2014). More specific to pacing, individuals are required to make decisions to increase intensity to enhance performance, but also to manage intensity to limit physiological fatigue. This process transpires by determining an appropriate action (increase or decrease work-rate) based on the available information (i.e. the magnitude of perceived exertion and knowledge of the task) (Renfree et al., 2014). Ultimately, during exercise, the bombardment of negative sensory information causes discomfort which requires a conscious decision to manage intensity. Therefore, the willingness of the individual to tolerate discomfort is crucial to pacing (Smits et al., 2014).

2.3 Summary of pacing theory

This review highlighted three main pacing models, the central governor, psychobiological and conscious awareness brain regulation model, which all differently explain the processes of how exercise is regulated. The critical differences between these models are the distinction between how the decisions to manage intensity are made. The central governor primarily regulates intensity subconsciously, while the psychobiological model continually has the brain in a conscious state. The conscious awareness brain

regulation model contributes regulation to states of awareness rather than solely in a conscious or subconscious state. Although different, collectively these models acknowledge the importance of prior experience, sensory feedback (aside from the psychobiological model) and situational factors all being able to influence the way exercise is regulated. However, while there is a plethora of evidence to support each of these factors, experimental evidence is still missing on many pacing moderators and how they may impact performance.

2.4 Identification of pacing moderators for investigation

Within all models, exercise intensity is regulated by the sensations of exertion/effort with decisions always referenced against a template exertion that is developed from prior experience. However, based on the amount of experience, the previously acquired template of effort may not always be the most optimal, as this template of effort is likely developed over several exercise bouts. The theoretical discussion has investigated the role of experience against no experience (Tucker, 2009). However, it is not yet determined what role similar experience but not the same experience of exercise has on pacing decisions. Additionally, as pacing has been demonstrated to be quite impactful on overall performance, it is surprising that the development and reproducibility of pacing have not been extensively researched. Therefore, the first pacing moderator to be investigated in this thesis will be the role of experience in developing a reproducible pacing profile.

Afferent feedback has been demonstrated to be a key mediator in exercise regulation (Amann et al., 2009). As afferent feedback from exercising muscle is manifested into the sensation of exercise-induced pain, this feedback plays a significant role in conscious and subconscious regulation. In fact, in the absence of afferent feedback, exercise intensity has been increased (Amann et al., 2009). Consequently, research has focused on manipulating afferent feedback to access the proposed exercise reserve

capacity and ultimately enhance performance. Reducing afferent feedback and the sensation of pain has been investigated previously (Mauger et al., 2010a). One possible intervention that has not been tested is the non-invasive pain relief method of transcutaneous electrical nerve stimulation (TENS). Subsequently, we will investigate the use of TENS to reduce exercise-induced pain, and the impact on performance.

The final pacing moderator identified for investigation in this thesis is the influence of competition on performance. For many years the ability of competition to influence pacing and enhance performance has been known (Triplett, 1898). In recent years, there has been an increased focus on the influence of perception of competition, in part due to the development of technology and the ability to control this in laboratory settings. Consequently, several avatar based exercise designs have been conducted (Konings et al., 2016; Williams, Jones, Sparks, Marchant, et al., 2015). However, the actual presence of competitors has not yet been fully explored. As such, in more ecologically valid circumstances, social and physiological factors are likely to be of more significant influence.

2.4.1 Prior experience

As previously stated, pacing during any form of exercise is regulated by the brain that processes many cues, to ensure maximum performance without exhausting the body's physiological systems (Edwards & Polman, 2012; Noakes, 2012). Regarding pacing, a critical variable is knowledge of the task at hand (Billaut, Bishop, Schaerz, & Noakes, 2011; Paterson & Marino, 2004; Stone et al., 2012). Information from similar experiences is crucial to successful pacing so that based on the demands of the task a suitable initial exercise intensity can be determined to limit the possibility of premature fatigue (Marino, 2004; Tucker, 2009; Ulmer, 1996). The importance of this factor in pacing is evident with false feedback of performance manipulating the role of previous

experience, as demonstrated with an increased performance in a subsequent bout after completing a longer than perceived task (Paterson & Marino, 2004). Alternatively, if the duration is varied or unknown, the role of any previous experience is to ensure task completion at a minimum, thus resulting in sub-optimal performance (Billaut et al., 2011). In this scenario, a more conservative intensity is selected to produce an intensity that is tolerable and will not reach maximum levels before the end of the exercise. In all these scenarios, sensations of exertion are referenced against mental representations of the exercise that have been developed by similar previous occurrences (Lambert et al., 2005). Overall, these demonstrate that previous experience in an exercise is of crucial importance to successfully pace a task.

Given the role that previous experience plays, it is essential to account for its influence on exercise testing. Aside from the reliability of testing procedures and equipment, care is needed with a repeated measures design to minimise within-subject variability, as this may be increased if the participant does not have suitable previous performances. Consequently, repeated tests may allow for different pacing strategies based on familiarity with the exercise task. Therefore, it is suggested to utilise a familiarisation session before conducting testing. However, there are no clear familiarisation guidelines to reduce within-subject variability of a pacing strategy.

For trained cyclists, time-trial (TT) mean power and time to completion are reasonably reproducible (Laursen, Shing, & Jenkins, 2003; Sporer & McKenzie, 2007; Zavorsky et al., 2007). This is due in part to an increased familiarity to the exercise, with previous experience allowing the athletes to understand the specific demands of the task (Mauger, Jones, & Williams, 2010b; Williams, Bailey, & Mauger, 2012). Furthermore, evidence suggests for the reliability of performance in self-paced tasks, that at least one familiarisation should be performed (Marino, Kay, Cannon, Serwach, & Hilder, 2002;

Schabort, Hawley, Hopkins, Mujika, & Noakes, 1998). The development of pacing strategies has been investigated in both cyclists (Thomas, Stone, Thompson, St Clair Gibson, & Ansley, 2012) and non-cyclists (Foster et al., 2009; Williams et al., 2012). Concerning those considered novices, improvement is seen in TT duration and differences of pacing in successive trials (Williams et al., 2012). Pacing strategy modification is also seen across sessions with adjustment after one trial (Corbett, Barwood, & Parkhouse, 2009), or after multiple trials (Foster et al., 2009). To specifically investigate TT reproducibility and pacing development, a search was conducted with the Scopus database using combinations of the following search terms; “pacing”, “strategy”, “familiarisation”, “experience” “reproducibility” and “time-trial”. Studies were included that had explicitly investigated changes in pacing and performance over multiple TTs. Additionally, studies were only included that had been designed without the introduction of any intervention that may influence performance (for example, the withholding of distance information). The findings from this search are presented in Table 2-1.

Table 2-1: Summary of studies investigating the reproducibility of cycling TT pacing and performance

Study	Participant information	Exercise	Number of trials	Rest period	Variables	Key Findings
Ansley, Schabort, St Clair Gibson, Lambert, and Noakes (2004)	*n*=7 Males Highly trained competitive cyclists	4-km TT Cycling	3	17 min	Duration PO VO_2 HR RPE Velocity EMG Muscle force	Similar duration ↑ Peak PO (10.3%) in 1st TT than other TT's Pacing strategies across all TT eliciting a maximal VO_2 response EMG changes tracked the increases and decreases in power output Modified pacing from the 1st trial in the 2nd & 3rd TT. Indicated by progressive blunted start, with greater PO towards the end of the trial
Corbett et al. (2009)	*n*=9 Males untrained but accustomed to exercise	2-km TT Cycling	3	Separate trials	Duration PO Work HR VO_2	No significant difference between TT's in duration ↑ PO during the first 500 m for TT1 ↑ PO during the final 750 m for TT2 & TT3 No further adjustment in pacing profile following the second TT
Foster et al. (2009)	*n* = Not reported Males and Females with little cycling experience	3-km & 10-km TT Cycling	6 & 3	Separate trails 2-4 days	Duration PO RPE HR	↑ PO during the first half of successive trials, indicating a progressively more aggressive early pace. No differences in terminal PO Non-significant PO differences during the last half of each trial. Stable performance template was achieved by the 3rd or 4th trial. Each trial was significantly faster than the preceding one.
Thomas et al. (2012)	*n*=17 Males Well trained cyclists	20-km TT Cycling	3	Separate trials 2-7 days	Duration PO RPM VO_2 HR RPE	The start and end of the trial had greater variability across TTs Reduced PO at the start of repeat trials Performance, perceptual and physiological response is reproducible over 3 TT's

Note: EMG, electromyography. HR, heart rate. PO, power output. RPE, rate of perceived exertion. RPM, revolutions per minute.TT, time-trial. VO_2, oxygen consumption.

To summarise, competitive cyclists demonstrated a reduced power output at the start of a 4-km (Ansley, Schabort, et al., 2004) and 20-km (Thomas et al., 2012) TTs. While similar results have been reported for non-cyclists performing a 2-km TT (Corbett et al., 2009). Given the importance of previous experience, it is not surprising to observe an increased performance in each TT repetition for non-cyclists. However, it appears that the pacing strategy was similar after three trials. This result highlights the need for adequate familiarisation to a task for those with limited experience.

Familiarisation sessions are utilised as practice trials to learn experimental protocols to reduce learning effects and systematic error (Hopkins, 2000). However, it is suggested for those with substantial previous experience (i.e. trained or experienced participants) a familiarisation may not be required (Sporer & McKenzie, 2007). In contrast, other investigations recommended at least one familiarisation trial (Abbiss, Levin, McGuigan, & Laursen, 2008; Laursen et al., 2003; Zavorsky et al., 2007). Specific to pacing, at least one familiarisation trial would be useful to reduce the variability of pacing profiles in cyclists (Thomas et al., 2012). Regarding the anticipatory regulation of exercise, there is evidence to suggest novice participants will most certainly need at least one familiarisation trial for pacing to be reliable between trials (Corbett et al., 2009; Foster et al., 2009; Tucker, 2009). Relating to the pacing literature, prior experience and therefore familiarisation sessions are a key factor in all pacing models as it provides the anchor point for within exercise pacing decisions in subsequent tasks (Tucker, 2009; Ulmer, 1996). By having prior experience, a template is developed of how the exercise can most optimally be performed. Templates for performance have been described for TT based exercises (Tucker, 2009), but also in team sports (Edwards & Noakes, 2009). In these pacing theories, calculation by the participant prior to, and within the task, always consider if the current effort is sustainable to obtain their goals and reach the end of

exercise anchor point. Explained by Edwards and Noakes (2009), athletes will likely consider their pacing template in three parts, macro-pacing, meso-peacing and micro-pacing. Macro-pacing relates to the overall plan for the exercise, meso-pacing splits the pacing into two halves, while micro-pacing relates to acute periods of intense exercise based on set point strategies. In this regard, any experience (i.e. a familiarisation) in the task would assist the participant in making appropriate calculations at each of these levels, for example, a casual runner not sprinting at the start of a marathon. However, these previous theories investigate pacing templates when there is either past experience or no experience at all. What is not clear is how efficient this process would be when the experience is not exactly the same. It is likely that this may not affect the overall pacing template, but the micro-pacing decisions may not be as nuanced as those who have more experience in the task. Therefore, it would be interesting to test if a similar, but not the same prior experience would also be beneficial in developing an optimal template. However, this has not yet been considered when familiarising participants to a task. Additionally, it has yet to be determined the best way to familiarise a participant to an entirely novel task in order to develop a stable pacing strategy. Consequently, it is currently unclear if findings from previous investigations using a self-paced exercise protocol are due to the intervention or are a result of a variable pacing strategy.

2.4.2 Afferent feedback and pain perceptions

The input that the brain receives from the skeletal muscle during exercise is crucial in determining exercise intensity (see Figure 2-6). Therefore, within central regulation models, afferent feedback is perhaps the single most important variable. Essentially, prior to and within the exercise, afferent signalling is responsible for informing on the muscle state and consequently the generation of the RPE. In turn, the CGM and the conscious awareness brain regulation model state that once RPE deviates away from the exercise

template (CGM) or becomes prominent (conscious awareness brain regulation model) that exercise intensity will be regulated to optimise pacing in order to fit the pre-determined template. The importance of afferent feedback has been demonstrated with the modification of information resulting in exercise intensity changes (Amann, 2011; Amann et al., 2008; Amann et al., 2009). Afferent Information is transmitted from the skeletal muscle via four different types of afferent fibres (types I, II, III and IV) (see Figure 2-6). Specifically, exercise sensitises and activates group III and IV afferent muscle fibres (O'Connor & Cook, 1999). During exercise, the increased production of endogenous algesics such as bradykinin, potassium, serotonin and histamine, sensitise or increase the firing rate of group III and IV fibres, while the production of hydrogen ions and prostaglandins also indirectly sensitise these nociceptors which results in a dull-aching or cramping pain (Marchettini, Simone, Caputi, & Ochoa, 1996; O'Connor & Cook, 1999). This information is then transmitted to the CNS providing insight to the metabolic state of the muscle based on the current exercise intensity (Amann, 2011; O'Connor & Cook, 1999) (see Figure 2-7).

The importance of afferent feedback on exercise performance is apparent in cases where fatigue is augmented via hypoxia or pre-fatigue. With altered arterial oxygen content during cycling TTs, performance was improved in hyperoxia (mean power output 414.5 ± 17.4 W) and decreased in hypoxia (mean power output 269.3 ± 7.6 W) compared to normoxia (mean power output 351.1 ± 13.2 W) (Amann et al., 2006). Additionally, it was also observed that peripheral fatigue measured via the reduction in quadriceps potentiated twitch force was similar at exercise termination regardless of exercise condition and performance (−33 to −35%, P=0.44) (Amann et al., 2006).

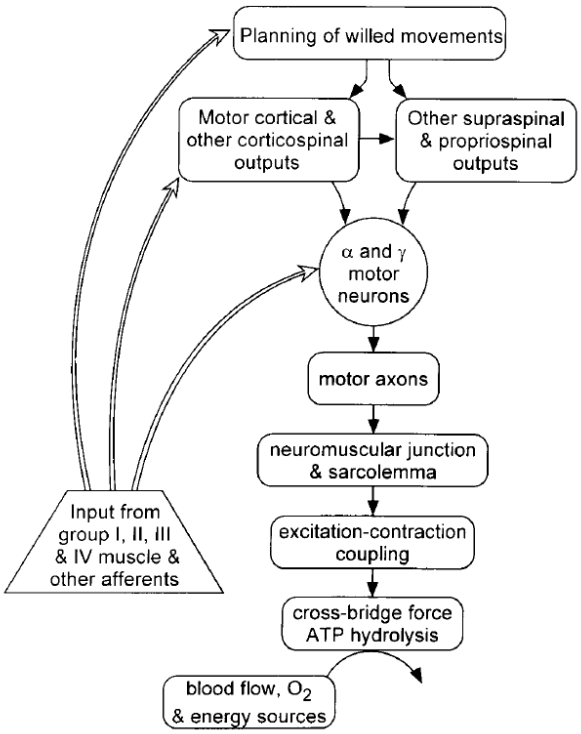

Figure 2-6: Diagrammatic representation of the "chain" involved in voluntary contractions (Gandevia, 2001).

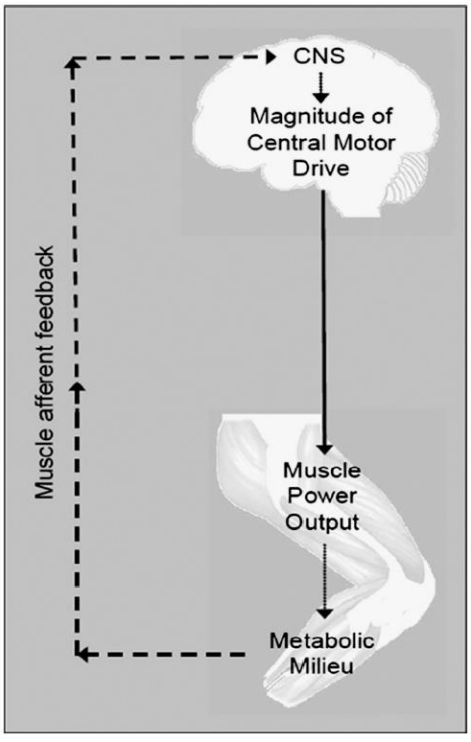

Figure 2-7: Schematic illustration of the interaction between afferent feedback from the muscle during exercise and the central nervous system which accordingly adjusts central motor drive. The solid line indicates the central motor drive to the locomotor muscle and the dashed line indicates feedback from afferent fibres within the muscle (Amann, 2011).

Consequently, a sensory tolerance limit was proposed that limits the development of peripheral fatigue (Amann et al., 2006). The sensory tolerance limit has also been demonstrated when exercising with different levels of pre-fatigue resulting in similar via the reductions in quadriceps potentiated twitch force (−35 to−37%, P=0.35) (Amann & Dempsey, 2008). Also, when locomotor fatigue was induced prior to a TT, a significant reduction in overall performance (298 ± 14 W, P<0.05) occurred compared to control (347 ± 14 W) (Amann & Dempsey, 2008). Alternatively, the increase of muscle damage associated with eccentric contractions resulted in performance reductions when running downhill (95.28 ± 1.93% of maximal running speed) as opposed to that of level (97.31 ± 1.29% of maximal running speed, P=0.04) and uphill running (98.09 ± 0.74% of maximal running speed, P=0.03) (Baron et al., 2009). In summary, these investigations indicate that the sensory tolerance limit controls fatigue levels to prevent unnecessary physiological harm (Amann et al., 2009; Gandevia, 2001; Hureau, Romer, & Amann, 2018; Noakes & St Clair Gibson, 2004). Furthermore, the absence of afferent feedback has also been examined by attempting to block the projection of sensory information (Amann et al., 2008; Amann et al., 2009).

First, TTs were performed with lidocaine administered via lumbar epidural anaesthesia (Amann et al., 2008). However, this study was limited in that the lidocaine negatively affected muscle force and consequently, TT performance was decreased (Amann et al., 2008). To address this limitation, the next investigation utilised fentanyl to only obstruct afferent information from group III and IV fibres (Amann et al., 2009). Consequently, by only impeding the afferent information from the exercising muscles, a higher EMG (12 ± 3%, P<0.05) and power output occurred (6 ±2%, P<0.05) in the first half of the TT, compared to control (see Figure 2-8). Overall, after administering fentanyl, the TTs were 3 ± 1% (P<0.05) faster than control. Essentially, the obstruction of afferent

information allowed for an increased intensity due to the athlete being unable to comprehend the increased pace was unsustainable for the entire trial. Importantly, the increased power output was only observed in the first half of the TT, which would have increased the development of peripheral fatigue beyond the sensory tolerance limit (Amann et al., 2009). For the second half of the TT, the reduction in power output would be due to excessive fatigue as well as the sensory tolerance limit being influenced by other feedback (for example the respiratory muscles) (Amann et al., 2009; Hureau et al., 2018). It is also important to note that while power output was reduced from 2km-4km, there was an increase of power in the final kilometre (see Figure 2-8). This demonstrates that while the obstruction of afferent information influences the feedback aspects of pacing, feedforward aspects are still working to regulate pace for optimum performance (St Clair Gibson et al., 2006). Although not acknowledged by the authors, the presence of the end spurt in the absence of peripheral afferent feedback demonstrates that both conscious and subconscious processes have determined there is enough metabolic reserve to complete the race while also increasing power to optimise performance without causing catastrophic physiological failure (St Clair Gibson et al., 2006). Overall, these results demonstrate afferent feedback does not exclusively regulate pace but also there is potential to improve exercise performance by manipulating sensory information.

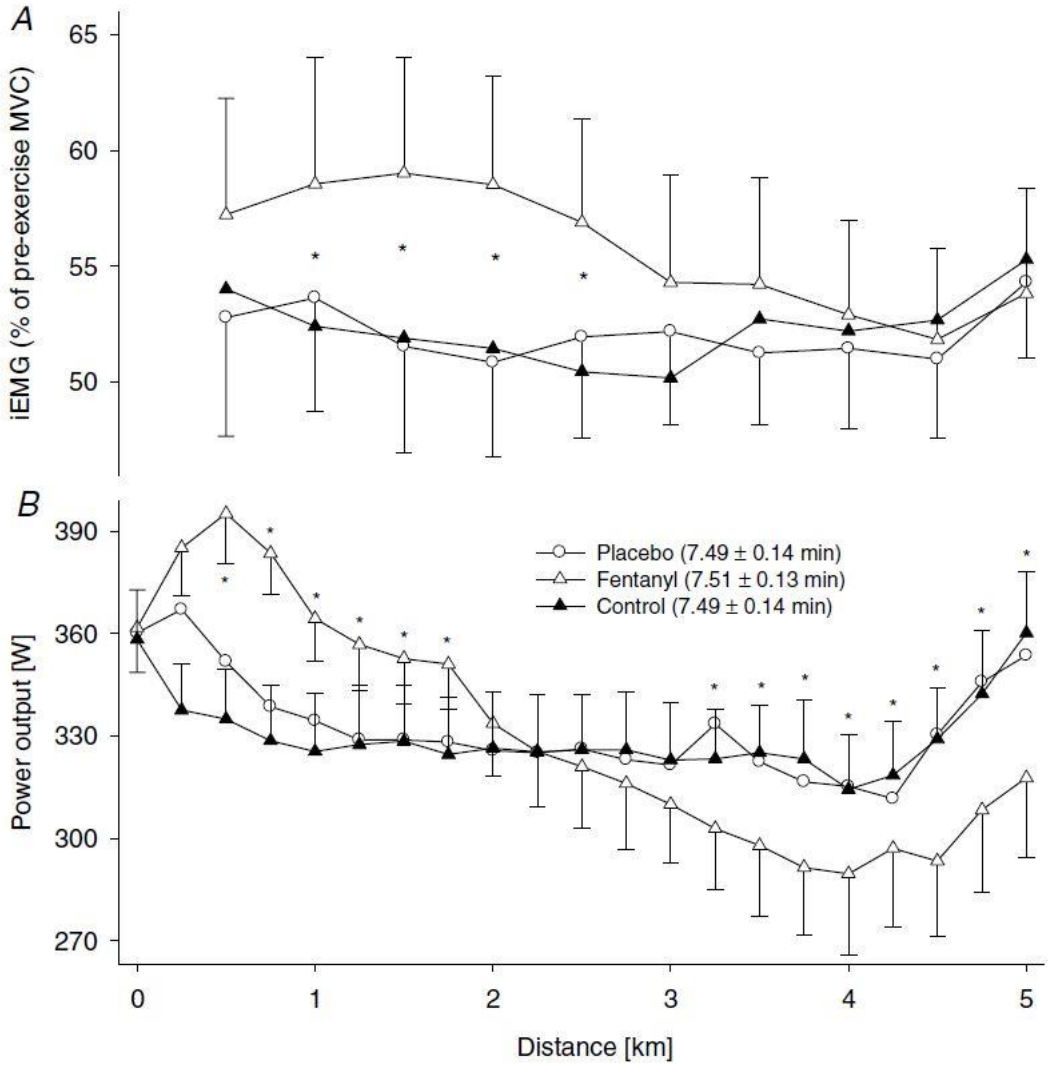

Figure 2-8: Effect of modified afferent feedback (via fentanyl) on neural drive (EMG of vastus lateralis) (A) and power output (B) during a 5-km cycling time-trial (Amann et al., 2009).

Regarding the CNS processing afferent information, the conscious awareness of exercise-related sensory information is the subjective sensation of exercise-induced pain (Loeser & Treede, 2008; Mauger, 2013). For lower exercise intensities, the associated low levels of afferent feedback from exercising muscles (for example, afferent information when walking) is not sufficient to trigger conscious awareness (Edwards & Polman, 2013). However, an increased exercise intensity will result in greater production of algesics within the skeletal muscle that triggers conscious awareness, therefore necessitating pacing decisions to change behaviour (Edwards & Polman, 2013; Swart et

al., 2012). Consequently, once afferent feedback triggers conscious awareness, exercise intensity is regulated to maintain the exercise-induced pain at a tolerable level (Edwards & Polman, 2013; Mauger, 2014). Importantly, this demonstrates that pain is a subjective sensation and in fact may not always be an accurate reflection of the metabolic state of the muscle. Along with this line of reasoning, the sensory tolerance limit likely corresponds to the level of discomfort the individual is willing to endure. Demonstrating the importance of pain perceptions, those who are willing to tolerate more pain have improved performance compared to others (Astokorki & Mauger, 2017a). While the importance of afferent feedback has been confirmed with invasive anaesthesia, this is not a practical use in exercise settings. Addressing this issue, other studies have been conducted to investigate the different ways afferent feedback in the form of exercise-induced pain can be managed during exercise.

Primarily these studies have investigated the use of drugs that have known analgesic properties. While demonstrating improvements on performance, pharmacological interventions such as aspirin and caffeine (Hudson, Green, Bishop, & Richardson, 2008; Motl, O'Connor, Tubandt, Puetz, & Ely, 2006) provide effects other than analgesia, which makes pinpointing the cause of performance changes difficult. Subsequently, acetaminophen (paracetamol) has been administered to investigate analgesia as additional effects are minimal (Mauger et al., 2010a). Mean power output during a TT (265 ± 12 vs. 255 ± 15 W, $P<0.05$) (Mauger et al., 2010a) and repeated-sprint exercise (391 ± 74 vs 372 ± 90 W, $P<0.05$) (Foster, Taylor, Chrismas, Watkins, & Mauger, 2014) has been increased following ingestion of acetaminophen compared to a control. In fact, when administered prior to the 16.1-km TT, there was an altered pacing profile with increased power output during the middle portion of the TT. As pain perceptions were not affected, it appears that the sensory tolerance limit was only

adjusted, allowing for exercise intensity to be increased before reaching this threshold (Mauger et al., 2010a). Consequently, there is the possibility for other analgesic interventions administered during self-paced exercise to adjust perceptions of pain, and possibly increase performance.

A non-pharmacological treatment for pain is transcutaneous electrical nerve stimulation (TENS). Application of TENS involves the delivery of electrical currents to the skin to stimulate peripheral nerves for pain relief and is considered inexpensive, safe, and easy to use (Johnson et al., 2015). It has been demonstrated that TENS is useful for multiple pain conditions such as chronic musculoskeletal pain and osteoarthritis (Johnson & Martinson, 2007; Johnson et al., 2015). Consequently, TENS could be an alternative to pharmacological analgesics during exercise to attenuate nociceptive stimuli that contribute to exercise-induced pain. The gate control theory of pain explains the mechanism of the analgesic effects of TENS (Melzack & Wall, 1965). Specifically, TENS stimulates opioid receptors (group II afferents) both spinally and supraspinally to excite inhibitory interneurons. Activation of the interneurons results in inhibition of the nociceptive stimuli from group III and IV afferent fibres located in the skeletal muscle (Johnson et al., 2015; Melzack & Wall, 1965; Sluka, Bjordal, Marchand, & Rakel, 2013). Therefore, TENS works to a similar mechanism as opioids demonstrated to influence exercise performance (Amann et al., 2009). However, the use of TENS during exercise on pain-free individuals and the effect of TENS on exercise-induced pain has not yet been researched thoroughly. There is merit to the use of TENS during exercise, as demonstrated by reductions in pain and restoration of quadriceps strength when knee pain was induced (Son, Kim, Seeley, Feland, & Hopkins, 2016). This finding suggests that TENS may be useful in reducing the amount of afferent feedback from group III and IV afferent fibres during exercise and could be used to reduce perceptions of exercise-

induced pain. From a pacing perspective, the use of TENS to reduce afferent feedback from group III and IV would create a 'buffer' in the participants pacing template. Specifically, much like the work for (Amann et al., 2009), application of TENS may allow for a greater exercise intensity for the same RPE as described by the CGM (Noakes, 2012) or before conscious awareness is obtained, and a change in behaviour is required (Edwards & Polman, 2013). Consequently, an intervention such as TENS could be used to enhance adherence to exercise and improve athletic performance.

2.4.3 Competition

With the exercise intensity determined by the individual, TTs allow for an investigation into the endurance based pacing strategies which a participant will self-select. As previously described in this literature review, pacing within a task is dependent on experience to develop a pacing template and sensory feedback to regulate to this template. However, not all endurance based exercise pacing occurs in isolated TTs, there are also competitive situations to consider, where the presence of competitors can provide the motivation that can alter the energy distribution required to achieve performance. The factor of motivation is acknowledged in all pacing models. However, this factor is key to the psychobiological model of pacing (Marcora, 2008). This model contends that exercise is regulated by the participant's motivation and their perception of effort to an intensity the individual is willing to exert. Consequently, as opposed to exercising alone, the introduction of competition would likely increase performance as this provides a motivational stimulus. This finding is true when exercising in the presence of a virtual avatar competitor that represents a previous performance (Corbett et al., 2012). In these situations, the presence or perception of a competitor encourages the athlete to make decisions they would not necessarily encounter if exercising alone (Smits et al., 2014). Changes in behaviour, when faced with competition, are due to the competitor providing

a different stimulus for task achievement (Triplett, 1898). Specifically, to win a race an individual must beat the nearest competitor (i.e. with a visual stimulus), while the goal of a TT is to complete the distance in the least amount of time possible (i.e. often without a visual stimulus). Also, the complex nature of real competition is complicated by tactical components such as drafting and end-spurts (Thiel, Foster, Banzer, & De Koning, 2012). Consequently, there has been limited research into the effects of real competition, while more studies have utilised computer software to create the perception of a competitor. To specifically investigate the influence of competitor(s) on TT pacing and performance, a search was conducted with the Scopus database using a combination of the following search terms; “pacing”, “strategy”, “competition”, “time-trial”. Studies were included for the period of 2012 to 2016 that had utilised the presence or perception (i.e. an avatar) of a competitor. The findings of this search are presented in Table 2-2, with the table split between studies utilising avatar or real competitors.

Table 2-2: Summary of studies investigating perception or presence of a competitor

Avatar as a competitor					
Study	**Participants**	**Exercise**	**Competition type**	**Variables**	**Key findings**
Corbett et al. (2012)	*n*=14 Male Non-trained	2-km TT Cycling	Participant was led to believe avatar was another participant by using dummy rider separated by a screen <u>5 Trials:</u> • 3 x Familiarisation TTs (FAM) • 1 x Control TT • 1 x Head to Head (HH) (Avatar representing best familiarisation time)	Duration HR VO_2 PO (aerobic and anaerobic) Work (aerobic and anaerobic)	HH duration faster than FAM and TT HH pacing matched familiarisation TT, greater power in later half of trial attributed to a greater anaerobic contribution Greater total work in HH, due to a greater anaerobic contribution
Jones et al. (2016a)	*n*=17 Male Trained	16.1-km TT Cycling	Competition against an avatar representing a previous performance Avatar was 102% faster than fastest baseline performance (FBL) <u>2 groups:</u> Accurate (ACC, *n*=9), aware avatar was 102% FBL Deceptive (DEC, *n*=8) unaware avatar was 102% FBL <u>4 Trials:</u> • 2 x Baseline TTs (To determine FBL) • 1 x Avatar TT: Avatar represents 102% of FBL • 1 x Subsequent control TT (Control accounting for the deceptive group now aware of deception)	Duration PO Speed Affect RPE Self-efficacy HR VO_2	Both groups performed Avatar trial faster than FBL and subsequent control No significant difference between ACC and DEC groups No significant difference between FBL and subsequent control Lower affect, self-efficacy and higher RPE when performing with Avatar compared to FBL Use of avatar has only acute effects on performance which are not sustained residually

Study	Participants	Exercise	Competition type	Variables	Key findings
Jones et al. (2016b)	*n*=20 Male Trained	16.1-km TT Cycling	Competition against an avatar representing a previous performance 2 groups: Control (CONT, *n*=10): avatar represents FBL Deception (DEC, *n*=10): avatar represents 102% faster than FBL 4 Trials: • 2 x Baseline TTs (To determine FBL) • 1 x Avatar TT: Avatar (FBL or 102% FBL) • 1 x Subsequent TT (SUB) (Control accounting for training effect)	Duration PO Speed Affect RPE Self-efficacy HR VO_2	Both groups performed faster with avatar than FBL and SUB No significant difference between FBL and SUB For DEC group, lower affect and higher RPE with avatar compared to FBL Deceptive feedback had no additional effect as the performance was not increased in SUB
Konings et al. (2016)	*n*=12 Male 2 years cycling experience	4-km TT Cycling	Competition against an avatar in the belief it was another participants performance. Avatar a manipulation of familiarisation trial. 4 Trials: • 1 x Familiarisation (FAM) • 1 x Control TT • 1 x Avatar SLOWFAST (Avatar started slower and finished TT faster compared to FAM performance) • 1 x Avatar FASTSLOW (Avatar started faster and finished TT slower compared to FAM performance)	Duration Power Velocity RPM RPE	Both avatar conditions were completed faster compared to control Reduced power in control compared to both avatar conditions during 1st km Higher power in FASTSLOW during the initial 750-m compared to SLOWFAST The behaviour of an opponent affects pacing-related decisions
Shei, Thompson, Chapman, Raglin, and Mickleborough (2016)	*n*=14 Male Trained	4-km TT Cycling	Competition against an avatar representing a previous performance 4 Trials: • 1 x Familiarisation • 1 x Control TT • 1 x Avatar 102% faster than control (unaware of deception) • 1 x Avatar 102% faster than control (aware of deception)	Duration Mean PO RPE Motivation	Participants can reproduce performance against a faster avatar when informed of deception Both avatar conditions faster than baseline No significant difference between the avatar conditions

Study	Participants	Exercise	Competition type	Variables	Key findings
Stone et al. (2012)	*n*=9 Male Trained	4-km TT Cycling	Competition against an avatar representing a previous performance. Participants led to believe that avatar represented baseline performance. <u>4 Trials:</u> • 1 x Familiarisation • 1 x Control TT • 1 x ACC (Avatar is an accurate representation of control) • 1 x DEC (Deceived with avatar 102% faster than of control)	Duration RPE VO_2 HR Mean PO PO (aerobic and anaerobic)	Reduced duration and increased power in DEC compared to control and ACC Reduced duration in ACC compared to control Greater anaerobic contribution to power output at 90% of the total distance in DEC compared to ACC DEC higher total RPE than control
Williams, Jones, Sparks, Marchant, et al. (2015)	*n*=15 Male Trained	16.1-km TT Cycling	Competition against an avatar in the belief it was another participants performance. Avatar was a previous performance. <u>4 Trials:</u> • 1 x Familiarisation (with visual display) • 1 x Control TT (with visual display) • 1 x No visual display • 1 x Avatar (avatar as fastest previous performance)	Duration PO Speed HR RPE Motivation Attentional focus	Avatar TT faster than control and no visual display Increased power, speed and HR in avatar TT than control and no visual display TTs No significant difference in RPE Internal attentional focus lower in avatar TT Increased performance due to greater external distraction which deters perceived exertion
Williams, Jones, Sparks, Midgley, et al. (2015)	*n*=15 Male Trained	16.1-km TT Cycling	Competition against an avatar in the belief it was another participants performance. Avatar a previous performance. <u>5 Trials:</u> • 2 x Baseline • 1 x Avatar 102 % faster than FBL (102%) • 1 x Avatar as 105 % faster than FBL (105%) • 1 x 2 avatars (1 x 102% and 1 x 105% faster than FBL) (102% and 105%)	Duration PO Speed HR RPE Affect Self-efficacy	Non-significant improvements in duration for deceptive competition TTs compared to baseline In (102% and 105%) TT there was lower self-efficacy compared to (105%) and (102%) TTs In (102% and 105%) TT there was lower affect compared to (105%) TT In (102% and105%) greater RPE than baseline

Real competition					
Study	**Participants**	**Exercise**	**Competition type**	**Variables**	**Key findings**
Bath et al. (2012)	*n*=11, M Club level runners	5-km TT Running	Competition was a 2nd runner (Adjusted speed based on participant behaviour) <u>5 Trials:</u> • TT1 (Control) • Fast paced trial (2nd runner in front of the participant by ~10m) • Even paced trial (2nd runner next to the participant) • Slow paced trial (2nd runner behind the participant by ~10m) • TT2 (Control accounting for training effect)	Duration HR RPE Subjective assessment of pacemaker on performance	No significant difference in pacing, performance, HR or RPE All participants incorrectly believed the presence of 2nd runner increased performance 9 of 11 participants believed it easier to complete TT with a 2nd runner in comparison to running alone
Tomazini et al. (2015)	*n*=9 Male Recreational runners	3-km TT Running	Competition was other runners <u>3 Trials:</u> • 1 x Familiarisation • 1 x Control TT • 1 x Collective race simulation (GROUP) (Group of 4-5 runners matched for performance times)	Duration Speed VO_2 Profile of mood states	Duration reduced in GROUP compared to control GROUP speed greater in first in first 500-m compared to control The end-spurt is decreased by the presence of competitors. The decrement in vigour is higher in the presence of competitors during running.

Note: ACC, accurate avatar. CONT, control. DEC, deceptive avatar. FASTSLOW, Avatar started faster and finished TT slower. FBL, fastest baseline performance. GROUP, Collective race simulation. HH, head to head. HR, heart rate. PO, power output. RPE, rate of perceived exertion. RPM, revolutions per minute. SLOWFAST, Avatar started slower and finished TT faster. SUB, Subsequent TT. TT, time-trial. VO_2, oxygen consumption.

Regarding the use of a competitor and the influence on performance, the use of an avatar to deceptively make a competitor faster than an athlete's previous known performance results in increased performance (Jones et al., 2016a; Jones et al., 2016b; Stone et al., 2012; Williams, Jones, Sparks, Marchant, et al., 2015; Williams, Jones, Sparks, Midgley, et al., 2015). Also, the behaviour of avatar competitors' influences participants to deviate from their pacing strategy (Konings et al., 2016). While the imitation of competition has demonstrated that performance can be improved, with the use of an avatar, competitive psychological dynamics are not present (Snyder, Anderson-Hanley, & Arciero, 2012). Only two studies have investigated the influence of actual competitors on pacing, with equivocal results (see Table 2-2) (Bath et al., 2012; Tomazini et al., 2015). In fact, compared to a virtual stimulus, the presence of real competitors results in increased exercise intensity due to increases in arousal and attentional processes (Ravaja et al., 2006; Snyder et al., 2012). Furthermore, these findings can be explained by pacing models, in that real competition provides greater motivation to participants and in turn, produces a greater willingness to exert effort.

Whether competition is real or virtual, performance improvements when exercising with competitors has been attributed to a number of factors. Increased motivation (Corbett et al., 2012), changes in psychological momentum (Perreault, Vallerand, Provencher, & Montgomery, 1998), or altered attentional focus (Williams, Jones, Sparks, Marchant, et al., 2015) have all been associated with performance improvements. Another factor that may moderate pacing in the presence of competitors is an individual's goal orientation. Goal orientation theory refers to how individuals estimate their levels of ability and effort within a task (Duda, 1992). Goal orientation theory classifies individuals and behaviours into two orientations; task and ego. An ego-orientated individual emphasises winning and self-judges performance based on social

comparison. While a task-oriented individual places emphasis on learning and improvement, and self-judges performance based on previous efforts (Duda, Chi, Newton, & Walling, 1995; Duda, Olson, & Templin, 1991). Accordingly, when exercising in a competitive environment, varying perceptions of competence and abilities will likely result in different pacing strategies based on differing goal orientations, motivational orientation and personal goals (Nicholls, 1984; Smits et al., 2014). However, the way in which exercise is paced with a competitor based on goal orientations has not yet been investigated.

2.5 Aims, objectives and hypotheses

The overall aim of this thesis was to further investigate factors known to influence pacing and performance in self-paced tasks (cycling TT). Overall, it was predicted that by taking a holistic approach to investigate pacing, this would enable examination of the different aspects of existing pacing models. Specifically, this thesis had three objectives:

1. Study 1: To examine the role of prior experience on the development of pacing profiles and TT performance;
2. Study 2: To examine the role of afferent feedback manipulation through TENS on pacing and TT performance;
3. Study 3: To examine the role of actual competitors and motivational orientation on pacing and TT performance;

Based on these objectives, this thesis tested the following hypotheses:

1. More than one familiarisation is required for novice participants to establish a stable pacing strategy;
2. A similar, but not identical, exercise task may provide a sufficient familiarisation to a maximal paced TT;

3. Application of TENS would increase the sensory threshold of exercise-induced pain allowing for a greater exercise intensity and increased TT performance;
4. When exercising with group competition, performance would be improved compared to a session with one competitor;
5. When in the presence of competition, ego orientated participants would have greater performance improvements, compared to task orientated participants.

CHAPTER 3. STUDY 1: FAMILIARISATION PROTOCOL INFLUENCES REPRODUCIBILITY OF 20-KM CYCLING TIME-TRIAL PERFORMANCE IN NOVICE PARTICIPANTS

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3.1 Abstract

Introduction: Exercise performance is reproducible in experienced athletes; however, less trained participants exhibit greater variability in performance and pacing. To reduce variability, it is common practice to complete a familiarization prior to experimental testing. However, there are no clear guidelines for familiarizing novice participants to a cycling time-trial (TT), and research findings from novice populations may still be influenced by learning effects. Accordingly, the aims of this study were to establish the variability between TTs after administering differing familiarization protocols (duration or type) and to establish the number of familiarization trials required to limit variability over multiple trials.

Methods: Thirty recreationally active participants, with no prior experience of a TT, performed a 20-km cycling TT on five separate occasions, after completing either a full (FF, 20-km TT, n=10), a half (HF, 10-km TT, n=10) or an equipment familiarization (EF, 5-min cycling, n=10).

Results: Variability of TT duration across five TTs was the lowest after completing FF ($P = 0.69$, $\eta p2 = 0.05$) compared to HF ($P = 0.08$, $\eta p2 = 0.26$) and EF ($P = 0.07$, $\eta p2 = 0.21$). In the FF group after TT2, the effect size for changes in TT duration

was small (d < 0.49). There were large differences between later TTs in HF (d = 1.02, TT3-TT4) and EF (d = 1.12, TT4-TT5). The variability in mean power output profiles between trials was lowest within FF, with a similar pacing profile reproduced between TT3-TT5.

Discussion: Familiarization of the exercise protocol influenced the reproducibility of pacing and performance over multiple, maximal TTs, with best results obtained after a full experience of the exercise compared to HF and EF. The difference of TT1 to later TTs indicates that one familiarization is not adequate in reducing the variability of performance for novice participants. After the FF and an additional TT, performance changes between TTs were small. However, a reproducible pacing profile was not developed until after the FF and two additional TTs. These findings indicate that a minimum of three full familiarizations are necessary for novice participants to limit systematic error before experimental testing.

3.2 Introduction

During exercise testing, particular care is needed to ensure reliability from testing procedures, equipment, and the "internal" ability of participants to achieve the goals of the task (Hopkins, 2000). As such, when planning a repeated measures design, within-subject variability must be considered. This is especially the case for closed-loop exercise tests allowing for continuous adjustments in pace that may impact overall performance. This may be a concern for self-paced exercises, such as a time-trial (TT), as intensity varies when attempting to complete the distance as quickly as possible. Consequently, repeating tests may result in different pacing strategies and, therefore, performance based on the preceding familiarisation.

Previous studies have shown that cycling TT duration and mean power are relatively reproducible in trained cyclists (Sporer & McKenzie, 2007; Zavorsky et al.,

2007). This comes as no surprise as athletes who are familiar with this exercise outside of laboratory conditions are likely to have deep-rooted pacing strategies that match the requirements of the given exercise (Mauger et al., 2010b; Thomas et al., 2012). However, well-trained athletes are not immune to variations in performance. During multiple 4-km (Ansley, Schabort, et al., 2004) and 20-km TTs (Thomas et al., 2012), competitive cyclists have shown an indication for an increased starting power output in the first TT, that is progressively reduced over two repeated trials. This finding is also true for novice participants performing three 2-km TTs (Corbett et al., 2009). Conversely, novices have also produced a greater mean power output in the third of three 10-km TTs (Foster et al., 2009). Within these studies, reproducibility of performance is investigated over three trials. Yet, the third trial may not truly reflect a consistent performance, as novice participants have also displayed an increase in power output between successive trials when 3-km TTs are repeated six times (Foster et al., 2009). Taken together, these contrasting findings highlight the need for clear familiarisation procedures (i.e. protocol and number of trials) for novice participants, to reduce systematic error (Hopkins, 2000). For experienced participants, at least one familiarisation is recommended for reproducibility of performance (Abbiss et al., 2008; Laursen et al., 2003; Stone, Thomas, Wilkinson, St Clair Gibson, & Thompson, 2011; Zavorsky et al., 2007). Additionally, at least one practice trial would be beneficial for experienced cyclists to develop a stable pacing strategy (Thomas et al., 2012). Yet, for novice participants, there are conflicting reports on the minimum number of familiarisation trials before a pacing profile can be reproduced (Corbett et al., 2009; Foster et al., 2009).

Furthermore, it is not clear what protocol a familiarisation trial should consist of, and there is a lack of data on such aspects. For an exercise that employs a similar intensity, it may be possible to use a different familiarisation duration, as this experience can lead

to the development of mental representations for the exercise to be performed (Micklewright et al., 2010). For example, when conducting 4-km and 6-km TTs in a random order, experienced cyclists can retain a pacing strategy that does not negatively impact performance. This is likely a result of similar TT distances (4-km vs 6-km) conjuring a previous pacing strategy that needs only minor adjustment (Mauger et al., 2010b). It is yet to be established if a similar finding reproducibility of pacing profiles would occur in novice participants who have no extensive experience to recall. Such a finding may be beneficial when familiarising a participant to a long duration exercise (e.g. 20-km cycling TT), as a shorter duration familiarisation may be just as efficient to generate a reproducible performance. In conjunction with having limited experience in the exercise, another factor to consider for novice participants is the familiarity with the testing equipment. For exercise tests that allow adjustments in pace, a poor understanding of the testing equipment may negatively influence overall performance and the development of a pacing strategy. However, to the author's knowledge, it has yet to be investigated how testing equipment familiarity alone may influence performance. In fact, there are currently no clear guidelines for familiarising novice participants to a cycling TT. As such, it is unclear if findings from previous research using a TT to measure an intervention are due to the intervention or simply a reflection of a variable pacing strategy.

The aims of this study were to investigate how performance is influenced by the duration and type of a familiarisation protocol and to establish the number of familiarisation trials required to develop a stable pacing profile over multiple trials. It was hypothesised that it would take more than one practice for novice participants to establish a stable pacing profile, and a similar, but not identical, exercise may also provide a sufficient familiarisation to a maximal physical task.

3.3 Methods

3.3.1 Participants

Thirty (18 female and 12 male) participants who were recreationally active, whilst relatively inexperienced at cycling, volunteered for this study (Table 3-1). It was required that participants did not have an extensive cycling history, were not currently active in cycling and had never previously completed a cycling TT. Participants were asked to refrain from any physical activity causing severe fatigue in the 36 hours' prior as well as any caffeine intake 2 hours prior to testing. Prior to commencing the study, all participants were screened for risk factors and suitability to the exercise using a medical questionnaire. This study was carried out in accordance with the recommendations of the National Statement on Ethical Conduct in Human Research as described by the National Health and Medical Research Council (NHMRC) of Australia. All experimental testing was conducted with the prior approval from Victoria University's Human Research Ethics Committee. All participants gave written informed consent in accordance with the Declaration of Helsinki.

Table 3-1. Group anthropometric characteristics.

Measure	**FF**	**HF**	**EF**	***P* value**
	n = 10	*n* = 10	*n* = 10	
Age (years)	21.40 ± 1.27	24.40 ± 6.36	23.40 ± 6.40	*P* = 0.72
Height (cm)	169.75 ± 6.98	168.80 ± 7.41	173.70 ± 7.14	*P* = 0.24
Body mass (kg)	68.74 ± 5.60	67.12 ± 13.90	67.22 ± 7.72	*P* = 0.94
PPO (W)	286.80 ± 27.10	269.80 ± 37.58	289.10 ± 51.34	*P* = 0.47
PPO (W/kg)	4.17 ± 0.37	4.10 ± 0.52	4.35 ± 0.86	*P* = 0.78
VO_{2peak} ($ml.min.kg^{-1}$)	42.40 ± 3.37	40.60 ± 5.25	43.40 ± 9.19	*P* = 0.56
VO_{2peak} ($L.min^{-1}$)	2.91 ± 0.32	2.69 ± 0.50	2.90 ± 0.64	*P* = 0.60

Note: Data presented as mean ± SD. Each group *n* = 10, which consists of *n* = 6 females and *n* = 4 males. PPO, peak power output obtained from the incremental test. VO_{2peak}, peak oxygen consumption. FF, full familiarisation. HF, half familiarisation. EF, equipment familiarisation.

3.3.2 Experimental procedures

Participants were required to attend seven sessions, which involved one familiarisation session, five self-paced 20-km cycling TT sessions, and one post-testing maximal incremental test for assessment of cardiorespiratory fitness. To ensure the experimental protocol was novel to participants, a 20-km cycling TT was utilised as it was expected that even with limited cycling experience, this exercise would be unknown to participants. Upon recruitment, a selective random process ensuring gender balance was used to assign participants to one of three familiarisations groups: *full* (FF), *half* (HF) or *equipment* (EF) familiarisations. In FF, participants performed a 20-km TT; in HF, they performed a 10-km TT, whilst in EF they performed five minutes of constant pace (75 Watts) cycling, which enabled participants to learn the mechanics of the bike, without experiencing a self-paced TT (Table 3-2). EF was included in the study design as a control group to quantify the variability of performance based on having no experience in the experimental exercise, but some familiarity with the testing equipment. To limit the influence of other external factors, all testing sessions were conducted at the same location and time of day (~ 1 hour), separated by a minimum of 48 hours.

Table 3-2. Overall performance data for familiarisation session

Measure	FF	HF	EF
Duration (s)	2708.35 ± 404.10	1362.77 ± 133.36	299.99 ± 0.01
Mean power (W)	122.71 ± 33.22	118.59 ± 30.51	75.00 ± 0.00
Mean power (% of PPO)	43.20 ± 11.82	43.91 ± 8.57	26.63 ± 4.34

Note: Data presented as mean ± SD. TT, time-trial. FF, full familiarisation. HF, half familiarisation. EF, equipment familiarisation.

3.3.3 Time-trials

All exercise was conducted on a Velotron Pro cycle ergometer (RacerMate Inc., Seattle, WA, USA). Prior to each testing session, a factory calibration was performed

using the Accuwatt "run down" verification program (RacerMate Inc.) accompanying the ergometer software. Within the familiarisation, participants set the ergometer to their own specifications, with values recorded and replicated for subsequent sessions. All TT protocols were controlled via Velotron Coaching software (Version 1.6.458, RacerMate Inc.) with all courses being flat with no wind effect. TTs were conducted in the same laboratory, with regulated environmental conditions (Temperature 22.4 ± 1.1°C, humidity 50.8 ± 7.5% and barometric pressure 762.9 ± 4.6 mmHg). No fan was provided to participants in all TTs, although they were permitted to drink water *ad libitum*. Participants were asked to remain seated throughout the entire protocol, and toe clips were used to prevent feet from slipping.

Preceding the TT, a warm-up (5-min cycling at 75 Watts) was conducted. In all TTs, participants were instructed to finish the required distance "as quickly as possible" by being free to change gear and cadence throughout the trial to what felt appropriate at the time. Changing of gear utilised the ergometer electronic gearing system with all TTs started in the same gear. To overcome flywheel inertia, participants were instructed to obtain a self-selected comfortable cadence immediately prior to beginning the trial, with the TT commencing with a verbal 3-s countdown from the researcher. Throughout all TTs, participants were blinded from all performance information, except for distance covered, and received no encouragement from investigators. Participants did not receive any information on how they performed until all TTs were completed (Sporer & McKenzie, 2007).

3.3.4 Maximal incremental test

After all TTs were completed, a maximal incremental test was conducted to characterise participant's peak oxygen uptake (VO_{2peak}) and peak power output (PPO). The maximal incremental test involved incremental stages of 30 Watts/min commencing

after a 3-min baseline period, cycling at a 30 Watts (females), or 60 Watts (males) resistance which is like the protocols used for those unaccustomed to cycling tasks (Williams et al., 2012). Participants were encouraged throughout the final stages, and the test ceased when the participant could not maintain a cadence above 60 rpm or volitional fatigue was achieved.

Prior to the incremental test, O_2 and CO_2 gas was calibrated with known concentrations and flow calibrations were performed using a 3-L calibration syringe. Participants were fitted with a headpiece to assist the appropriate function of a Hans-Rudolph two-way non-rebreathing valve. Expired gas was collected and analysed every 15-s (S-3A/I (O_2) and CD-3A (CO_2), AEI Technologies Inc., Pittsburgh, PA). VO2peak was calculated as the highest 30-s mean VO2. Peak power was extrapolated by using the formula (Peak power last completed stage (Watts) + time in the last stage (s)/60 × 30 (Watts)) (Lima-Silva et al., 2013).

3.3.5 Statistical analysis

All data were analysed using SPSS (version 22, SPSS Inc., Chicago, IL.) with data reported as mean ± SD. All data were tested for normality (Shapiro-Wilk test). When normality assumptions were violated, an equivalent non-parametric test was performed. Tests for homogeneity of variances were performed to ensure normality of the cohort for dependent variables. When homogeneity of variances was violated, Welch *F*-ratio is reported. The level of significance for all tests was set at $P < 0.05$. In the instance of a significant main or interaction effect, posthoc Sidak comparisons and *t*-tests were conducted to examine differences and its magnitude (effect size). Effect sizes for one-way and repeated-measures ANOVAs are reported as partial eta squared (η_p^2) with a small effect at 0.01-0.059, medium effect 0.06-0.139 and a large effect > 0.14. Effect

sizes for *t*-tests are reported as Cohen's *d* with a small effect being 0.2-0.49, medium 0.5-0.79 and large > 0.8 (Cohen, 1988).

For data analysis, given the inter-participant differences in TT power output, power has been reported as a percentage of the individual's PPO obtained from the maximal incremental (i.e. % of PPO). To examine differences between participants in the three different groups (FF, HF, and EF), one-way ANOVAs were conducted on anthropometric variables.

3.3.5.1 Analysis of between and within groups TT variability

To explore whether the three different familiarisation protocols had an influence on performance in terms of TT duration and TT mean power, we conducted a three (FF, HF, and EF) by five (TT) repeated-measure ANOVA. Follow-up one-way ANOVAs were conducted to investigate differences between familiarisation protocols (n = 3), with follow-up *t*-tests conducted to determine the effect size between familiarisation protocols for each TT. To examine differences between trials within-groups, one-way repeated-measures ANOVAs (trials, n = 5) were conducted, with follow-up *t*-tests conducted to determine the effect size between TTs for each familiarisation protocol. In addition, as the FF group familiarisation was the same protocol as the TTs, *t*-tests were conducted to determine the difference between the familiarisation trial and all other TTs in the FF group.

To examine the variability of performance over the five trials and between the three groups (FF, HF, and EF), we calculated the coefficient of variation (CV) using the formula $\mathrm{CV}_{1,2} = \mathrm{SD}_{1,2}/\bar{\mathrm{x}}_{1,2} \times 100$. The CV was calculated for TT duration and TT mean power with individual CV's calculated and averaged for groups.

3.3.5.2 Analysis of pacing profiles

To prepare for pacing profile analysis, mean power output profiles were established by normalizing each TT to 2000 data points (Smits, Polman, Otten, Pepping, & Hettinga, 2016). To examine the development of pacing profiles within each group, mean power output profiles were analysed by applying a regression model to establish the line of best-fit profile. The line of best-fit was established by considering the regression model with the highest explained variance (R^2) for each mean power output profile. To compare the within-groups between trials variance, we considered the magnitude of change in R^2 between trials as an indicator of variability in pacing profiles, with smaller changes in R^2 considered as lower variability between trials.

3.4 Results

There were no between-group differences for any anthropometric variables (Table 3-1).

3.4.1 Analysis of between and within groups TT variability

A significant interaction effect (protocol x trial) with large effect sizes was found for TT duration ($P = 0.02$, $\eta_p^2 = 0.16$) and mean power ($P = 0.02$, $\eta_p^2 = 0.15$) (Figure 3-1). Sidak posthoc comparisons exploring differences between the three groups at each trial did not show any significant differences. The largest difference between groups was in TT1, with HF group having an increased TT duration (Figure 3-1A) and decreased mean power (Figure 3-1B) compared to FF and EF.

One-way repeated-measures ANOVAs to locate differences between trials within each group showed no significant differences for TT duration (Table 3-3). There was a significant effect for mean power in HF and EF groups but not for FF. Posthoc comparisons did not reveal any differences. For both TT duration and mean power in both HF and EF, the effect size (η_p^2) was found to be large (Table 3-3). Between trials, the

effect size (*d*) was smaller in the FF group compared to HF and EF. For the FF group, there were small effect sizes between the familiarisation and TT1, whilst between TT1 and TT2, the effect sizes were moderate. For HF and EF, there were large effect sizes between TT1 and the other trials (Table 3-3). Reflecting effect size differences, CV data between successive trials are provided in Table 3-4. Overall, the lowest CV for TT duration and mean power occurred in FF group between TT3 and TT4, with TT4-TT5 CV comparable but minimally increased.

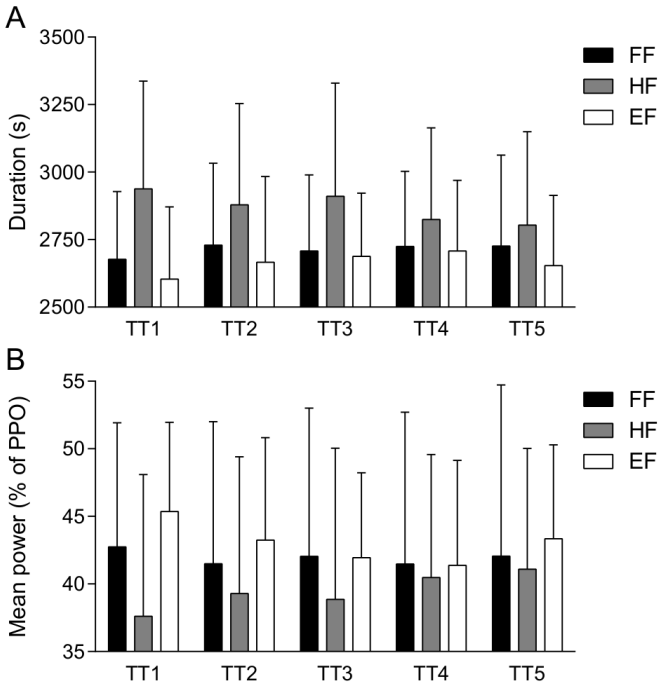

Figure 3-1 Mean ± SD TT performance measures. TT duration (s) (panel A) and mean power output (% of PPO) (panel B) for each TT. TT, time-trial. FF, full familiarisation. HF, half familiarisation. EF, equipment familiarisation.

Table 3-3. Within-group between TT differences in overall performance, with repeated measures ANOVA comparison and Cohen's d effect size for between TT differences.

Duration (s)							Mean power (% of PPO)						
Group	**Trial**	**TT1**	**TT2**	**TT3**	**TT4**	**TT5**	**Group**	**Trial**	**TT1**	**TT2**	**TT3**	**TT4**	**TT5**
FF	*FAM*	31.01 (0.19)	-20.99 (-0.23)	0.56 (0.00)	-16.01 (-0.10)	-18.17 (-0.11)	**FF**	*FAM*	0.45 (0.13)	1.70 (0.73)	1.16 (0.34)	1.72 (0.43)	1.14 (0.27)
	TT1	-	-52.00 (-0.55)	-30.46 (-0.55)	-47.03 (-0.65)	-49.19 (-0.70)		*TT1*	-	1.25 (0.52)	0.71 (0.34)	1.27 (0.46)	0.69 (0.24)
FF	*TT2*		-	21.55 (0.33)	4.97 (0.06)	2.81 (0.03)	**FF**	*TT2*		-	-0.54 (-0.34)	0.02 (0.01)	-0.56 (-0.24)
P = 0.69 η_p^2 = 0.05	*TT3*			-	-16.57 (-0.49)	-18.73 (-0.49)	*P* = 0.79 η_p^2 = 0.03	*TT3*			-	0.55 (0.53)	-0.02 (-0.02)
	TT4				-	-2.16 (-0.04)		*TT4*				-	-0.58 (-0.40)
	TT1	-	59.02 (1.36)	27.33 (0.65)	113.85 (1.84)	134.41 (1.54)		*TT1*	-	-1.68 (-1.06)	-1.25 (-1.07)	-2.86 (-1.82)	-3.48 (-1.62)
HF	*TT2*		-	-31.69 (-0.50)	54.83 (1.53)	75.39 (1.01)	**HF**	*TT2*		-	0.43 (0.25)	-1.18 (-1.32)	-1.80 (-0.97)
P = 0.08 η_p^2 = 0.26	*TT3*			-	86.52 (1.03)	107.08 (1.02)	*P* = 0.03 η_p^2 = 0.25	*TT3*			-	-1.61 (-0.93)	-2.23 (-0.95)
	TT4				-	20.56 (0.41)		*TT4*				-	-0.62 (-0.49)
	TT1	-	-62.24 (-1.41)	-84.09 (-1.36)	-104.52 (-1.82)	-50.28 (-1.16)		*TT1*	-	2.12 (1.37)	3.41 (1.47)	3.97 (1.91)	2.02 (1.15)
EF	*TT2*		-	-21.86 (-0.36)	-42.29 (-0.71)	11.95 (0.19)	**EF**	*TT2*		-	1.29 (0.61)	1.86 (0.94)	-0.10 (-0.05)
P = 0.07 η_p^2 = 0.21	*TT3*			-	-20.43 (-0.39)	33.81 (0.70)	*P* = 0.04 η_p^2 = 0.24	*TT3*			-	0.57 (0.29)	-1.39 (-0.80)
	TT4				-	54.24 (1.12)		*TT4*				-	-1.96 (-1.22)

Note: Data presented as the mean difference between TTs and (ES). Effect sizes in parentheses are presented as Cohen's *d* for differences in paired sample *t*-tests between trials. Values for Cohen's *d* are small effect at 0.2-0.49, medium 0.5-0.79 and large > 0.8. TT, time-trial. FAM, familiarisation. η_p^2, partial eta squared. FF, full familiarisation. HF, half familiarisation. EF, equipment familiarisation.

Table 3-4. Within-group CV between trials

	Duration (s)			Mean power (% of PPO)		
	FF	**HF**	**EF**	**FF**	**HF**	**EF**
CV FAM-TT1	4.67			10.78		
CV TT1-TT2	3.42	2.28	2.02	8.06	5.55	4.90
CV TT2-TT3	2.18	2.31	2.95	4.99	5.07	6.80
CV TT3-TT4	1.47	3.09	2.21	3.42	6.76	5.45
CV TT4-TT5	1.89	1.79	2.40	4.26	4.06	5.94

Note: Data presented as mean CV. CV, coefficient of variation. TT, time-trial. FAM, familiarisation. FF, full familiarisation. HF, half familiarisation. EF, equipment familiarisation.

One-way ANOVAs between groups revealed no significant difference for TT duration and mean power in any TT (Table 3-5). However, there was a large effect size (η_p^2) for differences in TT1 duration and a moderate effect size for TT1 mean power. Between HF and EF groups, there was a large effect size (*d*) for TT1 duration and mean power. Between HF and FF groups, there was a large effect size (*d*) for TT1 duration, whilst the mean power effect size (*d*) was moderate. The comparisons between FF and EF had a small effect size (*d*), whilst moderate effect sizes (*d*) were observed in TT2, TT3, TT5 duration between HF and EF groups (Table 3-5).

Table 3-5. Between-group differences in overall performance, with one-way ANOVA comparison for each trial and Cohen's *d* effect size for between-group differences.

Duration (s)					Mean power (% of PPO)				
Trial	**Group**	**FF**	**HF**	**EF**	**Trial**	**Group**	**FF**	**HF**	**EF**
TT1 $P = 0.06$ $\eta_p^2 = 0.19$	*FF*	-	-260.76 (-0.83)	73.71 (0.30)	**TT1** $P = 0.16$ $\eta_p^2 = 0.13$	*FF*	-	5.14 (0.55)	-2.61 (-0.34)
	HF		-	334.47 (1.04)		*HF*		-	-7.74 (-0.93)
	EF			-		*EF*			-
TT2 $P = 0.36$ $\eta_p^2 = 0.07$	*FF*	-	-149.75 (-0.46)	63.48 (0.22)	**TT2** $P = 0.65$ $\eta_p^2 = 0.03$	*FF*	-	2.20 (0.23)	-1.74 (-0.20)
	HF		-	213.22 (0.65)		*HF*		-	-3.94 (-0.46)
	EF			-		*EF*			-
TT3 $P = 0.25$ $\eta_p^2 = 0.10$	*FF*	-	-202.98 (-0.60)	20.07 (0.08)	**TT3** $P = 0.71$ $\eta_p^2 = 0.02$	*FF*	-	3.17 (0.30)	0.09 (0.01)
	HF		-	223.05 (0.69)		*HF*		-	-3.09 (-0.36)
	EF			-		*EF*			-
TT4 $P = 0.64$ $\eta_p^2 = 0.03$	*FF*	-	-99.89 (-0.34)	16.22 (0.06)	**TT4** $P = 0.97$ $\eta_p^2 < 0.01$	*FF*	-	1.01 (0.10)	0.10 (0.01)
	HF		-	116.11 (0.40)		*HF*		-	-0.91 (-0.11)
	EF			-		*EF*			-
TT5 $P = 0.58$ $\eta_p^2 = 0.04$	*FF*	-	-77.17 (-0.24)	72.61 (0.25)	**TT5** $P = 0.88$ $\eta_p^2 = 0.01$	*FF*	-	0.97 (0.09)	-1.28 (-0.13)
	HF		-	149.78 (0.52)		*HF*		-	-2.25 (-0.30)
	EF			-		*EF*			-

Note: Data presented as the mean difference between TTs and (ES). Effect sizes in parentheses are presented as Cohen's *d* effect size for differences in independent sample *t*-tests between groups for each trial. Values for Cohen's *d* are small effect at 0.2-0.49, medium 0.5-0.79 and large > 0.8. TT, time-trial. η_p^2, partial eta squared. FF, full familiarisation. HF, half familiarisation. EF, equipment familiarisation.

3.4.2 Analysis of pacing profiles

Characteristics of the line of best fit for 2000-point power distribution (W/PPO) curves are shown in Figure 3-2, with the highest R^2 for all trials was shown with a cubic regression model. Within-group variability in pacing strategy is established by investigating the differences in R^2 between subsequent trials. Variability in R^2 was lowest in the FF group ranging from 0.43-0.58 (Figure 3-2A), the HF group ranged from 0.32-0.63 (Figure 3-2B) and the EF group ranged from 0.46-0.77 (Figure 3-2C).

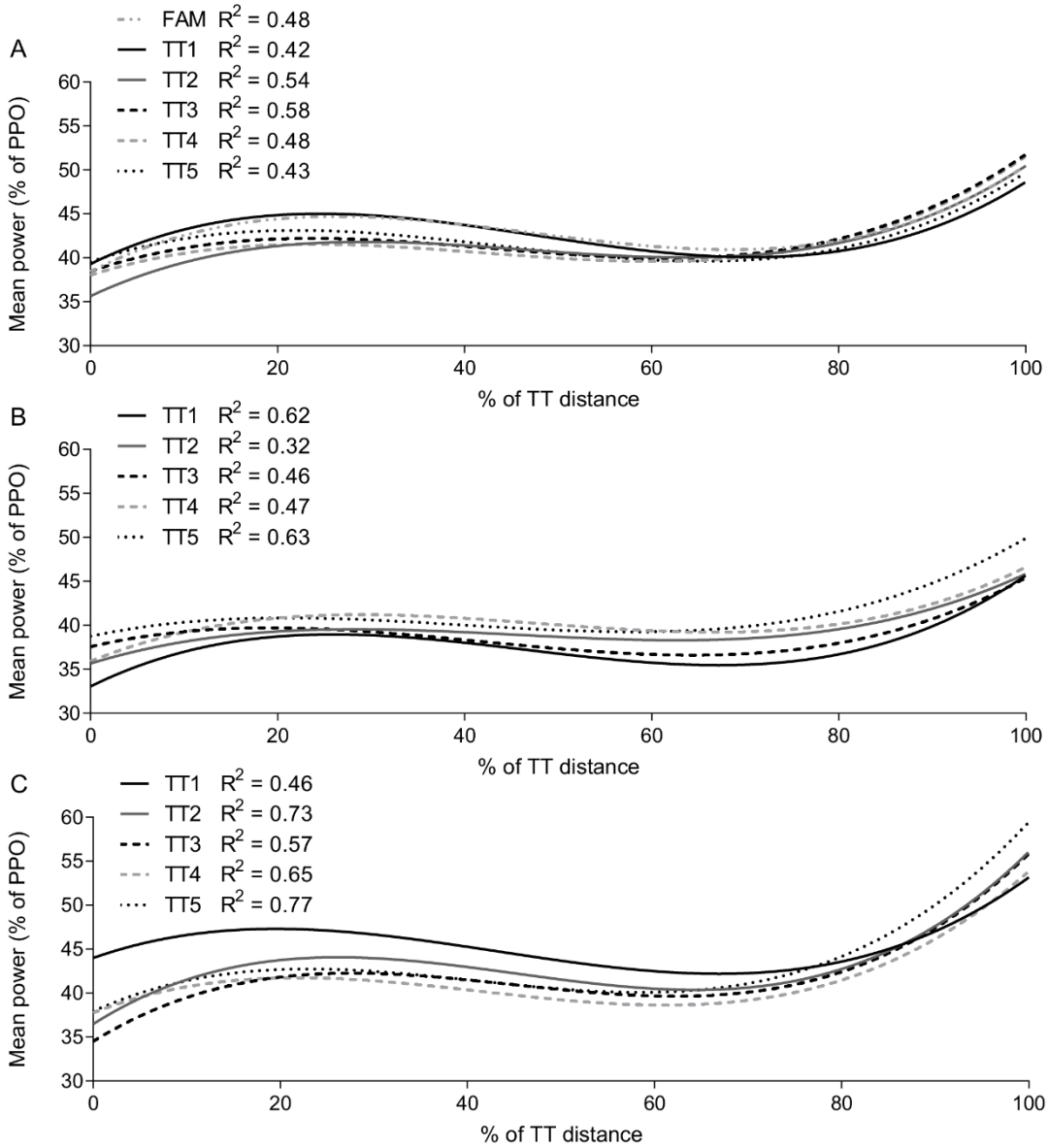

Figure 3-2 The line of best fit for each 2000-point mean power output profile.
FF (panel A), HF (panel B), EF (panel C). TT, time-trial. FAM, familiarisation. FF, full familiarisation. HF, half familiarisation. EF, equipment familiarisation. R^2, explained variance. FAM (dash and dot grey), TT1 (solid black), TT2 (solid grey), TT3 (dashed black), TT4 (dashed grey), TT5 (dotted black).

3.5 Discussion

This study investigated the efficacy of differing familiarisation protocols to limit the variability of pacing and performance over multiple trials. The main finding is that variability in pacing and performance was lowest after a full familiarisation and two additional TTs, while four or more trials did not improve results. These results are similar to previous research investigating familiarisations and the variability of performance (Marino et al., 2002; Schabort et al., 1998). However, within this study, we also investigated the variability of pacing profiles over multiple trials. Our results indicate that multiple familiarisations of a self-paced exercise are required before experimental testing to achieve enhanced reproducibility of pacing profiles.

3.5.1 Variability in performance

Previous exercise experience provides relevant information to determine an appropriate pacing strategy for subsequent trials that will lead to optimal performance (Tucker, 2009; Ulmer, 1996). Therefore, with different levels of experience (i.e. familiarisation), it is not surprising to observe large effects for between group performance differences occurring in TT1 in novice participants (Table 3-5 and Figure 3-1). These results are most likely due to the learning effects of the novice participant cohort. For TT1, the difference between FF and EF group was small (Table 3-5); however, there were large effects in comparison to the HF group. This suggests a familiarisation that is not identical to the exercise (i.e. HF) is less effective than very limited experience (i.e. EF) for best performance in one trial. This contrasts with findings on anticipatory regulation, as no experience means the participant has a poor understanding of exercise demands and no reference point to regulate too (Tucker, 2009). Yet, compared to no experience, it appears for novice participants, the experience of a similar mean power output sustained for half the duration (i.e. HF) is more detrimental to performance. It

appears that similar experience likely creates a discrepancy between the perceived and actual demands of the exercise, with a substantial change to the pacing strategy required. Similar changes in pacing have been demonstrated when exercise distance is varied, either knowingly (Billaut et al., 2011) or as a deception (Paterson & Marino, 2004). As TTs were repeated, pacing in all groups presumably becomes more refined and differences between groups were gradually reduced so that performance was comparable in TT4 and TT5 (Table 3-5).

Within HF and EF groups, but not FF, there were large effect sizes (η_p^2) for changes across all five TTs for performance measures (Table 3-3). This suggests that the application of one FF is a superior familiarisation protocol for reproducibility of performance over multiple trials. In addition, when comparing performance differences after completing one 20-km TT (i.e. the difference between familiarisation and TT1 in FF, and the difference between TT1 and TT2 in HF and EF), there were small differences in FF group, but large effects in HF and EF (Table 3-3). This finding suggests that HF and EF may be detrimental to performance over several trials, and one full familiarisation may be adequate for reproducibility of performance. Yet, as there was a moderate effect size (d) between TT1 and all other TTs in FF group (Figure 3-1 and Table 3-3), it appears that it may be prudent to implement more than one familiarisation. Well-trained cyclists need only one familiarisation trial to stabilize performance in a 20-km TT (Zavorsky et al., 2007), and this finding is also true for less experienced participants conducting 2-km TTs (Corbett et al., 2009). A 2-km TT, however, elicits a different pacing strategy than a 20-km TT (Abbiss & Laursen, 2008). In addition, the mechanisms of fatigue are likely to differ within shorter tasks, thus requiring less regulation of intensity (Tucker, 2009), presumably making it easier for untrained participants to pace appropriately. This current investigation was designed to confront participants with an exercise that is relatively

novel and highly dependent on complex internal regulation (Tucker, 2009). Therefore, it was expected that findings would give a better indication of the number of trials needed before reproducibility is obtained in novice participants. In support of our finding, trained cyclists have exhibited continued improvement after a second 8-mile TT (Noreen, Yamamoto, & Clair, 2010). However, as recent experience was lacking in these participants, it is possible that they needed to be re-familiarised, and the use of a pacer may have also influenced motivation. Regardless, this provides support for multiple familiarisations to reduce systematic error over multiple trials.

To indicate the number of trials required before variability in performance is reduced, performance measures were compared between trials (Table 3-3). Within FF Group, excluding the comparison with TT1 and mean power between TT3-TT4, the effect size (*d*) for performance changes between later TTs was small (Table 3-3). In contrast, there were large effects between later TTs for both HF and EF groups (Table 3-3). In conjunction, the between trial CV for TTs was lowest in FF group (Table 3-4), with CV for TT duration between TT3-TT4 and TT4-TT5 comparable to reported values from competitive cyclists (Noreen et al., 2010; Zavorsky et al., 2007). This strongly suggests that three full familiarisations can adequately reduce the variability in novice participants to comparable levels of experienced individuals. This finding is particularly important for researchers aiming to determine the magnitude of an intervention in novice participants. However, when interpreting these results, it is important to consider that biological variation can occur between subsequent tests, which may mask meaningful changes (McLellan, Cheung, & Jacobs, 1995). Consequently, instead of relying on test-retest results to assess reliability, it is suggested to utilise other dependent variables (McLellan, Cheung, & Jacobs, 1995). To this effect, although overall performance can be similar, the way in which the exercise is paced may differ (Ansley, Schabort, et al., 2004). In this

regard, an understanding of how TTs were paced would give important information on reproducibility of performance and whether a pacing profile has been established.

3.5.2 Variability in pacing profiles

Previous experience allows for an understanding of the physiological demands of the exercise so that an appropriate intensity can be initially set that requires less refinement throughout the task (Mauger, Jones, & Williams, 2009; Micklewright et al., 2010; Tucker, 2009). This has been demonstrated by participants with minimal experience increasing their starting power output when both 3-km and 10-km cycling TTs were repeated (Foster et al., 2009). Furthermore, without a familiarisation, it was only by the third or fourth TT that a similar pacing profile was achieved (Foster et al., 2009). In our investigation, the variability of pacing profiles (i.e. the magnitude of change in R^2 between trials) was lowest within FF group (Figure 3-2A). Although the pacing profile produced in the familiarisation and TT1 was similar, there is an apparent difference of TT2 in the FF group (Figure 3-2A). Most importantly, the stability of the pacing profile was greatest in TT3 ($R^2 = 0.58$) with no further improvement for later TTs (Figure 3-2A). This result strengthens the argument for multiple trials to familiarise novice participants. It should be noted, that the pacing profiles observed in this study will likely differ to a trained athlete (Foster et al., 2009) presumably due to participant capabilities and the willingness to exercise maximally (Edwards & Polman, 2013). However, the aim of this investigation was to observe how variability changed between TTs so a baseline performance could be identified. In this regard, these results provide evidence that three familiarisations should be administered to establish a reliable baseline in novice participants and to enhance reproducibility over several trials.

In all groups, there was an apparent difference in the pacing profile of TT1 (Figure 3-2), with EF TT1 the most dissimilar to other TTs (Figure 3-2C). The higher intensity at

the start of the TT1 is surprising given the lack of experience in the exercise, as it would be expected a more conservative approach would be taken (i.e. an intensity that can be maintainable for an extended period) (Lambert et al., 2005; Tucker, 2009; Williams et al., 2012). No experience of the exercise may have created a discrepancy between the perceived and actual demands of the exercise. Subsequently, the fast start strategy in TT1 may have contributed to reduced reproducibility of the pacing profile among the five TTs (Figure 3-2C). In contrast, a conservative approach was taken by HF participants, with much of TT1 having a reduced power output compared to later TTs (Figure 3-2B). Much like what was observed in the EF group, this difference likely occurs as the difference in experience creates a poor understanding of actual exercise demands. It is possible that participants were conservative during early TTs as they anticipated a greater metabolic cost than what was experienced in the familiarisation. However, as experience in the TT was gained, the intensity was increased in later TTs (Figure 3-1B & Figure 3-2B), as it becomes apparent that the TT could be completed without negative consequences. This willingness to work at a higher intensity as participants become more experienced in the exercise has been demonstrated previously (Foster et al., 2009).

Another indication of pacing variability is that the end spurt of TTs became larger as TTs were repeated in both HF and EF groups. This likely indicates the adoption of a different pacing strategy in the early part of TTs. Specifically, with more experience, participants have a greater understanding of exercise demands and presumably adopt a more manageable approach during the TT that allows a higher intensity towards the end of the bout (Micklewright et al., 2010; Williams et al., 2012). Along with this line of reasoning, participants in EF had a reduced end spurt in TT1 with the early unsustainable intensity in the first half of TT1 likely creating greater fatigue (Figure 3-2C), thus diminishing the ability to work at a higher intensity at the end of the TT. In contrast to

both HF and EF groups, there is no substantial change in the end spurt between TTs in the FF group. It is most likely the full prior experience from a familiarisation allowed participants to gain a better understanding of the exercise and may have adopted a more efficient even paced strategy (Abbiss & Laursen, 2008).

3.5.3 Limitations

In conjunction with the influence of prior experience, the knowledge of the actual performance of a task is also crucial in setting a successful pacing strategy (Micklewright et al., 2010). Information was withheld until completion of our study and therefore can be considered a limitation, as our participants may have reduced their variability between TTs if they were made aware of their performances. However, this information would have introduced a bias to our objective, so we preferred to withhold this information.

3.5.4 Practical applications

This investigation refines guidelines for familiarising novice participants to a cycling TT. Application of a full exercise familiarisation produced the greatest reproducibility in pacing and performance over multiple trials, compared to a half exercise familiarisation and no experience. Within the FF group, there were small differences in TT duration between TT2 and other TTs, indicating only two familiarisations may be required. Yet, a stable pacing profile was not developed until TT3 (Figure 3-2A). Taken together, these results provide support for the use of three full exercise familiarisations to minimize the variability often demonstrated by novice participants. In addition, the cohort of participants in this study had no experience in self-paced TTs and had limited experience in cycling. Taking this into account, it may be possible to extend the conclusion that three familiarisations should be administered to reduce variability in any self-paced exercise. It has also been observed that trained cyclists can display learning effects after a second TT (Noreen et al., 2010). In this situation,

recent experience in the exercise was lacking, suggesting experienced participants may need to be re-familiarised to the TT. With novice participants, as a worst-case scenario, this study gives merit to the use of multiple familiarisations to reduce systematic error, regardless of participant experience. However, it would likely warrant future investigations to determine if the same effects are seen in different modes of exercise, and the magnitude of effect in trained participants who lack specific experience in the exercise. Transferring our recommendations into practice, the application of three familiarisations may considerably add to lengthy testing protocols and likely impact on participant recruitment and retention. Additionally, in designing an experimental protocol, it may be a priority of a researcher to add another experimental condition at the expense of a lengthy familiarisation protocol, while not creating a significant time burden on the participant. To address this, it may be possible to reduce the time interval between familiarisation sessions without compromising pacing strategy development. In this study, trials were conducted at least 48 hours apart, however, for shorter TTs, similar to the protocol utilized by Mauger et al. (2009), it may be possible to conduct multiple trials within one session, to achieve a reproducible performance. However, this has not yet been tested with novice participants. Another possible solution to reduce the time requirements of multiple familiarisations could be the application of two familiarisation trials with a test-retest to determine if the variability of performance (i.e. overall time) and pacing (i.e. power profile) are acceptable. This approach would be similar to the work of Thomas et al. (2012). This approach would be able to detect any meaningful change when variation in the subsequent experimental is in excess of the test-retest variability. However, this process may not be suitable for novice participants who may have a large variation in initial trials due to still learning the task. Regardless, given the possible benefit, this approach is of merit to investigate in a novice cohort.

3.6 Conclusions

Prior experience is an important moderator of self-paced performance. Therefore, it is important for participants to gain experience in an exercise before conducting experimental testing to establish a reproducible baseline performance. This study demonstrates that three familiarisation trials of the exact experimental protocol should be administered to reduce variability across multiple trials in novice participants. This finding should be considered when interpreting the results of interventions that utilize self-paced tasks and unfamiliar participants. In conclusion, it is recommended that future investigations administer three familiarisation trials to reduce systematic error before experimental testing.

CHAPTER 4. STUDY 2: NO INFLUENCE OF TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION ON EXERCISE-INDUCED PAIN AND 5-KM CYCLING TIME-TRIAL PERFORMANCE

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4.1 Abstract

Introduction: Afferent information from exercising muscle contributes to the sensation of exercise-induced muscle pain. Transcutaneous electrical nerve stimulation (TENS) delivers low–voltage electrical currents to the skin, inhibiting nociceptive afferent information. The use of TENS in reducing perceptions of exercise-induced pain has not yet been fully explored. This study aimed to investigate the effect of TENS on exercise-induced muscle pain, pacing strategy and performance during a 5-km cycling time trial (TT).

Methods: On three separate occasions, in a single-blind, randomized and crossover design, 13 recreationally active participants underwent a 30-min TENS protocol, before performing a 5-km cycling TT. TENS was applied to the quadriceps prior to exercise under the following conditions; control (CONT), placebo with sham TENS application (PLAC), and an experimental condition with TENS application (TENS). Quadriceps fatigue was assessed with magnetic femoral nerve stimulation assessing changes in potentiated quadriceps twitch force at baseline, pre and post exercise. Subjective scores of exertion, affect and pain were taken every 1-km.

Results: During TTs, application of TENS did not influence pain perceptions (P = 0.68, ηp2 = 0.03). There was no significant change in mean power (P = 0.16, ηp2 = 0.16) or TT duration (P = 0.17, ηp2 = 0.14), although effect sizes were large for these two variables. Changes in power output were not significant but showed moderate effect sizes at 500-m (ηp2 = 0.10) and 750-m (ηp2 = 0.10). Muscle recruitment as inferred by electromyography data was not significant but showed large effect sizes at 250-m (ηp2 = 0.16), 500-m (ηp2 = 0.15) and 750-m (ηp2 = 0.14). This indicates a possible effect for TENS influencing performance up to 1-km.

Discussion: These findings do not support the use of TENS to improve 5-km TT performance.

4.2 Introduction

The purpose of pacing is to regulate exercise intensity throughout a task so that neuromuscular fatigue can be managed, while also considering other circumstantial factors that will impact on optimal performance, such as environmental conditions. Essentially, pacing prevents excessive physiological harm and maximizes goal achievement (Edwards & Polman, 2013). To accomplish this, decisions are made based on information received from both internal and external environments, to adjust exercise intensity (Edwards & Polman, 2013; Smits et al., 2014). Initially, pacing strategies are set in anticipation (Tucker, 2009; Ulmer, 1996), whilst regulation of intensity during exercise is influenced by afferent information from exercising muscle (Amann et al., 2009). Therefore, the ability to adjust or remove this information is of interest in pacing research, as there is potential to improve performance.

Exercise typically augments mechanical and chemical stimuli within the muscle, sensitizing and activating nociceptive group III and IV afferent muscle fibres. These communicate information on actual or potential muscle damage to the central nervous

system (O'Connor & Cook, 1999). Conscious awareness of this information forms the subjective sensation of exercise-induced pain (Loeser & Treede, 2008; Mauger, 2013). Pacing theory states that low signal (feedback) intensity will not trigger awareness (Swart et al., 2012). Yet, with an increasing stimulus intensity (i.e. intense exercise), conscious awareness is achieved, which results in appropriate decisions to change behaviour (Edwards & Polman, 2013; Swart et al., 2012). Therefore, once nociceptive signals and consequently perceptions of pain become prominent, effort will be regulated to maintain discomfort at a tolerable level (Edwards & Polman, 2013; Mauger, 2014; Swart et al., 2012). This concept of a 'sensory tolerance limit'(Gandevia, 2001; Hureau et al., 2018), likely occurs to prevent excessive physiological harm by limiting levels of fatigue (Amann et al., 2009). The sum of signals from a number of mechanisms contribute to this theory, including feedback from group III and IV muscle afferents but also feedback from respiratory muscles and corollary discharges (Hureau et al., 2018). Reductions to exercise performance and duration due to exercise-induced fatigue, are evidence of this concept (Amann et al., 2013). In addition, the importance of nociceptive information as part of a global tolerance limit has been demonstrated by altered nociceptive stimuli (i.e. induced or blocked), leading to changes in voluntary activation of muscle (Amann et al., 2009; Kennedy, McNeil, Gandevia, & Taylor, 2014). Only a small number of studies, investigating analgesic interventions to augment afferent information have focused on exercise pacing and performance. Injecting fentanyl increases initial power output, but results in excessive fatigue (Amann et al., 2009), while ingestion of acetaminophen can increase mean power output during a time-trial (TT) (Mauger et al., 2010a) and during repeated-sprint exercise (Foster et al., 2014). An increased exercise intensity suggests nociceptive signals affect self-pacing. Yet, in acetaminophen studies, there was no change in pain perceptions. This suggests a threshold of perceived pain was adjusted and exercise

intensity was increased to this tolerance limit. Therefore, there is merit for any analgesic intervention during self-paced exercise to adjust perceptions of exercise-induced pain allowing for an increased intensity (and possibly performance), before perceptions become prominent.

An alternative to ingested and injected analgesics is transcutaneous electrical nerve stimulation (TENS). Application of TENS involves low-voltage electrical currents administered to the skin for pain relief (Johnson et al., 2015). Analgesic effects are provided following the gate control theory of pain (Melzack & Wall, 1965), which controls the transmission of nociceptive information. Specifically, the stimulation provided by TENS targeting group II muscle afferent fibres excites inhibitory interneurons. This results in an attenuation of the ascending nociceptive stimuli from group III and IV afferent fibres (Johnson et al., 2015; Sluka et al., 2013). Based on this premise, it is possible that TENS could be used to attenuate nociceptive stimuli associated with aerobic exercise. Clinically, the analgesic effects of TENS have been demonstrated for chronic musculoskeletal pain (Johnson & Martinson, 2007). In pain-free individuals, the application can influence pressure pain thresholds (PPT) (Moran et al., 2011). During exercise in pain-free individuals, TENS application has improved tolerance by enhancing peripheral blood flow (Tomasi et al., 2015). Furthermore, when knee pain was induced, TENS has also reduced pain and restored quadriceps strength (Son et al., 2016). This suggests that TENS could be used in pain-free individuals to reduce pain perceptions, and possibly perceptions of exercise-induced pain. If demonstrated, a reduction of exercise-induced pain, in conjunction with possible alterations in muscle contractile properties and enhancement of blood flow, gives the potential for TENS application to be a performance enhancing strategy.

To the authors' knowledge, TENS has not been used in pain-free participants to modulate afferent feedback and reduce exercise-induced pain perceptions during self-paced exercise. Based on the potential to influence exercise-induced pain, the aim of this study was to investigate the efficacy of TENS administered before intense exercise to influence pain perceptions. It was hypothesized that TENS would influence the threshold for sensing exercise-induced pain, thereby increasing exercise intensity and performance for similar subjective pain perceptions. As TENS can influence muscle excitability and strength, a secondary objective was to assess within-exercise muscle recruitment (via electromyography) and neuromuscular fatigue. To allow the assessment of muscle recruitment, application of TENS was administered prior to exercise, in anticipation of approximately 30-mins of post-stimulation analgesia, utilizing similar TENS settings displaying increased PPT within this period (Moran et al., 2011; Pantaleão et al., 2011). To allow for exercise to be within the post-stimulation time frame, a 5-km cycling TT was utilized, as it was anticipated this would be completed in ~10-mins.

4.3 Methods

4.3.1 Participants

Thirteen recreationally active participants were recruited for this study (see Table 4-1). Written informed consent was provided in accordance with the Declaration of Helsinki. The inclusion of both males and females was based on indications sex has no influence on the level of exercise-induced pain within the time frame proposed for this study (Dannecker et al., 2012), with repeated measures trial design minimizing any potential differences. Using a medical questionnaire, all participants were screened for risk factors including suitability to the exercise, current pain, currently taking pain medication and any prior use of TENS. Participants who reported pain (chronic or acute) or prior use of TENS were excluded from the study. Participants were asked to refrain

from any physical activity causing severe fatigue in the 36 hours prior, as well as any caffeine intake or pain medication two hours prior to testing sessions. Procedures were approved by Victoria University's Human Research Ethics Committee.

Table 4-1 Participant anthropometric data.

	Female	**Male**	**Total**
	n = 4	*n* = 9	*n* = 13
Age (years)	27.5 ± 7.4	23.3 ± 4.2	24.6 ± 5.5
Height (cm)	166.0 ± 9.1	179.5 ± 7.0	175.3 ± 9.8
Body mass (kg)	62.2 ± 9.2	77.1 ± 7.8	72.8 ± 10.6
PPO (W)	250.3 ± 39.7	321.3 ± 23.0	299.5 ± 43.7
PPO (W/kg)	4.0 ± 0.4	4.2 ± 0.5	4.2 ± 0.5
VO_{2peak} ($L.min^{-1}$)	2.6 ± 0.6	3.8 ± 0.3	3.4 ± 0.7
VO_{2peak} ($ml.min.kg^{-1}$)	40.9 ± 6.3	49.4 ± 5.6	46.7 ± 6.9
Pain at PPO	7.8 ± 2.9	9.0 ± 1.1	8.6 ± 1.8

Note: Data presented as mean ± SD. PPO, peak power output. VO_{2peak}, peak oxygen consumption. Pain at PPO, rating of perceived quadriceps pain at PPO.

4.3.2 Experimental procedures

Participants reported to the laboratory for seven sessions, which included four preliminary and three experimental sessions. Prior to experimental sessions, three 5-km TT sessions were conducted to familiarise participants and ensure adequate reliability of pacing and performance (Hibbert, Billaut, Varley, & Polman, 2017). Furthermore, during the first session, participants were also familiarised with TENS, peripheral magnetic stimulation protocols and algometry (see procedures below). The final preliminary session was a peak oxygen uptake (VO_{2peak}) assessment to characterize participants' cardiorespiratory fitness. For experimental testing, on three different days separated by a minimum of 48 hours, participants performed three 5-km cycling TTs in a single-blind randomized order: control (CONT), placebo with sham TENS application (PLAC), and an experimental condition with TENS application (TENS). TENS was applied for 30-min before performing a cycling TT (see TENS procedure below). Maximal voluntary contraction (MVC) force, responses to magnetic stimulation of the quadriceps and PPT

were measured before TENS application (BASE), as well as pre (PRE) and immediately post (POST) exercise.

Upon reporting to the laboratory, participants were fitted with electromyography (EMG) electrodes (see below). A warm up of MVC and magnetic stimulation (see below) was conducted before BASE measurement. Participants were then fitted with TENS electrodes for 30-min of TENS application. A cycling warm-up (5-min cycling at 75 Watts) was conducted before PRE-measurement of MVC. Immediately following PRE-measurements, a 5-s sprint was conducted for EMG normalization purposes. Following this, the TT commenced after a verbal 3-s countdown from the researcher. To overcome flywheel inertia, participants were instructed to obtain a self-selected comfortable cadence immediately prior to beginning the TT. All exercise was conducted on a Velotron Pro cycle ergometer (RacerMate Inc., Seattle, WA, USA). Within the familiarisation sessions, participants set the ergometer to their own specifications with values recorded and replicated for subsequent sessions. All TT protocols were controlled via Velotron Coaching software (Version 1.6.458, RacerMate Inc.) with all courses being flat with no wind effect. Participants were permitted to drink water *ad libitum* during trials. Participants were instructed to finish the required distance "as quickly as possible", being free to change gear and cadence throughout the TT as desired. Participants were blinded from information except for distance covered. Upon TT completion, participants were quickly assisted in moving to the MVC and magnetic stimulation apparatus, for POST assessment.

4.3.3 VO_2 assessment

After TT familiarisation sessions, to characterize participants, VO_{2peak} was assessed via a maximal incremental test. A ramp protocol was utilized, that equated to 30 Watts/min which commenced after a 3-min baseline period, cycling at 0 Watts

(Vanhatalo, Doust, & Burnley, 2007). As participant familiarity with cycling varied, a similar test was chosen to that used for participants unfamiliar with cycling (Williams et al., 2012). Expired gas was collected and analysed every 15-s (S-3A/I (O2) and CD-3A (CO2), AEI Technologies Inc., Pittsburgh, PA). Prior to each test, gases were calibrated with known concentrations and flow calibrations were performed using a 3-L calibration syringe. Participants were encouraged throughout the final stages and the test ceased when the participant could not maintain a cadence above 60 rpm or volitional fatigue was achieved. Peak oxygen uptake was calculated as the highest 30-s mean VO_2 and peak power defined as the highest power at test conclusion. Subjective ratings for exertion (RPE) and quadriceps pain (pain scale) were measured every minute.

4.3.4 Transcutaneous electrical nerve stimulation (TENS)

Participants were acutely treated with TENS (N602 ProTens; Everyway Medical Instruments, New Taipei City, Taiwan) for 30-min prior to the exercise protocol. Two TENS units were used so that the area of stimulation could be increased, with one unit (two channels) dedicated to each leg. Stimulation was applied through 50 mm x 90 mm adhesive electrodes (Allcare; Everyway Medical Instruments, New Taipei City, Taiwan). TENS electrode placement occurred after BASE MVC measurement, with sites shaved before placement. At the conclusion of stimulation, TENS electrodes were removed. For electrode placement, participants were asked to lay in a supine position and perform a knee extension. Two electrodes were placed on the superior portion of the quadriceps, inferior to the inguinal fold over the areas of contracted muscle bulk. Two electrodes were also placed over the inferior portion of the quadriceps, one over the vastus lateralis and one over the vastus medialis. TENS was delivered in constant mode with settings fixed at a pulse width of 200-μs, and frequency of 82.6-Hz (Chen & Johnson, 2010). The duration and settings (pulse width and frequency) of TENS was based on previous studies

showing the effect of TENS on PPT (Moran et al., 2011; Pantaleão et al., 2011). In this investigation, for the assessment of muscle recruitment and practicality of exercise, application of TENS was administered prior to exercise in anticipation of approximately 30-mins of post-stimulation analgesia (i.e. increased PPT) as observed in previous studies (Moran et al., 2011; Pantaleão et al., 2011). Prior to study commencement, settings for the TENS units were verified using an oscilloscope (Rigol DS1054). Following calibration checks, transparent tape was placed over these controls to prevent any adjustment. For TENS application, participants were instructed to adjust the intensity (via manual dials) to a level of non-painful tingling below a level that evokes involuntary muscle contraction (Moran et al., 2011; Pantaleão et al., 2011; Son et al., 2016). Throughout 30-min TENS application, participants were asked to periodically increase the intensity to ensure this remained at the desired level. For PLAC condition, the same electrode placement was used, but stimulation intensity was set by the researcher. To appear that stimulation was present, the TENS unit power indicator was illuminated, although the equipment did not provide stimulation. For this condition, participants were told stimulation was set to a sub-sensory level (Cheing, Hui-Chan, & Chan, 2002). For TENS condition, participants were informed that they were receiving high TENS and low TENS for PLAC condition. In both conditions, participants were advised that they may or may not feel any stimulation, and in the absence of sensation, stimulation was still active and providing analgesic effects. To account for the time taken for TENS application, during CONT condition, participants laid quietly in a supine position for 30-mins.

4.3.5 Electromyography

Electromyographic (EMG) activity of six muscles (*vastus medialis, vastus lateralis, rectus femoris, biceps femoris, medial gastrocnemius and gluteus maximus)* was

recorded from the right lower limb via Ag/AgCl bipolar rectangular electrodes with a diameter of 30 mm x 20 mm and an inter-electrode distance of 20 mm (Blue Sensor N-00-S, Ambu Medicotest A/S, Ølstykke, Denmark). All signals were recorded continuously at 1500 Hz via a wireless receiver (Telemyo 2400 GT, Noraxon Inc., USA). Prior to electrode placement, the limb was shaved and abraded to minimize skin impedance, and appropriate electrode placement and functionality was checked before the start of each test. When the position of quadriceps electrodes overlapped with TENS electrode placement, electrode location was marked with a waterproof felt-tip pen to ensure reliable electrode replacement within sessions. All electrode sites were marked for reliable placement between subsequent testing sessions. To avoid artefacts from lower-limb movements, the electrodes were well secured with rigid tape. Raw EMG signals were band-pass filtered (12-500 Hz), were full-wave rectified and Root Mean Squared using Noraxon software (MyoResearch XP version 1.08.27). Mean RMS for individual muscles was analysed for 20-s at 250-m intervals of TT distance. Individual muscle RMS values were summed to estimate general muscle electrical activity (RMS_{sum})(Billaut, Davis, Smith, Marino, & Noakes, 2010), and is reported as a percent of the individual maximum value obtained during a pre-exercise sprint (O'Bryan, Brown, Billaut, & Rouffet, 2014).

4.3.6 Peripheral magnetic stimulation

Stimulation of the femoral nerve and quadriceps muscle was conducted using a magnetic stimulator (Magstim RAPID^2; JLM Accutek Healthcare, Homebush, NSW) and a double 70-mm coil (Amann, Romer, Subudhi, Pegelow, & Dempsey, 2007; Billaut et al., 2013; Katayama et al., 2004). Force responses were obtained at 1 kHz from a calibrated load cell (Extran 2kN “S” beam, model SW1, Applied Measurement, Melbourne, Australia). The load cell was connected to a non-compliant strap, which was

attached around the participant's leg just superior to the malleoli of the ankle. Voluntary force and neuromuscular testing was conducted at BASE, PRE (~3-min pre-exercise) and POST (between 40 to 60-s post-exercise). Allowing for removal of TENS electrodes and application of EMG electrodes, the delay between the end of TENS application and PRE, was approximately 10 minutes. The time taken from the start of PRE-assessment to TT start was ~6 minutes.

To determine the area of stimulation associated with the largest quadriceps twitch (Q_{tw}), the coil head was positioned high on the thigh, between the quadriceps muscle and the femoral triangle (Amann et al., 2007; Billaut et al., 2013; Katayama et al., 2004). This position was marked and kept the same for all trials. At BASE a warm-up was conducted with brief (~5-s) submaximal voluntary contractions increasing to an MVC separated by ~40-s. To indicate maximal depolarization of the femoral nerve, a ramp protocol of increasing stimulus intensity (from 70% -100%) was used to achieve a plateau in BASE Q_{tw} (Amann et al., 2007; Billaut et al., 2013; Katayama et al., 2004). A near plateau was achieved in all participants at 95%-100% stimulator output. For assessment, the stimulus power was set at 100% of maximum, and single stimuli were delivered. During a 5-s MVC of the quadriceps, the femoral nerve was stimulated (superimposed single stimuli) to determine the completeness of muscle activation (Amann et al., 2007; Billaut et al., 2013; Katayama et al., 2004). Stimulation was administered when the researcher visually identified a plateau in torque (Tofari, Opar, Kemp, Billaut, & Cormack, 2016). Three potentiated quadriceps twitches ($Q_{tw,\,pot}$) were obtained 5-s after the MVC. This procedure was performed three times at BASE and PRE (60-s of rest in between) such that nine $Q_{tw,pot}$ values were obtained, with the $Q_{tw,pot}$ averaged and analysed for peak force. The procedure was only performed once at end-exercise to reduce post-exercise assessment time and limit recovery as much as possible (Billaut et al., 2013). Surface EMG was used

to assess the membrane excitability via muscle action potentials (M-waves) during potentiated twitches, with peak to peak duration and amplitude measured. With single stimuli delivered during the MVCs the quadriceps central activation ratio (CAR) was calculated as the percentage of voluntary force obtained during the superimposed contraction, that is, CAR = MVC ÷ (MVC + stimulated force) (Kent-Braun, 1999; Tofari et al., 2016). Stimulation was delivered on visual identification of torque plateau, and in some cases, it occurred before or after the torque plateau. To account for this, a correction equation was used where torque was averaged over 100-ms before the superimposed peak (Marshall, Lovell, Jeppesen, Andersen, & Siegler, 2014; Tofari et al., 2016). Due to technical problems, some CAR data were not included, and these participants have been removed from analysis with total n =10.

4.3.7 Perceptual scores

A 6-20 scale of rated perceived exertion (RPE) (Borg, 1970), an 11-point bipolar feeling scale (FS) (Hardy & Rejeski, 1989) and a pain scale (O'Connor & Cook, 2001) were used to assess perceived effort, affect and perceived quadriceps muscle pain. Prior to commencing the study, participants were given instructions and explained all scales. During familiarisation and experimental TT's, ratings were recorded at every kilometre. At the conclusion of the study, participants were asked to subjectively access the effectiveness of TENS application. Participants were asked to rate on a 1-10 scale (1; a bit, 10; a lot), the relief from pain, and impact on performance that TENS application provided. Responses were received for both TENS and PLAC conditions.

4.3.8 Algometer

Measures of PPT were recorded for the pressure applied to the quadriceps with an algometer (FPX Algometer; Wagner Instruments) with a 1-cm^2 application surface. Recordings displayed in kilograms of force (kgf) were taken from the left leg at BASE,

in the last minute of TENS application (i.e. PRE-exercise) and at POST. Assessment site was the midpoint between the anterior superior iliac spine and head of the patella. Recordings were taken with pressure applied to relaxed muscle at a rate of 1 $kg \cdot cm^{-2} \cdot s^{-1}$. Participants verbally reported the first point when pain (distinct from pressure or discomfort) occurred, the algometry was immediately removed and the corresponding measurement recorded as PPT (Moran et al., 2011).

4.3.9 Statistical analysis

Conditions are defined as control (CONT), placebo with sham TENS application (PLAC), and an experimental condition with TENS application (TENS). All data were analysed using SPSS (version 22, SPSS Inc., Chicago, IL.), and reported as mean ± SD. Tests for homogeneity of variances were performed to ensure normality of the cohort for dependent variables. With normality confirmed, two-way repeated measures ANOVAs (Condition x distance) were used to analyse changes in RPE, FS and pain. One way repeated measures ANOVAs were used to analyse changes in total duration and average power, as well as 1-km duration and mean power. Two-way repeated measures ANOVAs (Condition x time) were used to analyse changes between BASE, PRE-and POST measurements for MVC, evoked response to magnetic stimulation and PPT. Percentage change between measurements (BASE-PRE and PRE-POST) was also investigated. To investigate pacing profiles, mean power and RMS_{sum} were analysed over 250-m using repeated measures ANOVAs (Condition x distance). Given inter-participant differences in TTs, power output is expressed as a product of an individual's mass (W/kg). When sphericity was violated, Greenhouse-Geisser correction was used to adjust degrees of freedom. Paired samples *t*-tests were used to analyse subjective ratings of the TENS. For a significant main effect, post-hoc comparisons were examined with a one-way repeated measures ANOVA with Sidak multiple comparisons and paired sample *t*-tests. Statistical

significance levels for all tests was set at $P < 0.05$. Effect sizes for ANOVA are reported as partial eta squared (η_p^2) with a small effect at 0.01, medium effect 0.06 and a large effect > 0.14. Effect sizes for t-tests are reported as Cohen's *d* with a small effect at 0.2, medium 0.5 and large > 0.8 (Cohen, 1988).

4.4 Results

4.4.1 Perceptual scores and pain

There was a significant distance effect for RPE, FS and pain (P < 0.01), with all conditions having an increase in RPE and pain, whilst having a decrease in FS (Table 4-2). No significant interaction (Condition x distance) effect was found for any perceptual score, RPE (P = 0.58), FS (P = 0.68) and perceived quadriceps pain (P = 0.68) (Table 4-2). However, FS showed a moderate effect size and RPE had a large effect size for the interaction and trial effects. There was also no change in pressure pain thresholds attributed to TENS (see Table 4-4 and Table 4-3). Post study subjective ratings of the effectiveness of TENS were different between PLAC and TENS conditions for the level of pain relief ($t_{(12)} = 2.68$ $P = 0.02$, $d = 1.55$) and positive influence on performance ($t_{(12)} = 4.68$ $P < 0.01$, $d = 2.70$) (Figure 4-1) with large effect sizes.

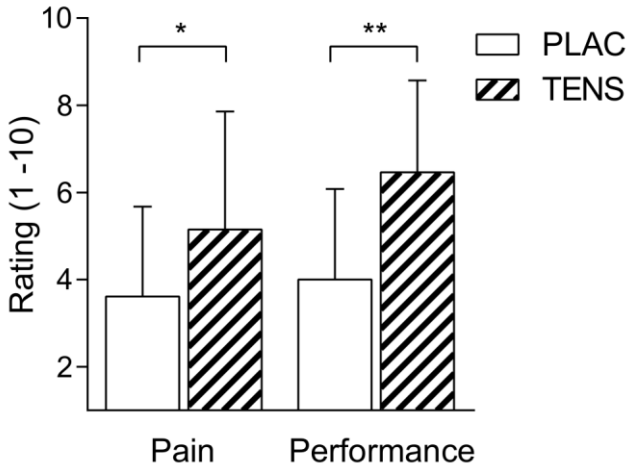

Figure 4-1 Mean ± SD TENS belief ratings. Participants ratings of pain relief (Pain) and subsequent influence on performance (performance). PLAC, placebo. TENS, TENS condition. Ratings are expressed on a 1-10 scale (1; a bit, 10; a lot). * indicates a difference for pain, $P < 0.05$. ** indicates a difference for performance $P < 0.01$.

Table 4-2 Subjective ratings for exertion, affect and pain at each kilometre of TTs

	1- km	2-km	3-km	4-km	5-km	Trial effect	Distance effect	Interaction
RPE								
CONT	11.69 ± 1.44	12.85 ± 1.77	13.69 ± 1.93	14.88 ± 2.38	16.77 ± 1.96			
PLAC	11.85 ± 1.68	13.00 ± 1.41	14.31 ± 1.25	15.00 ± 1.58	17.31 ± 1.75	$P = 0.12$ $\eta_p^2 = 0.16$	$P < 0.01$ $\eta_p^2 = 0.82$	$P = 0.58$ $\eta_p^2 = 0.16$
TENS	12.23 ± 0.73	13.62 ± 1.12	14.54 ± 1.27	15.31 ± 1.65	17.15 ± 1.52			
FS								
CONT	1.69 ± 1.88	0.54 ± 1.71	-0.23 ± 1.92	-0.54 ± 2.15	-1.31 ± 2.46			
PLAC	1.15 ± 1.41	0.46 ± 1.56	-0.31 ± 1.84	-0.62 ± 2.14	-0.92 ± 2.84	$P = 0.72$ $\eta_p^2 = 0.03$	$P < 0.01$ $\eta_p^2 = 0.69$	$P = 0.68$ $\eta_p^2 = 0.06$
TENS	1.15 ± 1.57	0.38 ± 1.66	-0.31 ± 1.84	-0.85 ± 2.30	-1.31 ± 2.66			
Pain								
CONT	2.19 ± 1.79	2.96 ± 2.09	3.92 ± 2.29	4.62 ± 2.73	6.12 ± 2.87			
PLAC	1.92 ± 1.31	2.92 ± 1.71	3.58 ± 1.89	4.38 ± 2.36	5.77 ± 2.62	$P = 0.68$ $\eta_p^2 = 0.03$	$P < 0.01$ $\eta_p^2 = 0.73$	$P = 0.68$ $\eta_p^2 = 0.05$
TENS	2.50 ± 2.21	2.81 ± 1.44	3.54 ± 1.90	4.35 ± 2.10	6.08 ± 2.36			

Note: Data presented as mean ± SD. RPE, Rate of perceived exertion. FS, feeling scale. Pain, perceived quadriceps pain. CONT, control. PLAC, placebo. TENS, TENS condition. η_p^2, partial eta squared. Significant distance effects are not shown.

4.4.2 Overall performance

There was no significant difference for mean power maintained over the TT ($F_{(1.8, 21.8)} = 2.0$, $P = 0.16$, $\eta_p^2 = 0.16$), although there was a large effect size (Figure 4-2A). Completion time between conditions was not significantly different ($F_{(2, 24)} = 1.9$, $P = 0.17$, $\eta_p^2 = 0.14$) and had a large effect size (Figure 4-2C). Average power for the first kilometre was not significantly different ($F_{(1.4, 16.6)} = 1.8$, $P = 0.21$, $\eta_p^2 = 0.13$) (Figure 4-2B), as was duration ($F_{(1.8, 21.5)} = 1.7$, $P = 0.20$, $\eta_p^2 = 0.13$) (Figure 4-2D), however both had a moderate effect size. Visual inspection of data (Figure 4-2D) shows a decreased time in TENS condition. Of all participants, nine had a reduced time in the TENS condition at one kilometre compared to CONT (-3.12 ± 5.58 s to CONT, 95% CI; -6.49, 0.26) (Figure 4-3D). For total TT duration eight out of 13 improved their time in TENS compared to CONT (-3.82 ± 12.96 s to CONT, 95% CI; -11.65, 4.01) (Figure 4-3C).

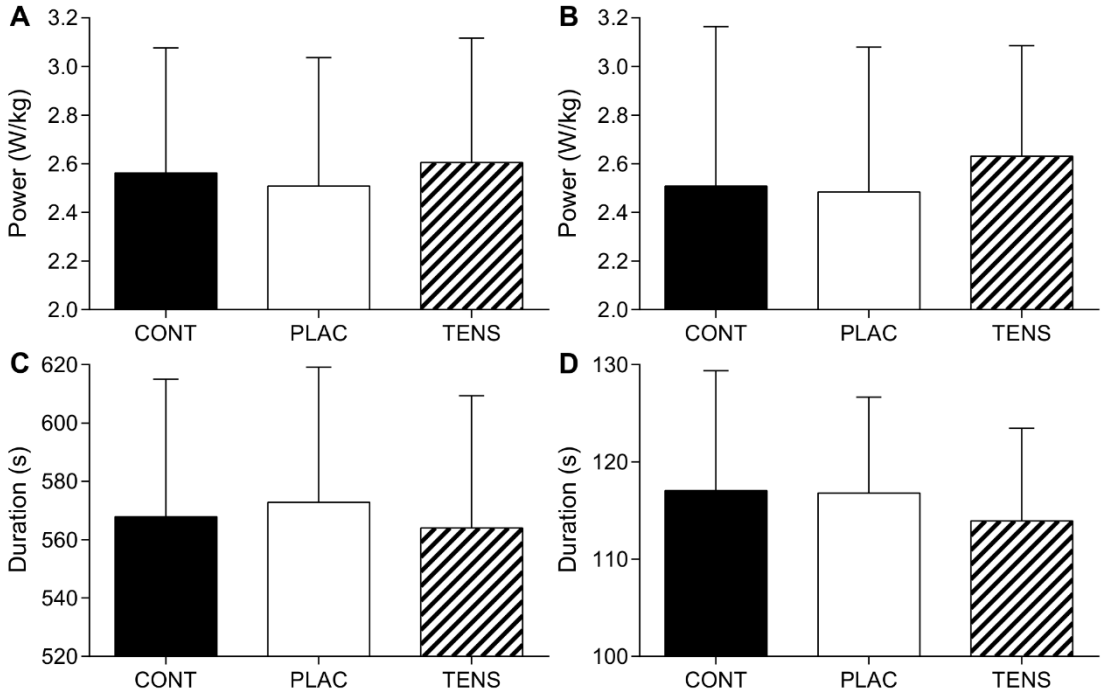

Figure 4-2 Mean ± SD TT performance measures. Mean ± SD TT mean power output (W/kg) (panel A), 1-km mean power output (W/kg) (panel B), TT duration (s) (panel C) and 1-km duration (s) (panel D). CONT, control. PLAC, placebo. TENS, TENS condition.

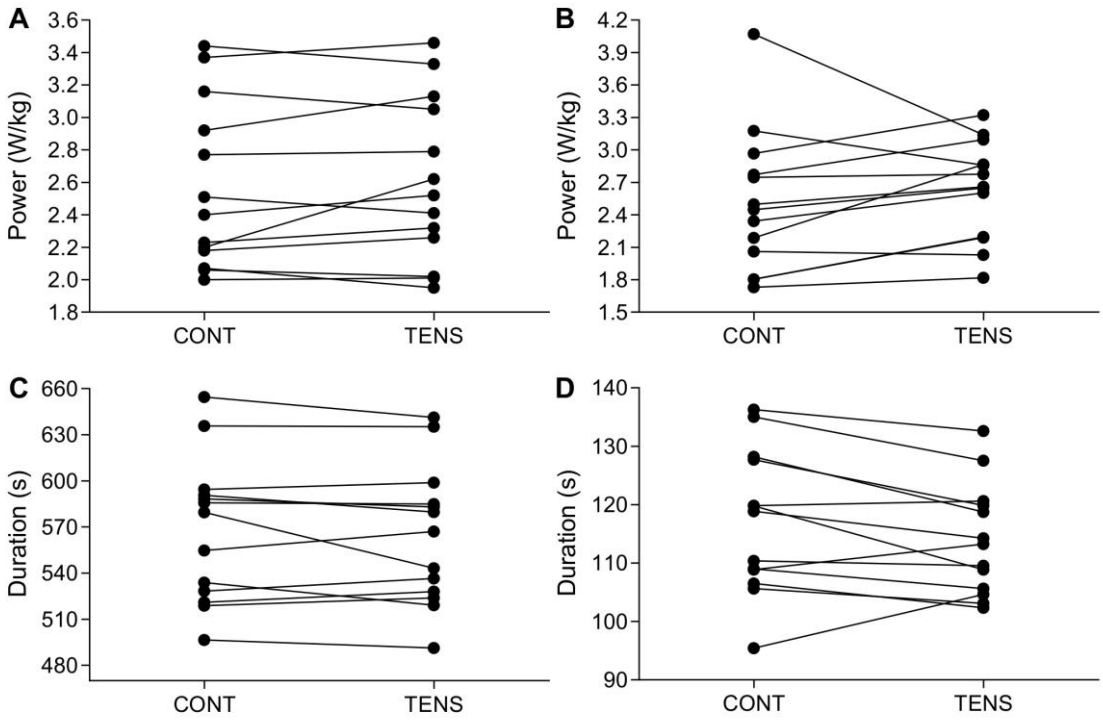

Figure 4-3 Individual changes for TT performance measures. TT mean power output (W/kg) (panel A), 1-km mean power output (W/kg) (panel B), TT duration (s) (panel C) and 1-km duration (s) (panel D). CONT, control. PLAC, placebo. TENS, TENS condition.

4.4.3 Pacing

There was no interaction (Condition x distance) effect for mean power over 250-m intervals ($F_{(38,456)} = 0.77$, $P = 0.83$, $\eta_p^2 = 0.06$). All TTs exhibited a similar pacing strategy, however there was greater variability in mean power in the first 750-m (Figure 4-4A). To investigate the variability at the start of the TTs, one way repeated measures ANOVAs between distance points were conducted at 250-m ($F_{(1.78, 21.36)} = 0.55$ $P = 0.56$, $\eta_p^2 = 0.04$), 500-m ($F_{(1.66, 19.91)} = 1.39$ $P = 0.27$ $\eta_p^2 = 0.10$) and 750-m ($F_{(1.69, 20.33)} = 1.31$ $P = 0.29$, $\eta_p^2 = 0.10$). Moderate effects sizes were observed at 500-m and 750-m. EMG data followed a similar pattern to power output with no significant interaction (Condition x distance) effect ($F_{(40,480)} = 1.01$, $P = 0.46$, $\eta_p^2 = 0.08$) (Figure 4-4B). Furthermore, greater variability between TTs was shown with large effects at 250-m ($F_{(1.5, 18.3)} = 2.31$, $P = 0.14$, $\eta_p^2 = 0.16$), 500-m ($F_{(1.7, 20.3)} = 2.05$, $P = 0.16$, $\eta_p^2 = 0.15$) and 750-m ($F_{(1.6, 18.8)} = 2.01$, $P = 0.17$, $\eta_p^2 = 0.14$).

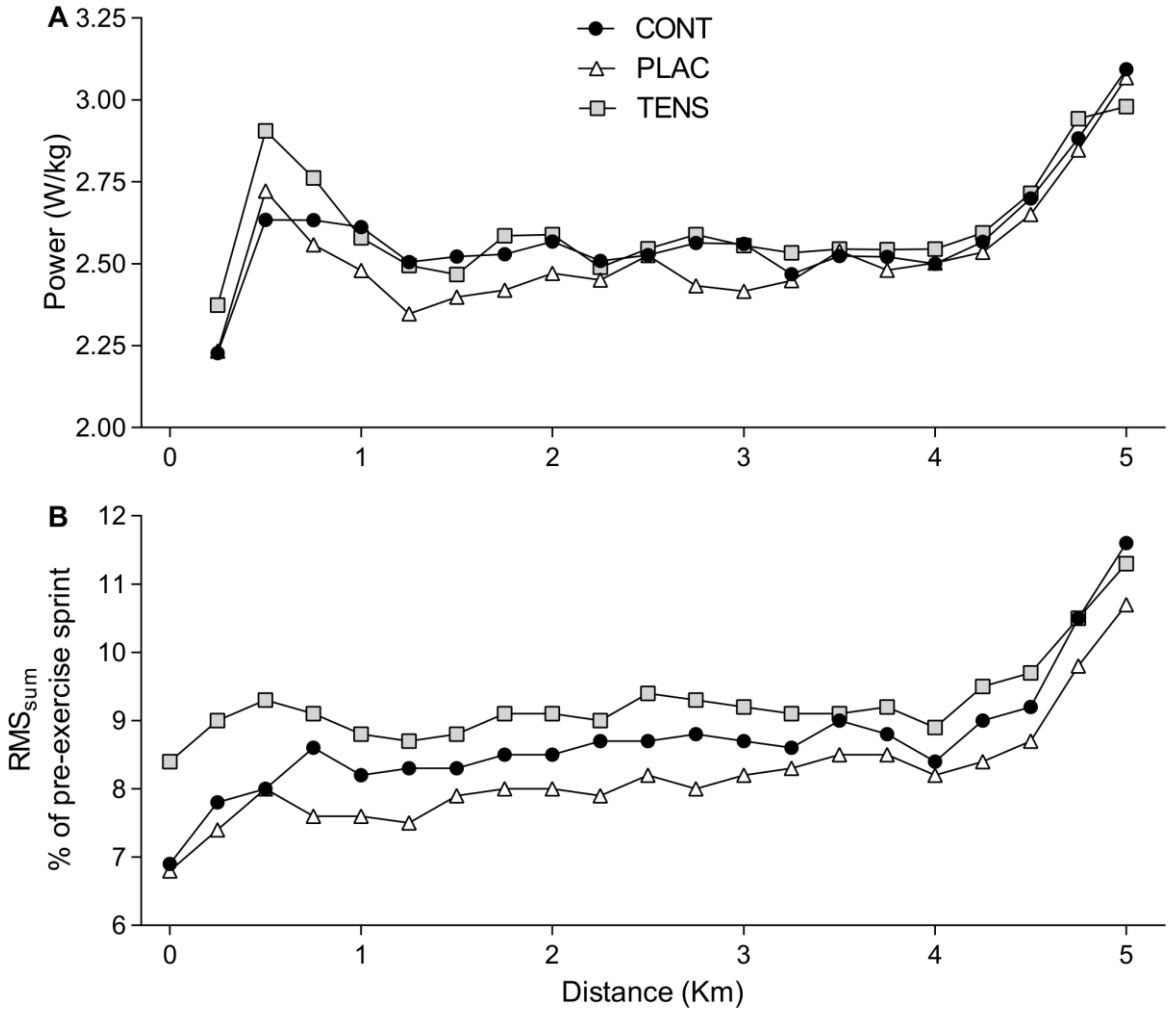

Figure 4-4 TT pacing measures. Group mean power output (panel A) and electromyography (RMS_{sum}) profiles (panel B). Mean power output is averaged over 250-m intervals. RMS_{sum} data are reported as a percentage of a pre-exercise sprint value, RMS_{sum} was measured for 20-s at 250-m intervals. Error bars have been excluded for clarity. CONT, control. PLAC, placebo. TENS, TENS condition.

4.4.4 Fatigue measurements

An exercise-induced reduction in MVC was recorded PRE to POST in all conditions (see Table 4-3), with only TENS application resulting in a significant reduction between BASE to PRE-measurements. This difference was not apparent when expressed as a percentage change from BASE-PRE measurements (see Table 4-4). Rather, MVC revealed a main effect of time with an exercise-induced reduction in all conditions, but no significant interaction (Condition x time). Mean Qtw,pot followed MVC values with all conditions having an exercise-induced reduction PRE-POST (Table 4-3 & Table 4-5). Only TENS condition had a reduction in raw Qtw,pot between BASE and PRE-measurements, but a non-significant percentage change (BASE-PRE) (see Table 4-5). There was no reduction in quadriceps CAR as a raw value (see Table 4-3) or as a percentage change (see Table 4-4). Percentage change responses to magnetic stimulation are shown in Table 4-5. There was an exercise-induced reduction in all measures, except M-wave variables.

Table 4-3 Raw changes in PPT, MVC and CAR and Qtw,pot

	BASE	PRE	POST	Trial effect	Time effect	Interaction
PPT (kgf)						
CONT	5.23 ± 3.93	4.99 ± 3.57	5.35 ± 3.42			
PLAC	4.76 ± 3.28	4.53 ± 2.60	5.35 ± 4.30	$P = 0.47$ $\eta_p^2 = 0.07$	$P = 0.10$ $\eta_p^2 = 0.19$	$P = 0.90$ $\eta_p^2 = 0.02$
TENS	5.17 ± 2.32	5.12 ± 2.80	5.63 ± 3.82			
MVC (N)						
CONT	262.70 ± 78.04	254.19 ± 72.33	207.90 ± 63.19*			
PLAC	259.52 ± 84.58	251.71 ± 66.23	211.54 ± 66.23*	$P = 0.97$ $\eta_p^2 < 0.01$	$P < 0.01$ $\eta_p^2 = 0.68$	$P < 0.05$ $\eta_p^2 = 0.18$
TENS	271.16 ± 68.04	251.73 ± 74.32#	197.55 ± 61.96*			
CAR						
CONT	95.26 ± 3.16	95.18 ± 2.65	94.66 ± 4.36			
PLAC	94.41 ± 3.48	94.89 ± 2.25	95.46 ± 2.41	$P = 0.70$ $\eta_p^2 = 0.04$	$P = 0.81$ $\eta_p^2 = 0.02$	$P = 0.44$ $\eta_p^2 = 0.10$
TENS	96.72 ± 3.42	95.17 ± 2.93	95.19 ± 2.31			
Qtw,pot (N)						
CONT	28.76 ± 8.75	26.93 ± 8.45	14.23 ± 7.15*			
PLAC	28.10 ± 7.84	27.44 ± 8.04	15.39 ± 8.44*	$P = 0.10$ $\eta_p^2 = 0.17$	$P < 0.01$ $\eta_p^2 = 0.80$	$P = 0.22$ $\eta_p^2 = 0.11$
TENS	30.34 ± 10.09	28.38 ± 9.82#	16.34 ± 9.87*			

Note: Data presented as mean ± SD. BASE, baseline. PRE, pre-exercise. POST, post-exercise. PPT, pressure pain threshold. MVC, maximal voluntary contraction. CAR, Quadriceps central activation ratio, for CAR $n = 10$. Qtw,pot, potentiated quadriceps twitch. CONT, control. PLAC, placebo. TENS, TENS condition. η_p^2, partial eta squared. Time point effects * difference to BASE and PRE-measurement, # difference to BASE measurement. Post-hoc tests for M-wave amplitude time effects revealed no difference between means.

Table 4-4 Percentage changes in PPT, MVC and CAR

	BASE - PRE Exercise	PRE Exercise - POST Exercise	Trial effect	Time effect	Interaction
PPT (kgf)					
CONT	-2.67 ± 19.07	6.65 ± 33.34			
PLAC	-1.71 ± 10.18	6.81 ± 22.49	$P = 0.98$ $\eta_p^2 < 0.01$	$P = 0.08$ $\eta_p^2 = 0.25$	$P = 0.99$ $\eta_p^2 < 0.01$
TENS	-2.56 ± 16.34	5.59 ± 22.37			
MVC (N)					
CONT	-2.51 ± 4.95	-17.46 ± 10.35*			
PLAC	-2.18 ± 7.05	-14.75 ± 12.89*	$P = 0.04$ $\eta_p^2 = 0.24$	$P < 0.01$ $\eta_p^2 = 0.66$	$P = 0.76$ $\eta_p^2 = 0.02$
TENS	-8.27 ± 8.92	-20.60 ± 13.74*			
CAR					
CONT	-0.06 ± 1.81	-0.54 ± 3.90			
PLAC	0.59 ± 3.13	0.65 ± 3.34	$P = 0.38$ $\eta_p^2 = 0.10$	$P = 0.65$ $\eta_p^2 = 0.02$	$P = 0.50$ $\eta_p^2 = 0.07$
TENS	-1.54 ± 3.20	0.07 ± 2.53			

Note: Data presented as mean percentage change between measurements ± SD. BASE, baseline. PRE, pre-exercise. POST, post-exercise. PPT, pressure pain threshold. MVC, maximal voluntary contraction. CAR, Quadriceps central activation ratio, for CAR $n = 10$. CONT, control. PLAC, placebo. TENS, TENS condition. η_p^2, partial eta squared. Time point effects * difference to BASE – PRE. Post-hoc tests for MVC trial effect revealed no significant difference.

Table 4-5 Percentage changes in evoked responses to magnetic stimulation.

	BASE - PRE Exercise	PRE Exercise - POST Exercise	Trial effect	Time effect	Interaction
Qtw,pot (N)					
CONT	-5.09 ± 13.11	-46.75 ± 17.59*	$P = 0.48$ $\eta_p^2 = 0.06$	$P < 0.01$ $\eta_p^2 = 0.83$	$P = 0.38$ $\eta_p^2 = 0.08$
PLAC	-2.25 ± 8.02	-44.56 ± 20.52*			
TENS	-5.92 ± 9.11	-41.43 ± 26.33*			
MRFD ($N.s^{-1}$)					
CONT	-3.91 ± 11.92	-56.73 ± 19.73*	$P = 0.48$ $\eta_p^2 = 0.06$	$P < 0.01$ $\eta_p^2 = 0.86$	$P = 0.24$ $\eta_p^2 = 0.11$
PLAC	-2.62 ± 9.31	-54.14 ± 20.78*			
TENS	-3.35 ± 16.81	-48.54 ± 23.32*			
CT (s)					
CONT	-0.61 ± 12.50	-23.78 ± 13.92*	$P = 0.44$ $\eta_p^2 = 0.07$	$P < 0.01$ $\eta_p^2 = 0.65$	$P = 0.33$ $\eta_p^2 = 0.09$
PLAC	-1.77 ± 18.50	-20.24 ± 12.60*			
TENS	4.74 ± 12.30	-23.87 ± 11.37*			
MRR ($N.s^{-1}$)					
CONT	-6.03 ± 19.81	-59.36 ± 15.22*	$P = 0.22$ $\eta_p^2 = 0.12$	$P < 0.01$ $\eta_p^2 = 0.88$	$P = 0.78$ $\eta_p^2 = 0.01$
PLAC	-2.70 ± 23.36	-53.31 ± 22.34*			
TENS	-0.40 ± 10.04	-55.59 ± 23.30*			
$RT_{0.5}$ ($N.s^{-1}$)					
CONT	-5.09 ± 13.25	-23.32 ± 19.02*	$P = 0.19$ $\eta_p^2 = 0.13$	$P < 0.01$ $\eta_p^2 = 0.56$	$P = 0.12$ $\eta_p^2 = 0.16$
PLAC	-3.15 ± 23.57	-21.98 ± 18.74*			
TENS	7.09 ± 17.06	-26.85 ± 15.85*			
M-Wave Amplitude (mV)					
CONT	2.63 ± 18.83	4.75 ± 13.50	$P = 0.22$ $\eta_p^2 = 0.12$	$P = 0.07$ $\eta_p^2 = 0.26$	$P = 0.45$ $\eta_p^2 = 0.06$
PLAC	-0.66 ± 7.73	3.03 ± 10.91			
TENS	1.89 ± 16.14	13.85 ± 21.50			
M-Wave Duration (ms)					
CONT	-4.71 ± 14.21	-7.11 ± 24.17	$P = 0.17$ $\eta_p^2 = 0.14$	$P = 0.49$ $\eta_p^2 = 0.04$	$P = 0.25$ $\eta_p^2 = 0.11$
PLAC	1.07 ± 17.25	7.96 ± 16.49			
TENS	-9.07 ± 37.90	-7.05 ± 27.86			

Note: Data presented as mean percentage change between measurements ± SD. BASE, baseline. PRE, pre-exercise. POST, post-exercise. Qtw,pot, potentiated quadriceps twitch. MRFD, maximal rate of force development. CT, contraction time. MRR, maximal rate of relaxation. $RT_{0.5}$, one-half relaxation time. CONT, control. PLAC, placebo. TENS, TENS condition. η_p^2, partial eta squared. Time point effects * difference to BASE – PRE.

4.5 Discussion

This is the first study to investigate the influence of TENS administered prior to a 5-km TT, on exercise-induced pain, with a focus on influencing exercise intensity and increasing performance. It was hypothesized, TENS application would adjust the threshold for sensing pain, allowing for increased power output for the same rating of pain. As hypothesized, TENS failed to significantly influence within-exercise subjective pain ratings, but no significant effect on pacing and performance was observed. However, a large effect size for TT duration and mean power indicate a possible difference in favour of TENS compared with PLAC. At the start of trials, moderate to large effect sizes indicate differences in power output and EMG data. This suggests a possible influence of TENS on anticipation and, consequently, the selection of an initial exercise intensity.

4.5.1 Pacing and performance

The application of TENS was associated with a large effect on EMG and a moderate effect on power output at the start of the TT, suggesting that TENS application may have influenced the participant's anticipation of the task (see Figure 4-2, Figure 4-3 & Figure 4-4). Afferent feedback is important in setting an initial exercise intensity (Tucker, 2009). This is evident with a reduced starting exercise intensity when homeostasis is threatened by hypoxia (Amann et al., 2007). Consequently, exercise intensity is reduced in an anticipatory fashion to limit excessive levels of fatigue and maintain homeostasis. Additionally, intensity is reduced in anticipation of exercise to prevent excessive heat storage and increases in body temperature when skin temperature is increased (Schlader, Simmons, Stannard, & Mündel, 2011) or in hot, humid conditions (Marino, Lambert, & Noakes, 2004). In these cases, exercise intensity is reduced as there is less work that is able to be conducted until body temperature reaches a critical level, and homeostasis is threatened. Alternatively, by using TENS to create the perception that

more work can be conducted before excessive fatigue occurs, it is likely that the intensity will be increased in anticipation of the exercise. Based on this hypothesis, our results seem to indicate that TENS application possibly limits afferent feedback activity prior to exercise, resulting in greater muscle recruitment (as inferred from EMG data) and power output at the start of the TT. This supports research indicating a higher intensity is chosen when afferent information is removed or modified (Amann et al., 2009). It is likely that this occurs due to TENS application attenuating nociceptive stimuli that inform on potential or actual muscle damage and metabolic activity. This would indicate to the brain that more work can be done without indication of serious consequences, creating a greater neural drive to exercising muscle.

TENS is shown to influence motor neuron excitability (Hopkins, Ingersoll, Edwards, & Klootwyk, 2002; Pietrosimone, Hart, Saliba, Hertel, & Ingersoll, 2009). In this perspective, it is interesting to note that TENS increased EMG activity, a surrogate for muscle recruitment (Ansley, Schabort, et al., 2004), at the start of the TT. This enhanced central neural drive was concomitant to a higher power output. Importantly, TENS did not produce any change in M-wave responses from BASE to PRE, indicating no change in resting muscle function before the cycling TT (see Table 4-5). However, another possible explanation for this result is that neuromuscular electrical stimulation can change voluntary muscle recruitment patterns, allowing for non-sequential activation of muscle fibres (Gregory & Bickel, 2005). Yet, stimulation protocols showing these effects are different from the method utilized in this study. It is possible this effect occurred, creating poor recruitment of muscle after TENS stimulation which may require a greater neural drive to be produced. Alternatively, there is an association between TENS and greater local blood flow (Hallen et al., 2010). This may lead to a greater activation of type I muscle fibres which are related to cycling efficiency, thus increasing EMG activity

(Coyle, Sidossis, Horowitz, & Beltz, 1992). These possible factors may explain the observed increase in EMG readings, allowing for higher muscle recruitment and greater power output during the early part of the TENS condition TT. However, as these factors were not directly measured in this study, we cannot identify the primary source of increased EMG readings from this investigation.

After the initial differences, all TTs exhibit a similar power output and EMG readings beyond one kilometre (Figure 4-4). An initial aggressive pacing strategy would likely assist performance in shorter tasks such as a 5-km TT (Abbiss & Laursen, 2008). This would create greater mechanical and chemical stimuli likely to trigger conscious awareness and influence pain perceptions (Edwards & Polman, 2013; Mauger, 2014; Swart et al., 2012). It is possible that this occurred in our study at approximately one kilometre, with increased exercised-induced stimuli diminishing the effectiveness of TENS. This may indicate that afferent information from active skeletal muscles is now unaffected and the participant uses this to pace performance. It is also likely at this stage of the intense exercise, feedback from a number of different sources, not just the active muscle, is pushing the individual close to their tolerance limit (Hureau et al., 2018). For these reasons, even with the non-significant differences in intensity at the start of the trial, it is not surprising to observe similar subjective responses for pain, feeling and exertion in all conditions. Therefore, these results support the theory that exercise is regulated in part by afferent feedback to a perceived pain threshold (Mauger et al., 2010a), which presumably plays a role in a global sensory tolerance limit (Hureau et al., 2018).

4.5.2 Practical implications

Application of TENS did not provide any overall performance improvement for a 5-km TT. However, there was a large effect size for TT duration and moderate effect size for duration of the first kilometre (see Figure 4-2 & Figure 4-3). These results provide

some support for the potential of TENS to increase exercise performance. Participants completed the first kilometre of the TTs within a range of 95.44 – 136.28-s, and the difference between TENS and CONT conditions being -3.12 ± 5.58-s. Therefore, this research identifies that any possible benefit of TENS administered prior to exercise may be limited to events of ≤ two minutes and where the exercise-induced pain is localized. However, the possible reduction in pain to increase exercise intensity poses ethical concerns for athlete safety. Administering an analgesic intervention will augment stimuli that warn of potential muscle damage, which creates the potential for a greater risk of injury through increased exercise intensity. Our study found no significant impact on exercise intensity, but also no indication of greater exercise-induced fatigue due to TENS application (i.e. PRE-POST measurement, see Table 4-4, Table 4-3 & Table 4-5). It may be of benefit for future investigations to confirm if effects of TENS application occur in elite populations, to highlight any potential benefits or concerns of TENS use.

One possible future investigation could look at the potential benefits of TENS use within a task. We tested the use of TENS prior to a task, with a 5-km TT chosen in anticipation that exercise would be conducted in a proposed post-stimulation analgesic period. Compared to a longer task (e.g. 20-km TT), a greater exercise intensity would be observed in a 5-km TT, and therefore, a greater nociceptive stimulus is expected. Accordingly, when pain is greater, it may be harder to distinguish small changes in pain perceptions that an intervention may provide. Also theoretically, it is possible that TENS could be beneficial for longer duration tasks which are more reliant on afferent feedback for regulation (Mauger et al., 2010a; Tucker, 2009), and where pain perceptions are expected to be less prominent. Furthermore, TENS is more likely to reduce pain perceptions when stimulation is active. Therefore, future investigations into the possible use of TENS to enhance exercise performance may look at utilizing TENS during trials

of greater length. Ethically, it is unlikely TENS could be used within a sporting event due to doping concerns, but there may be merit in use of TENS as a within-exercise training intervention.

4.5.3 Limitations

There are several limitations to this study. Perceptions of TENS for pain relief and influence on performance were greater than PLAC condition (see Figure 4-1). Measures were taken to minimize the influence of any placebo effect of TENS. However, participants would have clearly felt a difference in sensation between TENS and PLAC conditions. Furthermore, participants were made aware of the aims of the study, and informed they were receiving high or low TENS, but not aware of which intervention was placebo. This could have had implications on the results shown by TENS (Son et al., 2016). Placebo effects have been shown to influence exercise pain perceptions (Benedetti, Pollo, & Colloca, 2007) but also the ability to produce force (Broatch, Petersen, & Bishop, 2014). As participant's perceptions of TENS effectiveness on pain relief and performance were increased post study compared to PLAC condition (Figure 4-1), this could have produced changes at the start of the 5-km TT.

With physiological differences between participants, it is possible that there are responders and non-responders to this type of intervention (Figure 4-3). For example, the amount of subcutaneous fat may affect the amplitude of stimulation to afferent fibres (Hughes, Bennett, & Johnson, 2013). Hence, those with lower body fat may not be able to increase the amplitude of stimulation to a level that will stimulate deeper tissue (Hughes et al., 2013). This could possibly result in different levels of stimulation between participants, leading to differing levels of afferent information, and effect on performance. This is a limitation of the study, as the final current intensity was not recorded, we cannot confirm the dose received by participants. However, the application

of TENS was adjusted to an individual's own sensory threshold, in effect an individual's tolerance of the stimulation. It has to be noted that applying a TENS intensity higher than what a participant can tolerate would be unethical. However, it could be speculated that those who responded to the intervention (i.e. higher initial power output) (Figure 4-2 & Figure 4-3) were able to tolerate a higher current intensity during TENS application.

The potential of TENS to affect exercise-induced pain was based on previous research in pain free individuals that influenced PPT (Moran et al., 2011), but also restored muscle strength when the pain was induced (Son et al., 2016). Recent research however, has indicated a possibility for different subgroups of group III and IV muscle afferents which are sensitive to distinct metabolites. One subgroup is likely to respond to intramuscular metabolites associated with aerobic exercise, whilst another responds to noxious levels of metabolites (e.g. hypertonic saline) associated with ischemic contractions (Amann, Sidhu, Weavil, Mangum, & Venturelli, 2015). These differing characteristics of muscle afferents may be a possible reason why TENS failed to significantly change exercise intensity within this study. Whilst in comparison, analgesic effects are demonstrated during exercise when pain is induced (Son et al., 2016).

Reductions in MVC and Qtw,pot were observed from BASE to PRE for TENS condition (see Table 4-4), although percentage reductions were not significantly different (see Table 4-4 & Table 4-3). This likely resulted from the stimulation intensity being close to the threshold for muscle contraction. However, despite this apparent fatigue, it dissipated quickly as power was greatest in TENS condition early in the TT (see Figure 4-4A). Therefore, a possible limitation of prior to exercise use of TENS may be the application settings. Application duration should be limited and higher intensities avoided as this may induce peripheral fatigue that is detrimental to performance. Furthermore, PRE-assessment was conducted after the cycling warm-up, which may have contributed

to the reduced voluntary force, thus disguising the true influence of TENS on muscle strength properties. Settings for TENS were based on previous research indicating this would activate the gate control of pain and reduce feedback from group III and IV afferents (Moran et al., 2011). However, amplitude, stimulation duration, prior use and tolerance of opioids can compromise TENS effectiveness (Sluka et al., 2013). Participants currently taking pain medication were excluded from the study, but the prior use of opioids was not recorded. Typically, peak effects for analgesia provided by TENS will be greater when stimulation is active, or immediately after cessation (Moran et al., 2011; Vance et al., 2012). For this research, we conducted a 5-km TT, as we anticipated post-stimulation effects for approximately 30-mins would be present (Moran et al., 2011). As expected, within-exercise pain perceptions were similar, but there is an absence of significant differences in exercise intensity. Therefore, by administering the intervention prior to exercise, it is possible that analgesic effectiveness of TENS for this mode of exercise is reduced.

Although the current study has several limitations, the overall multidisciplinary approach allows for the assessment of a number of variables related to exercise performance. The aim of the study was to assess the efficacy of TENS on exercise performance, with a focus on exercise-induced pain. Although there were no significant differences in pain and performance, the reporting of multiple variables related to exercise intensity, fatigue but also psychological aspects represent strengths of this study.

4.6 Conclusions

In conclusion, this study found no significant effects of TENS administered prior to exercise on 5-km TT performance, although similar pain perceptions were observed. This casts doubt on the effectiveness of the application of TENS prior to exercise to modify afferent feedback and influence perceptions of exercise-induced pain. However,

there are indications TENS application may influence neural drive and power output at the start of a 5-km TT. Aside from any potential changes in pain perceptions, other possible reasons for this include psychological belief in the intervention and altered muscle recruitment. Future research could investigate the effectiveness of TENS on modifying the sensation of exercise-induced muscle pain, with a focus on TENS application during other forms of aerobic exercise including time to exhaustion tasks where the variables that may have limited this study can be more easily controlled.

CHAPTER 5. STUDY 3: GOAL ORIENTATION AND THE PRESENCE OF COMPETITORS' INFLUENCE CYCLING PERFORMANCE

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5.1 Abstract

Introduction: The aim of this study was to investigate time-trial (TT) performance in the presence of one competitor and in a group with competitors of various abilities.

Methods: In a randomized order, 24 participants performed a 5-km cycling TT individually (IND), with one similarly matched participant (1v1), and in a group of four participants (GRP). For the GRP session, two pairs of matched participants from the 1v1 session were used. Pairs were selected so that TT duration was considered either inferior (INF) or superior (SUP) compared to the other pair of participants.

Results: Overall, TT duration ($P = 0.86$, $\eta p2 < 0.01$) was not different between conditions, whilst heart rate (HR) was significantly greater in GRP compared to IND ($P < 0.01$, $\eta p2 = 0.16$). For INF, a large effect size for both mean power ($P = 0.07$, $\eta p2 = 0.15$) and HR ($P = 0.05$, $\eta p2 = 0.16$), indicates greatest effort in GRP. Pacing behaviour was affected by competition but similar in 1v1 and GRP for SUP, whilst large effect sizes indicate an increased power output in the initial 750-m for INF in GRP. Additionally, for INF, there was a significant correlation with ego orientation for an increase in TT duration between the GRP session and both the IND ($r = 0.43$, $P = 0.04$) and 1v1 ($r = 0.54$, $P = 0.01$) sessions.

Conclusion: For INF participants, the intensity was increased when competing in GRP. Yet, the presence of the SUP competitors resulted in lesser performance improvements for ego oriented INF participants. These findings demonstrate that consideration should be given to the ability of competitors in a group setting to provide adequate motivation.

5.2 Introduction

During exercise, an individual will regulate intensity to achieve personal goals and optimal performance while limiting the possibility of early exhaustion (St Clair Gibson et al., 2006). This process of pacing involves the consideration of many circumstantial factors to set and regulate an appropriate exercise intensity (Edwards & Polman, 2013; Smits et al., 2014). In competitive exercise situations, in addition to managing neuromuscular fatigue, pacing and overall performance are likely to be influenced by the presence or perception of a competitor (Hettinga, Konings, & Pepping, 2017; Renfree et al., 2014; Triplett, 1898).

In comparison to exercising alone, cycling time-trial (TT) performance is improved when exercising in the presence of a competitor (Triplett, 1898) and a virtual avatar competitor that represents a previous performance (Corbett et al., 2012; Stone et al., 2012). In addition, deceptively faster avatars as a motivational stimulus have resulted in increased performances (Jones et al., 2016a; Jones et al., 2016b; Stone et al., 2012; Williams, Jones, Sparks, Marchant, et al., 2015; Williams, Jones, Sparks, Midgley, et al., 2015). Furthermore, unsustainable behaviour (i.e. a fast start) of avatar competitors has enticed participants to change their pacing strategy (Konings et al., 2016). Taken together, these results demonstrate that the perception of competitors is an important consideration for pacing decisions, and this provides a stimulus that motivates for a greater performance. Yet, within these studies, by competing against a virtual avatar, the

psychological dynamics such as social facilitation that actual competition provides, are not present (Bond & Titus, 1983; Snyder et al., 2012). In fact, the presence of real competitors increases arousal and attentional processes, resulting in an increased exercise intensity in comparison to a virtual stimulus (Ravaja et al., 2006; Snyder et al., 2012). Previously, within pacing studies, the presence of competition has been imitated with a concealed dummy rider to deceive the participant that an avatar was an actual competitor (Corbett et al., 2012). Yet, the use of actual competition has been limited to a small number of investigations with equivocal results (Bath et al., 2012; Tomazini et al., 2015). A competitor mimicking the movement of the investigated runner did not improve running TT performance, as this was deemed an unsuitable motivational stimulus (Bath et al., 2012). In a more realistic competitive setting, running as a group of four to five matched participants resulted in a reduction of TT duration, with improvements attributable to a greater starting speed (Tomazini et al., 2015). However, the use of participants with similar performances limits the comparison between differing ability participants that would likely occur in a group competition setting. Additionally, from this study, it is not apparent if this group competition is more beneficial to performance than the competition provided by a similarly matched competitor. Nevertheless, for pacing considerations, actual competition creates athlete interactions allowing for opportunities to act, or to respond to the actions of competitors (Smits et al., 2014). In addition, the presence of group competition creates multiple athlete interactions as opposed to one competitor. However, a comparison between one competitor and many competitors in an actual competition setting has not yet been investigated.

Social facilitation theory provides an explanation of why performance alone or in the presence of others might differ (Bond & Titus, 1983; Snyder et al., 2012; Strauss, 2002). Furthermore, in a group setting, multiple inter-individual differences in

perceptions of competence and ability will create different approaches to a task, based upon motivational orientation and personal goals (Nicholls, 1984; Smits et al., 2014). Goal orientation theory refers to how individuals estimate their levels of ability and effort within a task (Duda, 1992). Based on the two perspectives of goal orientation theory (ego and task), individuals are likely to approach exercise tasks differently. An ego orientated individual will emphasize winning and might demonstrate different behaviour to a task orientated individual who emphasizes learning and improvement (Chi & Duda, 1995; Duda et al., 1991). Additionally, motivational orientation has been suggested to influence competitive behaviour. Intrinsic motivation will be a key driver for performance improvements, yet competition may influence perceptions of competence that may reduce intrinsic motivation (Ryan & Deci, 2017). Consequently, in examining the difference between competitive settings, it would be of interest to investigate goal perspectives and motivational orientation to clarify if responses to competition are similar or whether different ability opponents influence behaviour and decisions of the competing athlete.

The primary aim of this study was to investigate how pacing and performance are influenced when exercising in the presence of one competitor or multiple competitors. The secondary aim was to investigate the influence of goal orientation on the magnitude of performance change by manipulating the ability of competitors in a group setting. It was hypothesized that performance in a group setting would be improved compared to a session with one competitor, and that ego orientated participants would have greater performance improvements when exposed to competition, compared to task orientated participants. No predictions were made for the role of motivational orientation. To create a competitive environment, participants cycled on a stationary bike adjacent to competitors, with performance projected onto a monitor.

5.3 Methods

5.3.1 Experimental overview

Participants reported to the laboratory on eight occasions, which included five preliminary and three experimental sessions. To assess cardiorespiratory fitness, the first two preliminary sessions involved two incremental exercise tests to determine peak oxygen uptake (VO_{2peak}), the first being a familiarisation (see procedure below). As previous cycling experience varied between the participants, three familiarisations (FAM) to the 5-km cycling time-trial (TT) were performed to develop a reproducible pacing strategy and performance (Hibbert et al., 2017). For experimental testing, on three different days separated by a minimum of 48 hours, participants performed three 5-km cycling TT's in a randomized order: An individual 5-km TT (IND), a 5-km TT performed with another matched participant (1v1), and a 5-km TT performed in a group setting with four participants (GRP) (see procedure below).

5.3.2 Participants

In total, 24 (12 females, 12 males) recreationally active participants (Table 5-1) volunteered to take part in this study and provided written informed consent in accordance with the Declaration of Helsinki. Victoria University's Human Research Ethics Committee provided ethical approval for this study, and all procedures were conducted in accordance with the recommendations of the National Statement on Ethical Conduct in Human Research as described by the National Health and Medical Research Council (NHMRC) of Australia. Prior to commencing the study, all participants were screened for suitability to the exercise protocol and risk factors using a medical questionnaire. Participants were asked to refrain from any physical activity causing severe fatigue in the 36 hours' prior as well as any caffeine intake 2 hours prior to testing.

Table 5-1. Group anthropometric data.

Measure	INF	SUP	Total	*P* value
	n = 12	*n* = 12	*n* = 24	
Age (years)	24.58 ± 4.98	26.58 ± 4.10	25.58 ± 4.58	*P* = 0.30
Height (cm)	169.42 ± 6.49	176.25 ± 11.96	172.83 ± 10.04	*P* = 0.10
Body mass (kg)	69.96 ± 12.42	73.88 ± 15.75	71.92 ± 14.02	*P* = 0.51
PPO (W)	277.83 ± 54.13	316.58 ± 67.63	297.21 ± 63.09	*P* = 0.14
PPO (W/kg)	4.00 ± 0.65	4.32 ± 0.66	4.16 ± 0.66	*P* = 0.24
VO_{2peak} (ml.min.kg^{-1})	44.24 ± 7.88	47.92 ± 8.68	46.08 ± 8.32	*P* = 0.22
VO_{2peak} (L.min^{-1})	3.10 ± 0.77	3.54 ± 0.93	3.32 ± 0.87	*P* = 0.29
Ego	2.70 ± 0.99	2.73 ± 0.98	2.72 ± 0.96	*P* = 0.93
Task	4.40 ± 0.50	4.52 ± 0.41	4.46 ± 0.45	*P* = 0.54

Note: Data presented as mean ± SD. Each group *n* = 12, consisting of *n* = 6 females and *n* = 6 males. PPO, peak power output. VO_{2peak}, peak oxygen consumption. Ego, the mean of ego responses from the GOEM. Task, the mean of task responses from the GOEM. GOEM, goal orientations of exercise measure. INF, inferior. SUP, superior.

5.3.3 Participant characterisation

5.3.3.1 VO2 assessment

VO_{2peak} was assessed using a 30 Watts/min ramp maximal incremental test after a 3-min baseline period cycling at 0 Watts (Vanhatalo, McNaughton, Siegler, & Jones, 2010). Expired gas was collected and analysed every 15-s (S-3A/I (O2) and CD-3A (CO2), AEI Technologies Inc., Pittsburgh, PA), with gas and flow calibrations performed prior to each test. The test concluded when the participant could no longer maintain a cadence above 60 rpm, or volitional fatigue was achieved, with the participants encouraged throughout the final stages of the test. VO_{2peak} was calculated as the highest 30-s mean $VO_{2,}$ and peak power was defined as the highest power at test conclusion. As cycling experience between the participants varied, two incremental tests were conducted to ensure familiarity with the protocol.

5.3.4 Participant matching

The best performance (TT duration) from the three FAM TT's was used to match participants for the competition sessions. Participants were matched based on sex to

remove any possible physiological and perceptual influences of sex on the competition. Initially, participants were matched to a similar participant for the 1v1 session. These participants had a TT time that was overall between 16.41 ± 16.97-s of each other's best FAM TT duration. For the GRP session, two pairs of matched participants from the 1v1 session were used to make a group of four participants. In the GRP session, pairs of participants were selected so that one pair had a 5-km TT duration that was either considerably slower (between 110-120% of TT duration), or considerably faster (between 80-90% of TT duration) than the other pair of participants. For this session, the slower participants were categorised as inferior (INF), while the faster participants were categorised as superior (SUP). Overall for the GRP session matching, the SUP participants were 58.96 ± 22.09-s faster than the INF participants.

5.3.5 Goal Orientation

After the first FAM TT, participants completed a 10 question Goal Orientations in Exercise Measure (GOEM) to assess individual differences in goal perspectives in exercise settings (Petherick & Markland, 2008). The GOEM was used to assess ego and task orientation, with the measure consisting of two subscales, with five questions measuring ego and five questions measuring task orientation. Participants responded on a 5-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Orientation was measured as the mean of responses to the five subscale questions. The GOEM has shown to have strong psychometric properties and reliability (Petherick & Markland, 2008).

5.3.6 Time-trials

All exercise was conducted on Velotron Pro cycle ergometers (RacerMate Inc., Seattle, WA, USA), that had been fitted with a scientific SRM power meter (Schoberer Rad Meßtechnik, Jülich, Germany). A calibration of the power meter was conducted

before each test. Power output and heart rate (HR) were collected with a wireless Power control 7 unit and later downloaded using the SRM training system (Schoberer Rad Meßtechnik, Jülich, Germany). All TT protocols were controlled using the Velotron Interactive 3D software (Version 1.0, RacerMate Inc., Seattle, WA, USA) where the performance of the participant was projected onto a monitor. To increase visibility, the computer monitor was projected onto a 42" monitor, placed in front of the participant. All FAM and IND sessions were conducted with the cycle ergometer positioned centrally to the monitor behind the participant's avatar. For the 1v1 session, the cycle ergometer was again positioned behind the avatar, so that participants were approximately one metre apart. For the GRP session, as the 3D software only allows for two participants, two separate computers and monitors were used so that two participants were displayed on one monitor, and the other two were on another. In this session, participants were split from their 1v1 participant so that on each monitor there was an INF and a SUP participant.

Within the first FAM session, participants set the ergometer to their own specifications with values recorded and replicated for subsequent sessions. Upon arrival to the laboratory for experimental trials, participants completed a warm-up consisting of 5-mins of cycling at 75 Watts. To overcome flywheel inertia, participants were instructed to obtain a self-selected comfortable cadence immediately prior to beginning the TT, with the TT commencing after a verbal 3-s countdown from the researcher. Participants could change gear and cadence throughout the TT as desired with the instruction to finish the required distance "as quickly as possible". For the competition sessions, there was no instruction or incentive for the participant to beat their competitors. Instead, the participants were instructed to finish the required distance "as quickly as possible" in the presence of other competitors (Williams, Jones, Sparks, Midgley, et al., 2015). Participants were blinded from all information except for the distance covered, yet in the

1v1 and GRP sessions, participants could also see the distance covered by competitors as well as visual proximity via the computer avatar. Upon TT completion, participants were instructed to remain on the ergometer until all participants had completed the required distance.

5.3.7 Motivational orientation and perceptual scores

After completion of each TT, a 17-item version of the intrinsic motivation inventory (IMI) (McAuley, Duncan, & Tammen, 1989) was used to assess interest/enjoyment, perceived competence, and pressure/tension during that trial. Participants responded on a 7-point Likert scale ranging from 1 (*Not true at all*) to 5 (*Very true*). The IMI has been shown to have strong factor structure and reliability (McAuley et al., 1989). During each TT, at every kilometre, participants were asked to rate perceived exertion (RPE) (Borg, 1970) and affect (Hardy & Rejeski, 1989). Scales were placed adjacent to the monitor and in full view during the TT. Prior to commencing the study, all scales were explained to the participants.

5.3.8 Statistical analysis

Experimental TTs are defined as a TT conducted individually (IND), with a similarly matched participant (1v1) and a session where one pair of slower participants completes a TT with a pair of faster participants (GRP). Slower participants for the GRP session are defined as inferior (INF) and faster participants are defined as superior (SUP). All data were analysed using SPSS (version 22, SPSS Inc., Chicago, IL.) with data reported as mean ± SD. Statistical significance levels for all tests was set at $P < 0.05$. Tests for homogeneity of variances were performed to ensure normality of the cohort for dependent variables. When homogeneity of variances was violated, Welch *F*-ratio is reported for analysis of variance (ANOVA). When normality assumptions were violated for the Pearson correlation coefficient (r), Spearman's rho (r_s) was calculated. In the

instance of a significant ANOVA, post-hoc Sidak comparisons were conducted. Effect sizes for ANOVAs are reported as partial eta squared (η_p^2) with a small effect at 0.01-0.059, a medium effect at 0.06-0.139 and a large effect > 0.14. Effect sizes for correlations are reported as Pearson's *r* with a small effect at 0.10-0.29, a medium effect at 0.30-0.49 and a large effect > 0.5. Effect sizes for *t*-tests are reported as Cohen's *d* with a small effect at 0.2-0.49, a medium effect at 0.5-0.79 and a large effect > 0.8 (Cohen, 1988).

5.3.8.1 Preparation for data analysis

Given the inter-participant differences in TT power output, power has been reported as a percentage of the individual's PPO obtained from the maximal incremental test (i.e., % of PPO). As the IND and 1v1 sessions followed the same conditions for all participants, for the analysis of variables between sessions, group classification was ignored so that in each session $n = 24$. For correlation analysis, due to the inter-participant differences created by the study design (i.e., INF and SUP participants), overall TT duration has been calculated as differences between sessions. Changes in performance are defined as the difference between IND and 1v1 sessions (IND-1v1), the difference between IND and GRP sessions (IND-GRP) and the difference between 1v1 and GRP sessions (1v1-GRP).

5.3.8.2 Analysis of overall performance

To examine any differences between participant characteristics, an independent sample *t*-test was conducted on group (INF and SUP) anthropometric and goal orientation variables. To explore whether there was an influence of competition on TT performance measures, a one-way ANOVA (3 conditions) on TT duration, mean power and mean heart rate (HR) was conducted. To investigate differences created by the competitive stimulus (i.e. the difference in ability between INF and SUP), a one-way ANOVA for both INF and SUP groups was conducted. Based on the hypothesis of the GRP competition (i.e.

SUP being a competitive stimulus for INF participants), an independent samples *t*-test was conducted between the INF and SUP groups for the difference in TT duration between the 1v1 and GRP sessions.

5.3.8.3 Analysis of goal orientation

To investigate the influence of participant goal orientation (ego and task) on overall performance, Pearson product moment correlation coefficients (*r*) were calculated for ego and task scores from the GOEM and changes in TT duration between sessions. Pearson correlations were conducted on the whole group and the INF and SUP groups separately.

5.3.8.4 Analysis of motivational orientation and perceptual scores

To analyse if the competitive settings influenced IMI responses, exertion and affect between trials, a one-way ANOVA was conducted on mean IMI responses (n = 24) and for RPE and FS at each kilometre. To investigate the variation created by differences in the competitive stimulus (i.e. the difference in ability between INF and SUP), we conducted a one-way ANOVA for both INF and SUP groups for IMI responses, and for RPE and FS at each kilometre. To compare the difference in perceptual scores between INF and SUP within the GRP session, we conducted an independent samples t-test for IMI responses and for RPE and FS at each kilometre.

5.3.8.5 Analysis of pacing profiles

To compare pacing profiles, power output data was averaged over 250-m intervals, with one-way ANOVA's conducted for the mean of all participants (n = 24) at each 250-m interval. To compare power output changes within groups between trials (n = 3), one-way ANOVAs for each 250-m interval were conducted for the INF and SUP groups.

To investigate the influence of participant goal orientation (ego and task) on the change in pacing behaviour, a posteriori analysis of Pearson product moment correlation

coefficients (*r*) were calculated for ego and task scores from the GOEM and changes in power output at 250-m intervals between sessions. Pearson correlations were conducted on the group and the INF and SUP groups separately.

5.4 Results

5.4.1 Participant matching

There was no significant difference between the INF and SUP groups for any anthropometric variable (Table 5-1). Within the 1v1 session, the mean difference between participants was 19.64 ± 17.84-s. Within the GRP session, the mean difference between the pairs of participants was 17.33 ± 14.60-s, whilst the difference between the SUP and INF participants was 44.83 ± 18.53-s.

5.4.2 Analysis of overall performance

Overall, there was no significant effect for TT duration ($P = 0.86$, $\eta_p^2 < 0.01$) or mean power ($P = 0.23$, $\eta_p^2 = 0.04$) between conditions (Figure 5-1A, Figure 5-1B, Figure 5-2A, Figure 5-2B and Figure 5-2B). However, mean HR was significantly greater in GRP compared to the IND session ($P < 0.01$, $\eta_p^2 = 0.16$) (Figure 5-1C).

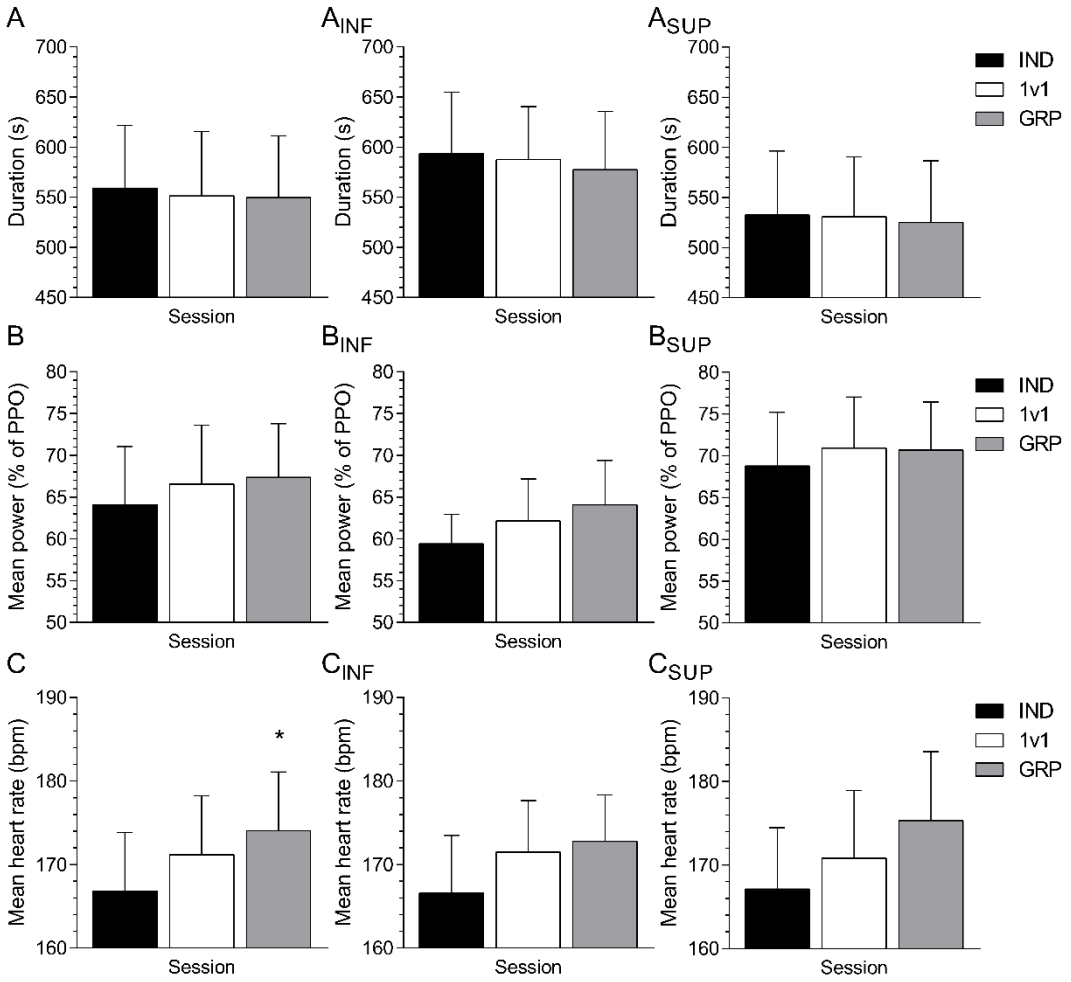

Figure 5-1 TT overall performance measures. Mean changes in TT duration (panels A), mean power (panel B) and mean HR (panel C) between IND (black), 1v1 (white) and GRP (grey) sessions. Mean changes for INF participants in TT duration (panel AINF), mean power (panel BINF) and HR (panel CINF). Mean changes for SUP participants in TT duration (panel ASUP), mean power (panel BSUP) and HR (panel CSUP). INF, inferior. SUP, superior. IND, individual TT. 1v1, two matched participants TT. GRP, TT with four participants (two INF and two SUP participants). * significant difference to IND.

For the INF group, there was no significant difference for TT duration ($P = 0.79$, $\eta_p^2 = 0.02$), mean power ($P = 0.07$, $\eta_p^2 = 0.15$) and HR ($P = 0.05$, $\eta_p^2 = 0.16$). There were however, large effect sizes for mean power and HR. Visualisation of data suggests there was increased mean power (Figure 5-1B_{INF}) and HR (Figure 5-1C_{INF}) in the GRP session. For the SUP group, there was no significant difference in TT duration ($P = 0.98$, $\eta_p^2 < 0.01$), mean power ($P = 0.64$, $\eta_p^2 = 0.03$) and HR ($P = 0.05$, $\eta_p^2 = 0.16$). There was a large effect size for HR, with visualisation (Figure 5-1C_{SUP}) suggesting an increase in the GRP session.

For the comparison of competitive stimulus, the change in TT duration between 1v1-GRP sessions was not significantly different (P = 0.10, d = 0.74) between the INF (-5.41 ± 10.82-s) and SUP (2.05 ± 10.22-s) groups. There was, however, a moderate effect size. Overall, 9 INF participants (Figure 5-2C_{INF}) and 6 SUP participants (Figure 5-2C_{SUP}) beat their 1v1 TT duration in the GRP session.

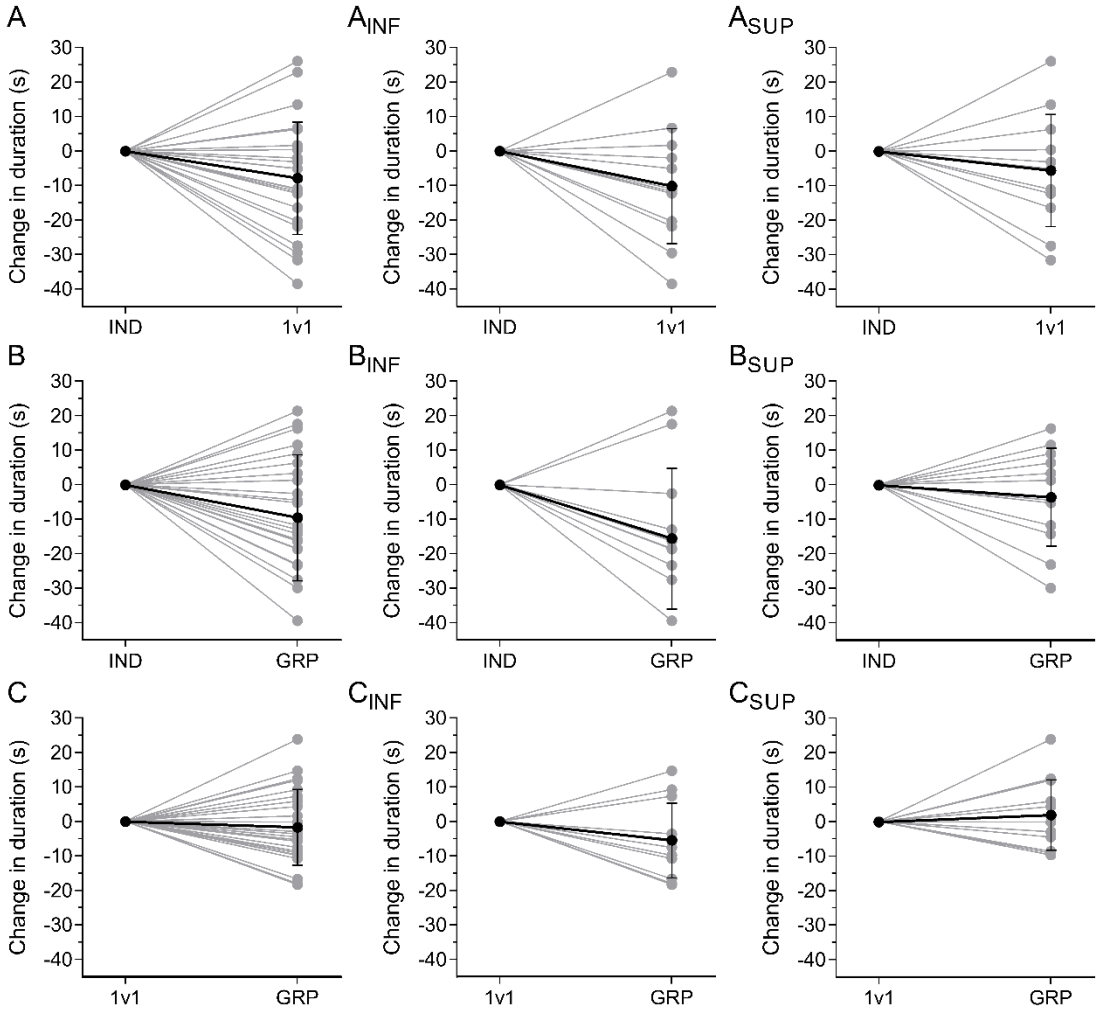

Figure 5-2 Individual changes in TT duration between sessions. Panels A, B & C, change in TT duration for all participants (n = 24) between IND-1v1 (panel A), IND-GRP (panel B) and 1v1-GRP (panel C). Panels AINF, BINF & CINF, changes in TT duration for INF participants (n = 12) between IND-1v1 (panel AINF), IND-GRP (panel BINF) and 1v1-GRP (panel CINF). Panels ASUP, BSUP & CSUP, changes in TT duration for SUP participants (n = 12) between IND-1v1 (panel ASUP), IND-GRP (panel BSUP) and 1v1-GRP (panel CSUP). INF, inferior. SUP, superior. IND, individual TT. 1v1, two matched participants TT. GRP, TT with four participants (two INF and two SUP participants).

5.4.3 Analysis of goal orientation

There was no significant correlation for change in TT duration between IND-1v1 for ego (r = 0.12, P = 0.59) or task (r_s = 0.09, P = 0.66). For all participants, ego orientation displayed significant correlations for a change in TT duration between GRP session and both the IND (Figure 5-3A) and 1v1 (Figure 5-3B) sessions. When analysed based on groups, ego orientation correlations were significant for changes in TT duration between IND-GRP and 1v1-GRP for INF (Figure 5-3A$_{INF}$ & Figure 5-3B$_{INF}$) but not the SUP group (Figure 5-3A$_{SUP}$ & Figure 5-3B$_{SUP}$).

For all participants, there was no significant correlation between task orientation and change in performance between any session (Figure 5-4A & Figure 5-4B). However, when analysed based on groups, there was a significant correlation between task orientation and a change in TT duration between IND-GRP for the SUP group (Figure 5-4A$_{SUP}$). Although not significant, there was a large correlation for a similar effect between 1v1-GRP sessions for the SUP participants (Figure 5-4B$_{SUP}$).

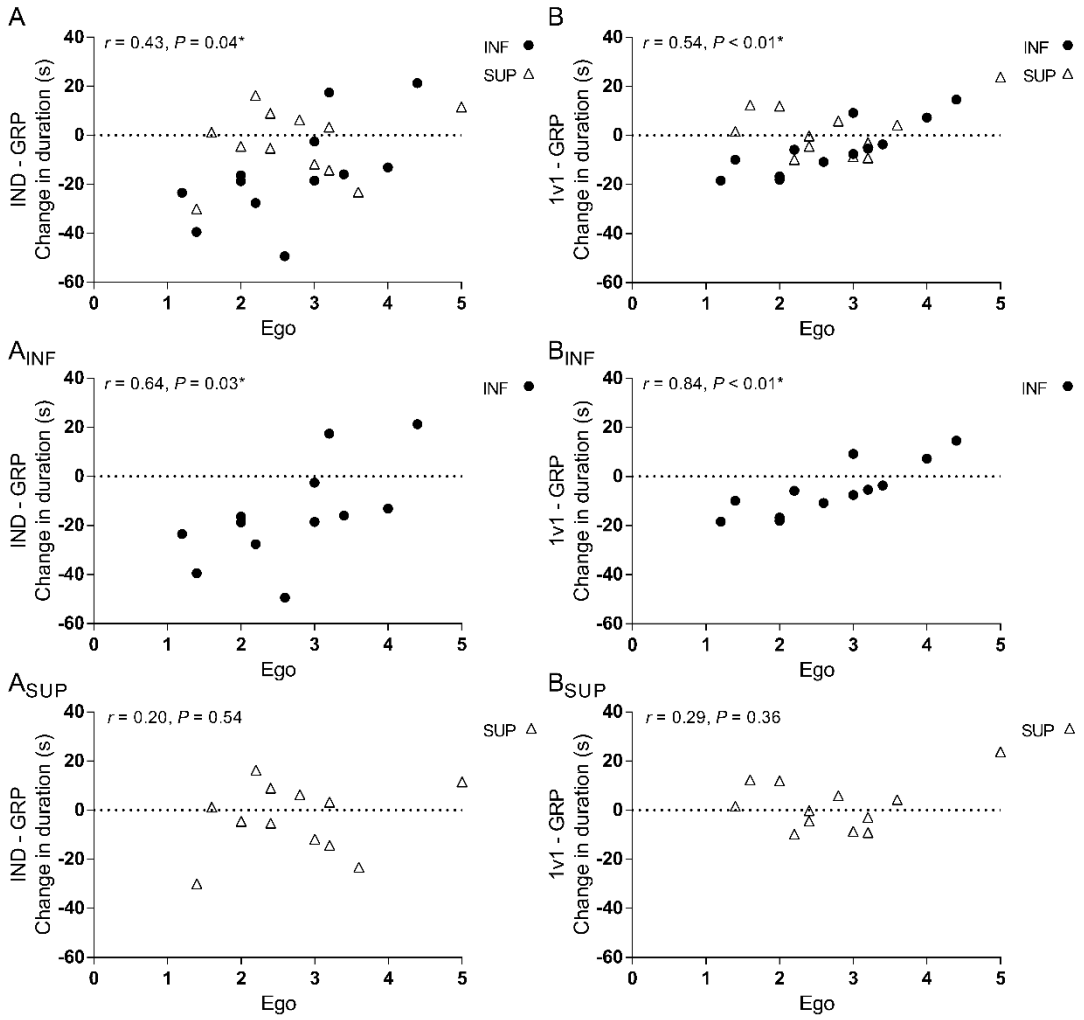

Figure 5-3 Correlation between ego orientation and change in TT duration between sessions. Panels A, AINF & ASUP, correlation between ego orientation and change in TT duration between IND and GRP sessions for all participants (n = 24) (panel A), INF participants (n = 12) (panel AINF) and SUP participants (n = 12) (panel ASUP). Panels B, BINF & BSUP, correlation between ego orientation and change in TT duration between 1v1 and GRP for all participants (n = 24) (panel B), INF participants (n = 12) (panel BINF) and SUP participants (n = 12) (panel BSUP). IND, individual TT. 1v1, two matched participants TT. GRP, TT with four participants (two INF and two SUP participants). INF, inferior (black circle). SUP, superior (white triangle). Correlation data presented as Pearson correlations (r). * Significant correlation.

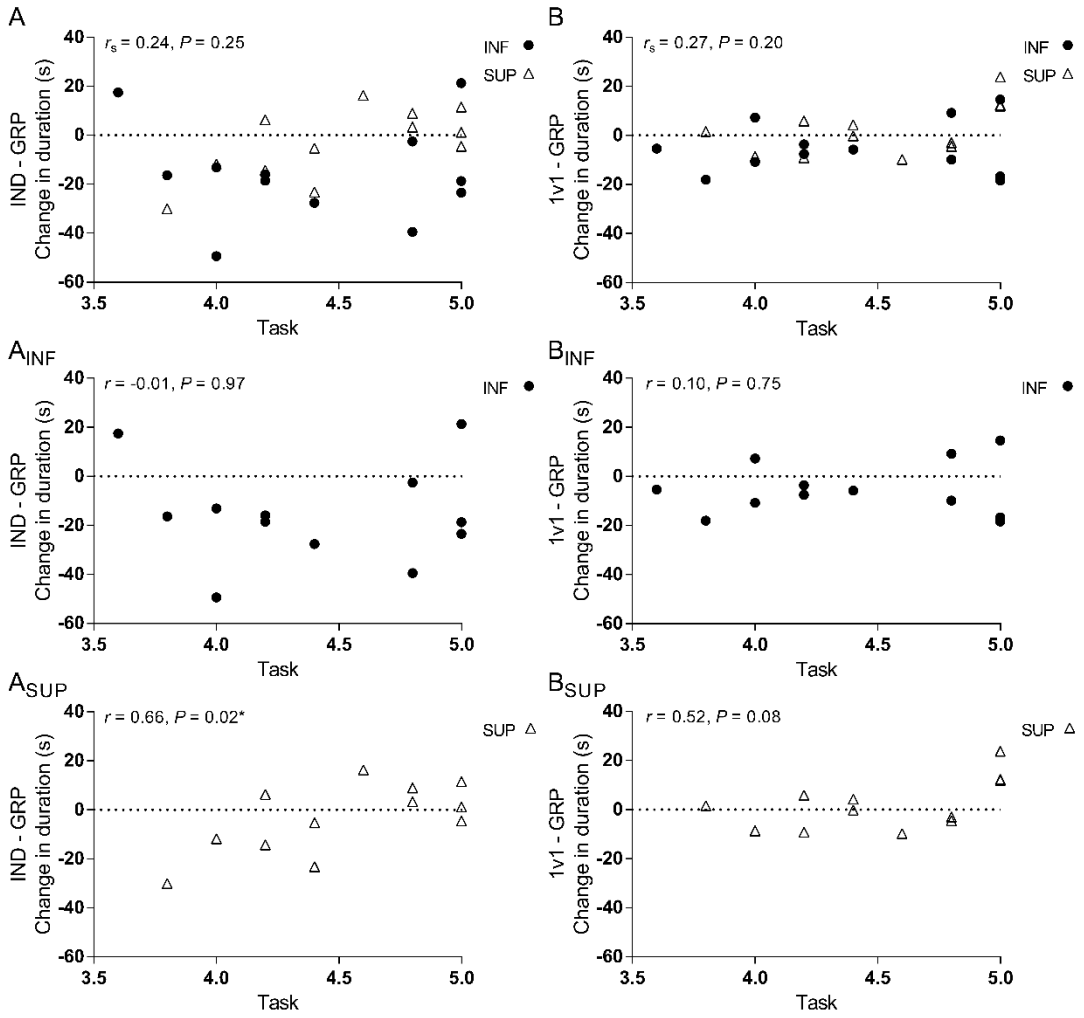

Figure 5-4 Correlation between task orientation and change in TT duration between sessions. Panels A, AINF & ASUP, correlation between task orientation and change in TT duration between IND and GRP sessions for all participants (n = 24) (panel A), INF participants (n = 12) (panel AINF) and SUP participants (n = 12) (panel ASUP). Panels B, BINF & BSUP, correlation between task orientation and change in TT duration between 1v1 and GRP for all participants (n = 24) (panel B), INF participants (n = 12) (panel BINF) and SUP participants (n = 12) (panel BSUP). IND, individual TT. 1v1, two matched participants TT. GRP, TT with four participants (two INF and two SUP participants). INF, inferior (black circle). SUP, superior (white triangle). Correlation data presented as Pearson correlations (r). When normality of data was violated, correlation is reported as Spearman's rho (rs). * Significant correlation.

5.4.4 Analysis of motivational orientation and perceptual scores

Analysis of motivational responses revealed no significant difference between sessions for interest/enjoyment, perceived competence and pressure/tension. For analysis within the INF and SUP groups, there was no significant difference in any motivational response. However, a moderate effect size for pressure/tension in the INF group (*P* =

0.07, $\eta_p^2 = 0.11$) indicates an increased pressure/tension for the GRP session (3.75 ± 1.39) compared to the IND (2.80 ± 1.02) and 1v1 (3.10 ± 1.12) sessions. In the GRP session, the perceived competence of the SUP group (5.15 ± 1.38) was significantly greater (P = 0.02, d = 1.07) than the INF group (3.78 ± 1.30). There was no significant mean change, or within group change for RPE or FS at any TT distance, this was also the case for the analysis of the INF and SUP groups.

5.4.5 Analysis of pacing profiles

Pacing profiles for all participants are shown in Figure 5-5A. IND power output was significantly lower compared to 1v1 and GRP at 500-m (P = 0.01, $\eta_p^2 = 0.12$), and only significantly lower than GRP at 750-m (P = 0.03, $\eta_p^2 = 0.09$). At 250-m there was no significant difference (P = 0.07, $\eta_p^2 = 0.07$), although there was a moderate effect size.

There was no significant difference between trials for the INF group (Figure 5-5B), although there were moderate effect sizes at 250-m (P =0.12, $\eta_p^2 = 0.12$), 500-m (P = 0.13, $\eta_p^2 = 0.12$) and 750-m (P = 0.16, $\eta_p^2 = 0.11$). For the SUP group, mean power was significantly lower in IND compared to 1v1 and GRP at 500-m ($P < 0.01$, $\eta_p^2 = 0.25$) (Figure 5-5C). There was no significant difference, but moderate effect sizes at 250-m (P = 0.15, $\eta_p^2 = 0.11$) and 750-m (P =0.10, $\eta_p^2 = 0.13$).

Given these changes in pacing profiles, Pearson correlation coefficients (r) were calculated for ego and task scores from the GOEM and the change in mean power within the first 750-m for both INF and SUP groups. However, there was no significant correlation for ego or task between any competition setting.

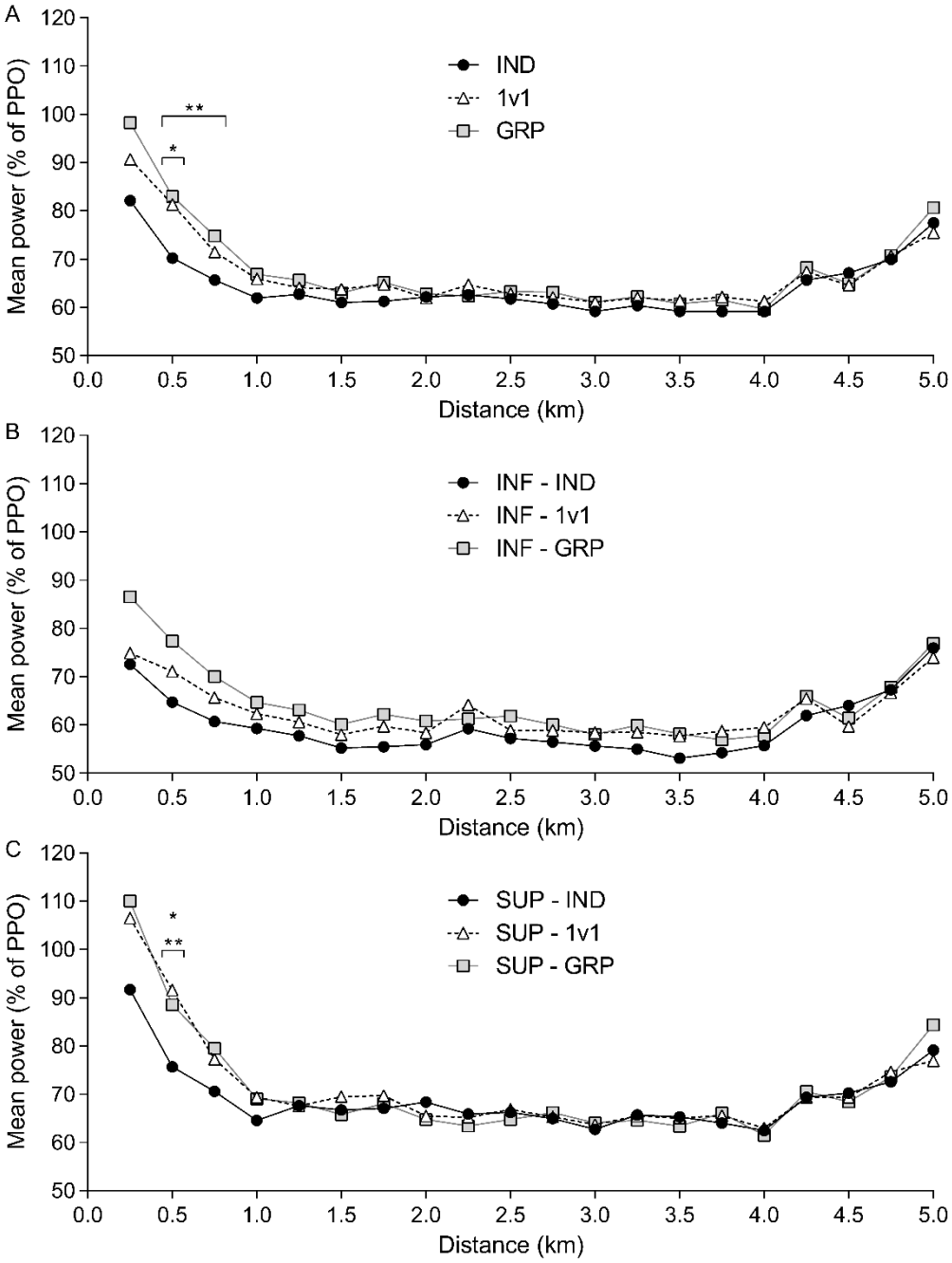

Figure 5-5 Mean power output pacing profiles. Mean power output averaged over 250-m intervals for all participants (n = 24) (panel A) between IND (black circle), 1v1 (white triangle) and GRP (grey square). Mean power output averaged over 250-m intervals for INF participants (panel B). Mean power output averaged over 250-m intervals for SUP participants (panel C). INF, inferior. SUP, superior. IND, individual TT. 1v1, two matched participants TT. GRP, TT with four participants (two INF and two SUP participants). * Significant difference between IND-1v1. ** Significant difference between IND-GRP.

5.5 Discussion

This study was the first to investigate the influence of actual competition with one and multiple competitors, as well as the effect of goal and motivational orientation on cycling TT pacing and performance.

5.5.1 Comparison between competition sessions

The presence of actual competition in the 1v1 and GRP competition settings produced no significant change in 5-km TT performance for all participants. However, a large effect for mean power output for INF participants indicates increased work in the GRP session compared to IND (Figure 5-1B$_{INF}$). In addition to this, HR was greater in GRP compared to IND for all participants (Figure 5-1C), with large effects sizes for both INF (Figure 5-1C$_{INF}$) and SUP (Figure 5-1C$_{SUP}$) participants. To explain this, HR may reflect increased arousal in the presence of others (Bond & Titus, 1983), which is increased further with multiple competitors (Cooke, Kavussanu, McIntyre, & Ring, 2013). Taken together with the observed change in power output, these results indicate a slightly increased exercise intensity at the beginning of the TT that can be attributed to the presence of competitors in the GRP session. Given the previous research with the perception of a 1v1 competitor (Corbett et al., 2012) and the presence of competitors in a group setting (Tomazini et al., 2015), these results of an increased intensity were expected compared to exercising alone. Consequently, we aimed to investigate any possible difference in performance between these two differing competition settings.

A direct comparison between the 1v1 and GRP sessions indicates no difference in mean performance measures (Figure 5-1A and Figure 5-1B). When investigating individual results, 15 out of 24 participants improved their time in GRP compared to 1v1 (Figure 5-2C). Of these 15 participants, 9 were INF participants (Figure 5-2C$_{INF}$), and 6 were SUP participants (Figure 5-2C$_{SUP}$). Accordingly, in comparison to the 1v1

competition, this suggests our GRP session design provides lower levels of benefit for SUP participants. In fact, performance in both the 1v1 and GRP sessions was identical for SUP participants (Figure 5-1A$_{SUP}$, Figure 5-1B$_{SUP}$, and Figure 5-5C). Therefore, it appears the added INF competitors were of no benefit to the SUP participants as they did not provide an interaction that required the SUP participants to respond (Smits et al., 2014). Indeed, this finding is consistent with social facilitation theory, in that performance is likely to be affected more by the presence of others if they are perceived to be important competitors (Bond & Titus, 1983). Accordingly, for the INF participants, the addition of SUP competitors provides a motivational stimulus greater than the 1v1 session, resulting in enhanced performance, explained by the large effect on mean power (Figure 5-1A$_{INF}$ and Figure 5-1B$_{INF}$). Consequently, this demonstrates that the presence of a competitor must be an appropriate motivational stimulus for any potential performance improvement (Bath et al., 2012; Bond & Titus, 1983).

In terms of pacing profiles, the presence of the SUP competitors in the GRP session was associated with a large effect on power output in the first 750m of the TT for the INF participants (Figure 5-5B). Explaining this, the addition of the SUP competitors creates a stimulus for the INF participants to change their pre-established pacing profile. Consequently, the motivation to be competitive results in an increased power output to match the SUP opponents (Konings et al., 2016). However, matching the superior opponents is more physically demanding (Lander, Butterly, & Edwards, 2009) and this would create a greater metabolic disturbance requiring management of pace in order to avoid detrimental metabolic consequences (St Clair Gibson et al., 2006). At the start of the TT, this afferent information is not accurately considered as the attentional focus is shifted away from internal aspects relating to the physiological status and toward the behaviour of competitors (Williams, Jones, Sparks, Marchant, et al., 2015). However, as

afferent information becomes more prominent, regulation will be necessary, and accordingly, after 750-m, GRP pacing follows a similar profile to IND and 1v1 for the INF participants. For the SUP participants, power output was similarly increased in both 1v1 and GRP compared to IND in the first 750-m (Figure 5-5C). In addition to our mean performance results, this indicates our GRP competition provides no additional benefit or change in exercise strategies. These results are likely due to the behaviour of the nearest competitor being unchanged between conditions, with the added presence of the INF participants not influencing SUP performance.

Although the INF participants increased power output at the start of the GRP TT (Figure 5-5B), power output was still relatively greater for the SUP participants (Figure 5-5C) during this part of the TT. Consequently, the difference between the INF and SUP participants would be well established in the initial stages of the GRP TT. This is an important factor to consider for group exercise settings, as a negative perception of competence can decrease motivation (Ryan & Deci, 2017) and result in performance reductions (Mauger, Jones, & Williams, 2011). In fact, post TT ratings demonstrate the difference in perceived competence between the participant groups. Additionally, a moderate effect size indicates a likely increase in pressure/tension for INF in the GRP TT. Taking these results into account, it would be expected that INF participants would have reduced performance in the GRP session. Yet the large effect of mean power and no change in interest/enjoyment indicates this was not the case (Figure 5-1B_{INF}). Although the INF participants perceived themselves as less competent than their SUP counterparts, it is likely motivation was still adequate from their INF 1v1 opponent. However, another possible explanation for these changes in performance is the way individuals approach a task based on goal orientations.

5.5.2 Influence of goal orientation

In conjunction with investigating the possible differences between competitive settings, the secondary aim of our study was to investigate the impact of goal orientations on performance within our competitive environments. It was hypothesised that based on personal goals, the interaction of multiple competitors might result in responders and non-responders to the differing exercise conditions. In fact, within the GRP session, there was a significant relationship between ego orientation of the INF participants competing against SUP competitors (Figure 5-3A_{INF} & Figure 5-3B_{INF}), whilst no correlation for the SUP participants competing against INF participants was found (Figure 5-3A_{SUP} & Figure 5-3B_{SUP}). These results demonstrate that when competing against SUP opponents, ego-oriented individuals are less likely to respond to the presence of a SUP competitor and improve performance. This is due to ego individuals evaluating performance on social comparison and perceptions of competence (Nicholls, 1984). With a difference in the competence perceptions between our groups in the GRP session, ego orientated INF individuals likely exhibited negative achievement behaviours allowing them to avoid disgrace by not achieving their goal through lack of effort (Nicholls, 1984). This appears to be the case as the highest ego orientated INF participants accounted for diminished performance in the GRP session (Figure 5-3A_{INF} & Figure 5-3B_{INF}).

Another potential explanation of these results is the instruction given to participants that created a more task involving scenario. For all competition TTs, participants were instructed to do their best while they ride with individuals who may be slower or faster than them. This means that, even for those who exhibit high ego orientations, the goal of each TT is self-improvement, which presumably diminished the importance of ego goals and appealed to the participant's goals of task mastery and improvement (Reinboth & Duda, 2016). In fact, as evidence of this, there was no

significant end spurt in the 1v1 or GRP sessions as participants did not increase power output to beat a competitor, although this has been demonstrated previously with competition (Corbett et al., 2012; Stone et al., 2012). Given the task involving scenario, it is surprising that there was a correlation for the SUP participants in the GRP TT (Figure 5-4A_{SUP}), with those with greater task orientations having reductions in performance. It is unclear as to why this is the case. It may be that these participants are conflicted by the presence of the competitors. Along with this line of reasoning, the presence of competitors provides external sensory input and reduces internal attentional focus (Williams, Jones, Sparks, Marchant, et al., 2015) which may be a conflict for task individuals that does not enable them to focus on their goal of the exercise. Nevertheless, this result is another indication that the addition of INF participants in a GRP TT, is of no additional benefit to SUP participants.

5.5.3 Limitations

Given the design of our research and instructions to participants, we have inadvertently created a task involving a scenario that may limit our conclusions as to how ego and task individuals respond to differing competition settings. It was anticipated that if participants were free to dictate outcome (i.e. employing tactics) that this would be a detriment to performance (Thiel et al., 2012). Fundamentally, tactics will likely hinder the best performance but increase the likelihood of a positive competitive outcome (Hettinga et al., 2017). Therefore, for this investigation, we looked at the improvement that competition might provide when the effort is maximal, but the investigation of tactical components and goal orientations may be an area for future research. Additionally, in highlighting the difference between actual and virtual competition, within this study we have only utilised actual competition, and have not addressed a direct comparison between real competition and an avatar for this mode of exercise. Ultimately,

the use of actual competition represents a strength of this study as it improves ecological validity. Yet, the use of actual competition also provides several limiting variables compared to an avatar, including the inability to standardise the 1v1 and GRP competitors, as well as variability in matching participants and controlling for differences in ability.

Another possible limitation of this study is how our GRP TT was constructed to create differences in the performance levels of the competitors. By having two sets of 1v1 participants make up a group of 4 participants, we have created a setting that does not truly represent a real group condition where performances could be more varied. Rather this condition could be seen as a set of 1v1 participants completing the trial with some social facilitation, given that the difference between the sets of 1v1 participants was substantial (44.83 ± 18.53-s). While this experimental design enabled us to investigate the goal and motivational orientation of our participants, an actual group condition in a controlled environment is an area for future research.

5.6 Conclusions

The presence of a competitor is known to influence pacing and performance. However, this study found no significant difference in 5-km TT performance between 1v1 or GRP competition settings. Yet, large effects on power indicate that INF participants are motivated to match SUP competitors in the initial stages of GRP exercise that may lead to small improvements in overall performance. Yet in a GRP setting, SUP participants may be detrimental to INF participants who are ego orientated, whilst INF participants provide no benefit to the performance of SUP participants. Overall, these findings demonstrate that competition is an important determinant of pacing and performance, and consideration should be given to the ability of competitors in a group setting to provide adequate motivation to achieve performance improvements.

CHAPTER 6. GENERAL DISCUSSION AND CONCLUSIONS

6.1 Overall aim and main findings

The overall aim of this thesis was to examine factors that have previously been identified to influence pacing and performance. Individually, prior experience, exercise-induced pain and competition were considered for their impact on self-paced cycling TTs. As the results of this thesis were discussed in chapters 3, 4 and 5, this chapter will discuss the objectives and meaningful findings from each of the three studies and their contribution to scientific knowledge. The practical applications, limitations and future research directions arising from the thesis will also be discussed.

6.1.1 Chapter 3. Study 1

The first study considered the role of prior experience on pacing and TT performance, with the objective to determine an appropriate familiarisation protocol to reduce variability across repeated trials. While previous studies investigating overall performance have shown that variability is reduced after two trials (Marino et al., 2002; Schabort et al., 1998), other previous works have indicated variability over several trials with novice participants and competitive cyclists (Corbett et al., 2009; Thomas et al., 2012). Based on this, it was predicted that more than one familiarisation would be required for novice participants to establish a stable (i.e. optimal) pacing strategy. This prediction was supported by the observation that multiple familiarisations were required to reduce systematic error in both overall performance and the way the task was conducted.

Given the role of prior experience in pacing development (Tucker, 2009), the prediction was that a similar, but not identical, exercise task may provide a sufficient familiarisation to a maximal paced TT. However, of the three familiarisation protocols

tested, a similar familiarisation protocol was deemed inferior to full familiarisation for performance and the reproducibility of pacing. This particular finding is in agreement with anticipatory pacing models, as a full familiarisation provides the participants with specific experience in the task. Therefore, a complete performance template has been obtained that only requires fine-tuning over subsequent bouts.

In summary, the main finding of this study is that variability in pacing and performance was lowest after a full familiarisation and two additional TTs, while four or more trials did not improve results. Based on these conclusions, both the second and third studies of this thesis were designed to include this familiarisation protocol to ensure that the relatively novice participants were adequately familiarised to cycling TT's before conducting experimental testing.

6.1.2 Chapter 4. Study 2

The objective of the second study was to examine the ability of TENS to reduce afferent feedback from group III and IV afferent fibres during exercise and how this may affect pacing and TT performance. It was hypothesised that the application of TENS before exercise would influence afferent feedback and increase the sensory threshold of exercise-induced pain, allowing for greater exercise intensity and faster TT performance. This hypothesis was based on the ability of TENS to reduce afferent feedback and the theory that this would create a 'buffer' in the participants pacing template. Specifically, the application of TENS would allow for a greater exercise intensity before exercise-induced pain reached a level that would require a change in behaviour, as described by the CGM and conscious awareness model. Specifically, these predictions were based on previous studies that had demonstrated performance improvements when afferent feedback was blocked or reduced (Amann et al., 2008; Amann et al., 2009).

After TENS application, perceptions of pain were similar in both placebo and control conditions even though the participant's subjective belief in TENS had a positive influence on their performance. However, there were no significant differences in pacing or TT performance, which indicates the limited effectiveness of TENS application before exercise to influence perceptions of exercise-induced pain. Although there were no significant differences, there were some indications of a possible effect at the start of the trials which gives promise for future research on TENS and exercise performance.

6.1.3 Chapter 5. Study 3

The third study of this thesis examined the role of actual competitors and motivational orientation on pacing and TT performance. It was predicted that when exercising in a group competition setting, performance would be improved compared to a session with one competitor. This prediction was based on the ability of competition to provide motivation to participants. As explained by the pacing models highlighted in the literature review, competition provides motivation to participants and in turn, produces a greater willingness to exert effort. Consequently, our prediction was based on previous findings that by having multiple competitor interactions an improved performance would be observed (Tomazini et al., 2015). Changes in HR and large effects for power output indicated an increased intensity in the group competition session. However, as demonstrated in previous studies, these changes may actually represent random fluctuations that occur when exercising with competition (Palmer, Hawley, Dennis, & Noakes, 1994). Additionally, the results of our study in a laboratory environment are difficult to compare to those in a field setting, due to the drafting and possible team strategies that occur in the field (Padilla, Mujika, Orbañanos, & Angulo, 2000). Overall, there was no significant evidence to indicate an improvement compared to cycling with one competitor.

Given the motivation of ego-oriented participants (Chi & Duda, 1995; Duda et al., 1991), it was also predicted that when in the presence of competition, ego-orientated participants would have greater performance improvements, compared to task-orientated participants. However, diminished performance improvements were observed for higher ego-oriented participants when competing against superior opponents, while additional inferior participants provided no benefit to the performance of superior ego-oriented participants.

Overall, predictions for this study were not supported. While our findings added to the existing knowledge that competition is an essential determinant of pacing and performance, it was also found that consideration should be given to the ability of competitors in a group setting to provide adequate motivation to achieve performance improvements.

6.2 Theoretical applications

Based on the findings from each of the studies, this thesis provides several theoretical implications. All pacing models indicate that an athlete will draw on previous experience in the task to determine if the intensity is "appropriate" for the current exercise (Edwards & Polman, 2013; Tucker, 2009). Based on this, it can be considered that any experience in the task would be more beneficial than no experience at all, as this would allow at least some reference point to regulate exercise intensity appropriately. However, results from chapter 3 demonstrate that similar, but not the same, exercise can have a detrimental influence on exercise over repeated bouts. Theoretically, this is important as it establishes that for pacing to be most successful, a participant must have experience in the specific exercise being undertaken, rather than similar experience. It appears that similar experience confuses the perceived and actual demands of the exercise, which impacts on pacing and overall performance. Also, from chapter 3, the results of end spurts

becoming larger as TTs were repeated for the similar- and no-experience groups likely indicates a lesser understanding of the task demands as opposed to the full-familiarisation group. This information readily strengthens the importance of specificity of experience for the development of a consistent pacing profile, rather than similar experience. Similar findings supporting task specificity have been observed for skill learning (Sigmundsson, Trana, Polman, & Haga, 2017).

As well as any previous experience in the exercise, physiological inputs are important in the initial stages of exercise (Tucker, 2009). In chapter 4, TENS application was associated with increased power output at the start of the trial, indicating that the manipulation of afferent feedback can influence the anticipatory regulation of exercise. However, after 750m of the TT, the performance of the TENS group was similar to the comparator conditions. These results add additional data to the pacing theory that indicates exercise is regulated in part by afferent feedback to a perceived pain threshold (Mauger et al., 2010a).

In chapter 5, the presence of actual competitors provides additional evidence on social facilitation theory, in that performance is likely to be affected more by the presence of others if they are perceived to be important (Bond & Titus, 1983). In the initial stages of the TTs, the uncertainty of competitor skill creates a stimulus for the participants to change their pre-established pacing profile, much like the results of Konings et al. (2016). However, by using actual competition in this study, we were able to demonstrate that once an opponent is considered too superior, ego-oriented individuals are less likely to respond positively to improve performance. This finding is theoretically important, as it demonstrates the ecological validity of utilising actual competition, as opposed to the perception of a competitor in investigational studies which may not translate to real-world scenarios.

Overall, the studies of this thesis were not designed to directly challenge the concepts of the pacing models identified in the literature review (Chapter 2), but to add additional data to known pacing factors. Of the pacing models discussed, all models acknowledge the importance of prior experience (Chapter 3), and situational factors (Chapter 5) for exercise regulation. As afferent sensory feedback is not considered within the psychobiological model, this model is not supported by our data (Chapter 4). Of the remaining models, the distinction between the CGM and the conscious awareness brain regulation model is whether regulation of the exercise occurs primarily subconsciously or into relative states of awareness. In addition, the primary role of the CGM is to maintain homeostasis, to which the introduction of motivational variables questions the foundation of the model (Inzlicht & Marcora, 2016). Accordingly, it is difficult to attribute the influence of goal, and motivational orientation from chapter 5 to the primarily subconscious regulation of the CGM. However, the results from chapter 5 demonstrate that pacing is a decision-making process, with appropriate actions taken when a stimulus increases in intensity. Consequently, the data from this thesis supports the conscious awareness brain regulation model for exercise pacing.

6.3 Practical applications

The findings from this thesis provide some practical applications for laboratory and applied settings. As multiple pacing factors were investigated, practical applications do not arise from the thesis overall, but from the individual studies. Regarding study specific practical applications, a full familiarisation conducted three times, is most effective to ensure reproducibility of pacing and performance in subsequent TTs in relatively novice participants. Importantly, this finding provides a baseline protocol for future research utilising a repeated measures design. However, when implementing these findings, researchers should also consider the biological variation can occur between subsequent tests, which may mask meaningful changes (McLellan, Cheung, & Jacobs, 1995). As indicated, our research utilised novice participants, and it is unclear whether similar results would be found for more experienced cyclists where variation may be less. The number of practice TTs required may depend on the cyclist's experience in engaging in TTs rather than as a cyclist. However, this would require further exploration. Regardless, it is recommended that irrespective of athlete experience, multiple familiarisations should be used before exercise testing.

Unfortunately, this thesis alone cannot confirm there is a benefit in administering TENS before exercise to enhance performance. However, there is potential for TENS to benefit events of less than 2 min and where the exercise-induced pain is localised, in which case the practical applications are limited. On the other hand, administration of TENS before exercise is not recommended for tasks longer than 2 min, as it appears that residual effects are limited. Consequently, future studies might explore whether TENS might be beneficial during actual TT performance.

Regarding the investigation of competition, the findings from this study provide applied knowledge for the optimisation of competition training protocols, but also

evidence for best performance in multiple competitor competitions. When designing training programs in a group setting, the athletic coaching staff should take note of athletes' ability and motivational orientation in order to provide adequate motivation to achieve optimal performance improvements. For example, those high in ego-orientation might benefit from competing against those of similar or lower ability so they can demonstrate their superiority. On the other hand, those high in ego-orientations might not give their best when performing against those who are superior to them.

6.4 Limitations

The specific limitations from each of the chapters are:

6.4.1 Chapter 3. Study 1

- The withholding of performance information from participants may have reduced the reproducibility between trials. Therefore, the inclusion of this information would likely increase reproducibility.

6.4.2 Chapter 4. Study 2

- The knowledge of the study aims may have inadvertently influenced the belief in the TENS intervention.
- As the placebo condition of this study had an absence of sensation, the effectiveness of this as a comparator may be limited.
- Due to physiological differences between participants, it is possible that there are responders and non-responders to TENS. However, this was not controlled for in this study.
- Analgesic effects of TENS are more prominent during active application; therefore, by administering TENS before exercise, it is possible that analgesic effects were reduced.

6.4.3 Chapter 5. Study 3

- By excluding competitive constructs, this study inadvertently created a task involving scenario which limits our conclusions as to how ego and task individuals respond to other competition settings.
- This chapter highlighted the difference between actual and virtual competition, but a direct comparison between real competition and an avatar was not investigated.
- The use of actual competition does not allow for standardisation of the 1v1 and GRP competitors between participants.

6.5 Future research directions

While the data from this thesis has provided insight into interventions that may assist athletic training and performance, the findings and the limitations have also raised several potential research directions.

6.5.1 Chapter 3. Study 1

Firstly, the finding for the need of multiple familiarisations requires future investigation to determine if the same effects occur in different modes of exercise, and the magnitude of effect in trained participants who lack specific experience in the exercise.

As the use of three familiarisations adds a significant time requirement to experimental protocols, it may be possible to reduce the time interval between familiarisation sessions without compromising pacing strategy development. In this study, trials were conducted at least 48 hours apart, however, for shorter TTs, similar to the protocol utilised by Mauger et al. (2009), it may be possible to conduct multiple trials within one session, to achieve a reproducible performance. However, this would need to be tested.

Another issue requiring investigation is the experience of the athlete and the specificity of the tested exercise. For example, an experienced cyclist may not have specific experience in conducting TTs, which likely makes the task at hand unfamiliar. Although previous studies have provided guidelines for reducing variability in experienced cyclists (Thomas et al., 2012), it is still not clear if these participants had specific experience in TTs. Subsequently, it would be of interest to investigate the amount of practice required to achieve stable performance for experienced participants who are unfamiliar with the task.

6.5.2 Chapter 4. Study 2

As indicated in the limitations of chapter 4, to understand the role of TENS on exercise pacing, it would be of benefit to investigate athletic populations to highlight any potential benefits or concerns of TENS use. Also, it was initially suggested that future research should investigate the potential benefits of TENS use within a task. Since then additional studies have shown within exercise TENS improves 10-mile TT duration, via the production of greater mean power output (Astokorki & Mauger, 2017b) and TENS used during resistance exercise allows participants to complete more set repetitions for the same pain perceptions (Menezes et al., 2018). Therefore, it appears that the use of TENS to reduce exercise-induced pain is most effective when TENS is active and applied during the exercise, and the findings from our study indicate there is limited benefit to TENS application before exercise. The latter, however, might depend on the task to be executed after TENS application. For example, it might be that TENS before a Wingate test is beneficial to performance. Additionally, there are other variables of TENS which require further research, including the duration of application, pulse width, frequency and the sites on the body which would benefit athletes the most.

6.5.3 Chapter 5. Study 3

Although this would remove the important social aspects of competition, it would likely be of benefit to investigate the influence of goal orientations with the use of a virtual avatar competitor. The use of an avatar would allow greater control of the competitor and could be manipulated to determine the of the level of superiority or inferiority that evokes the greatest response from the participant.

While our investigation utilised real competition to create a more ecologically valid study design, we have failed to address the need for a comparison between real and virtual competition settings. Competing against virtual competition will limit psychological dynamics (Bond & Titus, 1983; Snyder et al., 2012). However, the research into the comparison of virtual and real competition is dated and since then virtual competition software has evolved (Ravaja et al., 2006; Snyder et al., 2012). It would be of merit to conduct another investigation to compare real competition and an avatar for this mode of exercise.

As highlighted in the limitations of this chapter, our study was limited by removing the tactical components of competition. However, these variables are crucial to the successful outcomes of exercise, and the investigation of tactical components and goal orientations may be worth investigation.

Although we have demonstrated that motivational orientation can influence exercise behaviour, other psychological factors like self-confidence or coping strategies might also influence the TT behaviour of participants and are worthwhile to investigate in self-paced tasks. Also, the impact of self-efficacy has been investigated previously (Jones et al., 2016a; Jones et al., 2016b), yet this factor has not been investigated with actual competition, which may result in different conclusions as opposed to competing against an avatar.

6.6 Conclusion

Overall, this thesis investigated three pacing factors that had not yet been comprehensively tested. This research is of importance as a greater understanding of how exercise is self-regulated is crucial to unlocking the potential for increased exercise performance. The main results and conclusions of this thesis shed light on the highlighted pacing factors of experience, exercise-induced pain and competition, and how these can impact on performance during self-paced cycling TTs. Accordingly, these findings provide information to benefit the development of sound experimental protocols as well as providing a mechanistic understanding of the development of exercise scenarios and interventions that can be beneficial to performance outcomes.

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APPENDIX A: INFORMATION FOR PARTICIPANTS

A.1 Study 1 - Information to participants

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled

The role of task familiarity on the development and reproducibility of pacing within exercise testing.

This project is being conducted by a student researcher Andrew Hibbert as part of a PhD study at Victoria University under the supervision of Professor Remco Polman, Dr. Matthew Varley and Dr. Francois Billaut from the College of Sport and Exercise Science.

Project explanation

This project aims to examine the efficacy of different familiarisation sessions on subsequent performance testing, and the possible effectiveness of reducing learning effects and increasing reliability of testing. Although knowledge of endpoint and effects of learning are known to play a role in pace determination, the effect of familiarisation on pacing has not been extensively studied. Therefore, the results of this research will have significant and direct application for further investigations into determining the appropriate number of familiarisation sessions and performance trials needed to produce a reliable pacing profile in exercise testing.

What will I be asked to do?

If you give consent to participate in this project, you will be asked to visit the Exercise Physiology Laboratory at Victoria University Footscray Park campus to take part in the following testing and training sessions:

- 1 x 1.5hr pre-testing session
- 4-5 x 1.5hr performance-testing sessions
- 1 x 1.5hr post-testing session

We will first ask you to fill in several short questionnaires about your family medical history and your exercise habits to determine your ability to participate in this study. Prior to beginning the testing sessions, you will be randomly allocated to either a repeat-sprint (RS) or time-trial (TT) protocol, and to either a full familiarisation (FF), modified familiarisation (HF) or equipment familiarisation (EF).

Therefore, you will be allocated to one of six groups;

- RS-FF
- RS-MF
- RS-EF

- TT-FF
- TT-MF
- TT-EF

How will this project be conducted?

Pre-experiment subject screening:

All testing will be conducted in accordance with current guidelines for testing in the Exercise Physiology Laboratory, College of Sport and Exercise Science, Victoria University. You will be initially screened for cardiovascular risk factors and any health issues of relevance to the study via questionnaire. Participants with the following conditions will be excluded from the research as it may be unsafe for you to conduct the exercise intervention: diabetes (type 1 or 2), chronic heart disease, sever hypertension (systolic 160-179 mmHg, diastolic 100-109mmHg), severely overweight/obese (BMI>30), if you have had uncontrolled metabolic (such as uncontrolled diabetes) and/or cardiovascular disease, any recent significant injury that will impede your ability to perform exercise during the study or any other contraindications that will impede your ability/safety during exercise.

If you are deemed healthy and at low risk of any adverse events, you will be ask to complete a designated protocol

Full familiarisation

As part of this group in pre testing you will perform the entire protocol as familiarisation:
RS groups: 10x15 second sprints, with 30 seconds rest
TT groups: 20km time-trial

Modified familiarisation

As part of this group in pre testing you will perform a modified protocol as familiarisation:
RS groups: 5x15 second sprints, with 30 seconds rest
TT groups: 10km time-trial

Equipment familiarisation

As part of this group in pre testing you will perform a familiarisation with the equipment:
RS groups: 5minutes jogging on non-motorised treadmill followed by 2 sprints at 70% of maximum and 1 sprint at 100% of maximum
TT groups: 5 minutes moderate cycling on cycle ergometer

Performance testing:

Repeat sprint exercise – (RS groups only):
Each repeat-sprint exercise session will be comprised of a warm-up at a speed of 10 km h^{-1}, for 5-minutes on a motorised treadmill followed by 2 sprints at 70% of maximum and 1 sprint at 100% of maximum on the non-motorised treadmill. For the repeat sprint exercise you will perform 10, 15-second sprints, interspersed with 30 seconds of passive recovery between repetitions. The high intensity efforts, each lasting only a few seconds, and with very short recovery, are designed to reproduce high-intensity demands in team sports. RS exercises are extensively used in the VU Exercise Physiology Laboratory and across the world.

Time-Trials – (TT groups only):

A standardised 5-min warm-up prior to exercise will be administered. Performance measures will comprise of a 20km time-trial. This will be performed on a cycle ergometer as quickly as possible. You will be asked to remain seated throughout all trials; you will be allowed to change up/down gear ratios as required. The only feedback to be provided will be work completed/to go, this will be presented as 'distance covered'

Maximal voluntary contraction (MVC) test (non-invasive):

Immediately before and after exercise, you will be required to complete 3 x 5-s maximal contractions of the quadriceps muscle, using an iso-kinetic dynamometer (Cybex). This protocol is designed to measure muscle strength of the knee extensors and is a well-established and accepted protocol. During the 5-s contractions, we will be encouraging you to push to your maximum.

Electromyography (EMG) recording (non-invasive):

Small, self-adhesive surface electrodes will be attached to the skin over the belly of the dominant muscles of the right lower limb. This will not affect exercise movements in any significant way, but may require the area to be shaved and cleaned before attaching the electrodes. The recording of EMG will be administered during the MVC test and throughout exercise performance.

Responses to exercise:
RPE: A measure of the rate of perceived exertion (RPE) will be obtained during and after exercise based on the 6-20 Borg scale, rating how hard the exercise "felt".

PE: A measure of perceptions of exercise (PE) will be obtained during and after using an 11 point bipolar scale [+5 (very good) to -5 (very bad)]

Post testing:

For the RS group a post-testing session will be performed to determine your peak power output PPO.

PPO testing– (RS groups only):
Post testing performance for RS will consist of one laboratory session, where you will perform the dedicated warm up and then one maximal sprint effort to determine maximal power output (As previously described under repeat sprint exercise).

For the TT group a post-testing session will be performed to determine your VO_{2max}.

Graded exercise test – (TT groups only):
Post testing performance for TT groups will consist of a graded exercise test (GXT). During this session you will undertake a maximal incremental exercise test to exhaustion for baseline determination of peak oxygen uptake.The test will be performed on an electronically-braked bicycle ergometer and will consist of a 5 min warm up phase (75W), a one minute recovery phase, and a gradual incremental phase until fatigue.

The incremental phase will start at 100 Watts and increase by 50W after 150 seconds after a further 150s, the stages will be increased by 25W every 150s thereafter until you reach volitional fatigue. Pedalling cadence will be fixed at 70 revolutions per minute (RPM), and during this test you will be required to wear a heart rate monitor. Expired gases will also be analysed during the test with the use of a metabolic cart (Metcart Metabolic System). This test is routinely performed in our laboratory.

Important things to understand and what are the potential risks of participating in this project?

Before you volunteer to this study, make sure you read carefully the items below:

1. You are free to withdraw from this study at any time without any consequences or need for explanation

2. All exercise activity carries a risk of injury and risks of suffering a heart attack or stroke. It is important that you tell us if you have any medical condition.
3. For any medical emergencies a call to 000 will be made. The researchers will also commence appropriate first aid methods while waiting for the emergency team to arrive.
4. All exercise sessions involve risks of fainting, soft-tissue injury, muscle soreness and stiffness and sudden death due to myocardial infarction. The risk of such events is relatively low.
5. Furthermore the exercise protocols involve the possibility for mood changes such as irritability and depression. To minimise the risk of any psychological stress, your results will remain confidential. If you become stressed as a result of your participation please feel free to consult Dr Harriet Speed a registered psychologist free of charge on (03) 99195412 or at harriet.speed@vu.edu.au

What will I gain from participating?

From participating in this study you can expect to increase your understanding of fitness tests used by sport scientists, which will be performed in a state-of-the-art purpose-built testing facility. We cannot guarantee or promise that you will receive any direct benefit from your participation; however, you will receive free information about your own physical capabilities (i.e. Peak power output or VO_{2max}). This data is valuable for determining your fitness and designing your own training regimes.

How will the information I give be used?

The information you provide to the researchers will be kept strictly confidential, data you provide will be stored under alphanumeric codes (i.e. without your name or personal details) which only the researchers will be able to identify. Data collected from your performance testing, along with other participants, will be used to better understand the appropriate number of familiarisation sessions and performance trials needed to produce a reliable pacing profile in exercise testing.
The data that will be collected throughout the study will be used/published as group data in peer-reviewed journals and conference presentations. No personal details will be revealed without your consent.

Who is conducting the study?

This study is being conducted by Victoria University, College of Sport and Exercise Science, Institute of Sport, Exercise and Active Living.
For further information regarding this study, please contact the main researchers

Professor Remco Polman	ph: (03) 9919 5974	email: remco.polman@vu.edu.au
Dr. Matthew Varley matthew.varley@vu.edu.au	ph: (03)9919 5275	email:
Mr. Andrew Hibbert andrew.hibbert1@live.vu.edu.au	mob: 0400772879	email:

Any queries about your participation in this project may be directed to the Principal Researcher listed above. If you have any queries or complaints about the way you have been treated, you may contact the Ethics and Biosafety Coordinator, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4148.

A.2 Study 2 - Information to participants

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled

The use of Transcutaneous Electrical Nerve Stimulation (TENS) to reduce the perceptions of fatigue in exercise.

This project is being conducted by a student researcher Andrew Hibbert as part of a PhD study at Victoria University under the supervision of Professor Remco Polman, Dr. Matthew Varley from the College of Sport and Exercise Science; Institute of Sport Exercise and Active Living and A/Prof François Billaut from Université Laval, Département de kinesiology, Québec, Canada.

Project explanation

This project aims to examine the use of transcutaneous electrical nerve stimulation (TENS) to reduce the perceptions of fatigue and therefore influence performance in exercise. TENS is a method of low-voltage electrical currents to the skin via surface electrodes commonly used for the treatment of chronic and acute pain.

All exercise naturally involves a level of discomfort associated with fatigue (i.e. fatigue induced soreness), this information is important in determining exercise performance. Investigation into exercise has established that fatigue and the associated responses can be identified as a negative emotion in an individual's sense of effort. Essentially performance is determined by the level of negative emotions (discomfort) an individual is willing to encounter. Therefore, the use of TENS in this setting is planned to be used to 'mask' the sensations and therefore the perception of fatigue during a cycling time trial.

Prior to taking part in this study, all participants will be required to complete a risk factor assessment questionnaire, which will identify issues that may influence your capacity to participate. This questionnaire will help to minimise the risk of physical complications, only if you are free from health and function issues that could affect your participation in the project will you be able to participate.

If you choose to volunteer, you will be randomly allocated to one of two groups either TENS application during exercise (TENSduring) or TENS application prior to exercise (TENSprior). You will be required for six sessions (approximately 1.5 hour each). This will involve one familiarisation to the exercise protocol, familiarisation to the maximal voluntary contraction and magnetic stimulation and familiarisation to TENS, one familiarisation session to the exercise protocol, one pre testing session for baseline testing and three experimental testing sessions which involve a control (no TENS application), and two intervention (TENS application) sessions.

What will I be asked to do?

If you give consent to participate in this project, you will be asked to visit the Exercise Physiology Laboratory at Victoria University Footscray Park campus to take part in the following testing and training sessions:

- 7 sessions

- 1 x familiarisation to TENS
- 2 x familiarisation to exercise
- 1 x VO_{2max} testing session
- 3 performance testing sessions (cycling time-trials with TENS application)

We will first ask you to fill in a risk factor assessment questionnaire about your family medical history and your exercise habits to determine your ability to participate in this study. Prior to beginning the testing sessions, you will be randomly allocated to one of two groups either TENS application during exercise (TENSduring) or TENS application prior to exercise (TENSprior). This process is conducted via a coin toss where you have a 50-50 chance to be placed in either condition, the outcome of this process is final, and you will only be able to participate in the condition you have been allocated.

How will this project be conducted?

All sessions will be separated by a minimum of 48hrs to provide appropriate recovery and limit the effect of fatigue, and will be performed at the same time of day in order to limit the influence of everyday rhythms on performance and physiological responses. In the 24 hours prior to each session, you will be asked to refrain from vigorous activity and ingestion of caffeine, alcohol or other drugs. This is in order to provide consistency between testing sessions, as vigorous activity may cause some pre-fatigue or general soreness, alcohol has a diuretic effect and can cause dehydration, caffeine is shown to effect alertness and muscle activation which can actually improve performance.

Pre-experiment subject screening:

All testing will be conducted in accordance with current guidelines for testing in the Exercise Physiology Laboratory, College of Sport and Exercise Science, Victoria University. You will be initially screened for cardiovascular risk factors and any health issues of relevance to the study via questionnaire.

Participants with the following conditions will be excluded from the research as it may be unsafe for you to conduct the exercise intervention:

- Diabetes (type 1 or 2),
- Chronic heart disease,
- Have a pacemaker
- Sever hypertension (systolic >160mmHg, diastolic >100mmHg)
- Obese (BMI>30),
- If you have had uncontrolled metabolic (such as uncontrolled diabetes) and/or cardiovascular disease
- Any recent significant injury that will limit your ability to perform exercise during the study (i.e. any leg injury)
- If you may be pregnant or any other contraindications that will impede your safety during exercise.
- Are regularly taking pain medications (Such as paracetamol or ibuprofen)
- Have used TENS in the past

If you are deemed healthy and at low risk of any adverse events, and you have given informed consent you will be ask to take part in the following protocol:

Session 1: Familiarisation to exercise protocols and TENS (approximately 1.5hr duration)

These sessions is designed to ensure you become accustomed to the demands of a 5km time-trial, and comfortable with completing the task a quickly as possible. After providing informed consent, you will perform

a standardised 5-min warm-up, and then a 5km time-trial will be conducted. This will be performed on a cycle ergometer as quickly as possible.
After the time-trial, you will be familiarised with maximal isometric voluntary contraction (MVC) testing and peripheral magnetic stimulation (PMS) for the assessment of voluntary activation and muscle function. You will perform several MVCs (as many as needed to become familiar with the technique and confident of producing a maximal effort) with a superimposed magnetic stimulation (see below for procedure details). This session will also familiarise you with TENS application which involves associated electrode placement, settings and protocol (see procedure details). Furthermore, to confirm TENS response, pressure algometry (see procedure details) will be applied. This process has been used previously to confirm the application of TENS.

Session 2: Familiarisation to Exercise protocol (approximately 1.5hr duration)

These sessions are designed to ensure you become accustomed to the demands of a 5km time-trial, and comfortable with completing the task a quickly as possible.
A standardised 5-min warm-up prior to exercise will be administered, and then a 5km time-trial will be conducted. This will be performed on a cycle ergometer as quickly as possible. You will be asked to remain seated throughout all trials; you will be allowed to change up/down gear ratios as required. A heart rate monitor will be worn throughout both familiarisations. The only feedback to be provided will be work completed/to go, this will be presented as 'distance covered'.

Session 3: Graded exercise test (approximately 1.5hr duration)

During this session you will undertake a maximal incremental exercise test to exhaustion for baseline measurement of oxygen uptake (VO_{2peak}) and peak power output (PPO). This test will require you to wear a heart rate monitor and have a mouthpiece inserted and a nose clip attached in order to collect information on how your body uses oxygen during exercise. The test will be performed on an electronically-braked bicycle ergometer and will consist of a gradual incremental phase until fatigue.

The incremental phase will commence at a low intensity (30 watts), and slowly increase (30 watts per minute).

The following criteria will be used to determine when to stop the test;

1. You wish to stop (voluntary exhaustion i.e. you cannot work any harder)
2. You are unable to maintain the pedal rate above the required 60RPM
3. Onset of angina (chest pain) or angina like symptoms
4. You experience shortness of breath, wheezing, leg cramps or severe leg pain
5. There are any signs of nausea, light headedness, confusion, and facial pallor.

Session 4-6: Performance testing (approximately 1.5hr duration)
The 3 sessions will be as follows (these will be conducted in a randomised order):

1 X Control session:
This session will be conducted in the exact same fashion as the familiarisation i.e. no TENS application

2X TENS application sessions:
Both sessions will involve a 5km time-trial with TENS application (see procedure details).
Upon arriving at the laboratory you will be fitted with associated electrodes for TENS and EMG, after application of TENS you will be required to complete a 5km-time trial (as previously described in the familiarisation). Before during and after the trial you will be required to give your response to a number of scales (see procedure details) and after completion of the trial you will be required to fill out a 30 point questionnaire (see procedure details).

Brief description of the main procedures to be used:
All investigators are fully experienced in using these techniques.

Transcutaneous Electrical Nerve Stimulation:
TENS electrodes will be fitted over the thigh (quadriceps) muscles (low and high ends) in order to achieve the pain-relieving response over the entire muscle group. See picture for an example. Electrodes placed on the skin will be used to apply stimulation the legs and provide an analgesic (pain-relieving) effect. TENS stimulation is usually painless; however, some participants may not feel comfortable with the sensation associated with the stimulation. TENS will be applied by allowing you to increase the intensity of TENS to achieve a strong non-painful tingling without noticeable muscle contraction. TENS will be controlled by you and at any point there is a sensation of discomfort you are able to switch the device off. At the point of switching off any discomfort caused by the TENS will immediately cease. For group (TENSprior) this process will be conducted by sitting/lying comfortably for 30 minutes prior to exercise. For group (TENSduring) this process will be conducted the by sitting/lying comfortably for 5 minutes prior to exercise, and then throughout the exercise duration.

Pressure Algometry (non-invasive):
Pressure algometry will be applied by having you lay on a padded bench; the algometer probe will then be pushed onto the midpoint of the quadriceps at a constant rate. You will be asked concentrate on the sensations in the leg until the pressure becomes only noticeably painful (Pain measurement 1) and then definitely painful (Pain measurement 2); at which point you will state this verbally and the investigator will immediately withdraw the probe from the skin.

Electromyography (EMG) recording (non-invasive):
Small, self-adhesive surface electrodes will be attached to the skin over the belly of the dominant muscles of the lower limb. This will not affect exercise movements in any significant way, but may require the area to be shaved and cleaned before attaching the electrodes. The recording of EMG will be administered throughout exercise performance.

Maximal voluntary contraction test (non-invasive):
Whilst lying on a bench, with the knee flexed at 90° (0° = knee fully extended) over the end of the bench. The upper body, hips and thigh will be strapped on the bench to reduce body movement. You will be asked to perform a series of maximal knee extensions of 4 seconds, before and immediately after the TENS application and exercise (3 times in 1 session) . This test will determine the maximal isometric strength of your quadriceps muscle.

Peripheral magnetic stimulation (non-invasive):
While lying on a bench to assess your maximal strength, a series of magnetic stimulations of the quadriceps will be used at rest and during the contractions to measure muscle function properties and voluntary activation. Magnetic stimulation is usually painless; however some participants may experience a slight discomfort or pain during stimulation. A thorough preliminary session to get accustomed to the stimulation will be performed in session 1.

Responses to exercise:
A measure of the rate of perceived exertion (RPE) will be obtained during and after exercise based on the 6-20 Borg scale, rating how hard the exercise “felt”.
A measure of feelings of exercise (FS) will be obtained during and after using an 11 point scale [+5 (very good) to -5 (very bad)].
A measure of sense of effort (SE) will be obtained during and after exercise with a 0-10 [0 (no effort) to 10 (maximal effort)] scale. Other items to be included in this measurement will include overall peripheral discomfort, perceived difficulty breathing, perceived limb discomfort all [0 (nothing at all) to 10 (maximal)] scale.

Skeletal discomfort: This involves rating regions of the body (i.e upper and lower legs) in terms of perceived comfort; ratings are given out of 5, with 1 being comfortable and 5 extremely uncomfortable.

Questionnaire: Post exercise you will be given a questionnaire (30 questions) to complete, about the exercise just undertaken.

Important things to understand and what are the potential risks of participating in this project?

Before you volunteer to this study, make sure you read carefully the items below:

1. You are free to withdraw from this study at any time without any consequences or need for explanation
2. There is a slight chance you will experience discomfort associated with the TENS, any discomfort will be quickly disappear following the removal of stimulation. If you feel at any stage that the discomfort associated with any technique is unbearable you can choose to withdraw from the research.
3. You are required to complete a risk factor questionnaire. It is important to be truthful as this will help researchers determine if participating in this study is appropriate for you.
4. All exercise sessions involve risks of fainting, soft-tissue injury, muscle soreness and stiffness. The risk of such events is relatively low.
5. All exercise activity carries a risk of injury and risks of suffering a heart attack or stroke. It is important that you tell us if you have any medical condition**.**
6. For any medical emergencies a call to 000 will be made. The researchers will also commence appropriate first aid methods while waiting for the emergency team to arrive.
7. Furthermore the exercise protocols involve the possibility for mood changes such as irritability and depression. To minimise the risk of any psychological stress, your results will remain confidential. If you become stressed as a result of your participation please feel free to consult Professor Tony Morris a registered psychologist, who is not involved in the study but knows about it on (03) 9919 5353 or at tony.morris@vu.edu.au (free of charge).

What will I gain from participating?

We cannot guarantee or promise that you will receive any direct benefit from your participation. However, from participating in this study you may expect to increase your understanding of fitness tests used by sport scientists, which will be performed in a state-of-the-art purpose-built testing facility.; however, once all testing sessions are completed you will receive free information about your own physical capabilities (i.e. Peak power output or VO_{2max}) and an overview of your performance in the various trials.

How will the information I give be used?

The information you provide to the researchers will be kept strictly confidential, data you provide will be coded and stored (i.e. without your name or personal details) which only the researchers will be able to identify.

The data that will be collected throughout the study will be used for the purpose of Mr. Andrew Hibbert completing his PhD thesis. Data will also be published as group data in peer-reviewed journals and conference presentations by Mr. Andrew Hibbert. No personal details will be revealed without your consent, any at no time will you be personally identifiable in the presentation of these results.

Who is conducting the study?

This study is being conducted by Victoria University, College of Sport and Exercise Science, Institute of Sport, Exercise and Active Living.

For further information regarding this study, please contact the Principal or Student Investigator.

Investigators:

Dr. Matthew Varley Principal investigator ph: (03) 9919 5275 email: matthew.varley@vu.edu.au
Mr. Andrew Hibbert Student investigator mob: 0400772879 email: andrew.hibbert1@live.vu.edu.au
Professor Remco Polman - Associate investigator
A/Prof François Billaut - Associate investigator

If you have any queries or complaints about the way you have been treated, you may contact the Ethics and Biosafety Coordinator, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4148.

A.3 Study 3 - Information to participants

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

INFORMATION TO PARTICIPANTS INVOLVED IN RESEARCH

You are invited to participate

You are invited to participate in a research project entitled

Influence of competition on cycling time trial performance

This project is being conducted by a student researcher Andrew Hibbert as part of a PhD study at Victoria University under the supervision of Professor Remco Polman, Dr. Matthew Varley from the College of Sport and Exercise Science; Institute of Sport Exercise and Active Living and A/Prof François Billaut from Université Laval, Département de kinesiology, Québec, Canada.

Project explanation

Often exercise is conducted with competition, this may include one other individual (head to head) or often exercise may be undertaken with many competitors (such as a marathon or cycling race). This project aims to examine the influence of competition both against 1 participant and in a group, and how this effects pacing and performance in cycling time trials.

Pacing is the management of effort in exercise in order to control fatigue symptoms but also to maximize the chance of achieving the goals of the task. In races, the goal of the task is to win the race, but individuals will often plan to finish as quickly as possible. Therefore, other competitors need to be considered when planning how hard to push and when. It has long been known that individuals can perform better with competition, but it is not well understood how this improvement in performance is achieved (i.e. pacing). To investigate the effect that competition can have on pacing you will perform a 5 km cycling time trial in three different conditions; one individual time trial, a time trial with one competitor and one time trial with 3 competitors.

Prior to taking part in this study, all participants will be required to complete a risk factor assessment questionnaire, which will identify issues that may influence your capacity to participate. This questionnaire will help to minimise the risk of physical complications, only if you are free from health and function issues that could affect your participation in the project will you be able to participate. This investigation will allow us to better understand the behavioural mechanisms underlying central regulation in exercise, most importantly conducting exercise in a social setting.

What will I be asked to do?

If you give consent to participate in this project, we will first ask you to fill in a risk factor assessment questionnaire about your family medical history and your exercise habits to determine your ability to participate in this study. If you are deemed healthy and at low risk of any adverse events, and you have given informed consent you will be asked to visit the Exercise Physiology Laboratory at Victoria University

Footscray Park campus to take part in the following testing and training sessions. For further information on the details see: How will this project be conducted?
Outline: 8 sessions

- Session 1: This involves an a practice of the incremental test to measure aerobic fitness (Graded exercise test, GXT)
- Session 2: This involves the GXT testing session
- Session 3: Involves a 5 km cycling time trial (TT) familiarisation
- Session 4: Involves a 5 km TT familiarisation
- Session 5: Involves a 5 km TT familiarisation
- Sessions 6-8: 3 time-trial testing sessions
    - 1 x individual 5 km TT
    - 1 x 5 km TT with 1 competitor
    - 1 x 5 km TT with 3 competitors

How will this project be conducted?

Pre-experiment subject screening:

All testing will be conducted in accordance with current guidelines for testing in the Exercise Physiology Laboratory, College of Sport and Exercise Science, Victoria University. You will be initially screened for cardiovascular risk factors and any health issues of relevance to the study via questionnaire.

Participants with the following conditions will be excluded from the research as it may be unsafe for you to conduct the exercise intervention:

- Diabetes (type 1 or 2),
- Chronic heart disease,
- Have a pacemaker
- Sever hypertension (systolic >160mmHg, diastolic >100mmHg)
- Obese (BMI>30),
- If you have had uncontrolled metabolic (such as uncontrolled diabetes) and/or cardiovascular disease
- Any recent significant injury that will limit your ability to perform exercise during the study (i.e. any leg injury)
- If you may be pregnant or any other contraindications that will impede your safety during exercise.

If you are deemed healthy and at low risk of any adverse events, and you have given informed consent you will be ask to take part in the following protocol:

Session 1: Familiarisation to Graded Exercise Test (GXT)
(Approximately 1.5 hr duration)

During this session you will undertake a maximal incremental exercise test to exhaustion to familiarise you with the GXT protocol. This test will require you to wear a heart rate monitor and have a mouthpiece inserted and a nose clip attached in order to collect information on how your body uses oxygen during exercise. The test will be performed on an electronically-braked bicycle ergometer and will consist of a gradual incremental phase until fatigue.

The incremental phase will commence at a low intensity (0 watts), and slowly increase (30 watts per minute).

The following criteria will be used to determine when to stop the test;

1. You wish to stop (voluntary exhaustion i.e. you cannot work any harder)

2. You are unable to maintain the pedal rate above the required 60RPM
3. Onset of angina (chest pain) or angina like symptoms
4. You experience shortness of breath, wheezing, leg cramps or severe leg pain
5. There are any signs of nausea, light headedness, confusion, and facial pallor.

Session 2: Graded Exercise Test (GXT) (approximately 1hr duration)

During this session you will undertake a maximal incremental exercise test to exhaustion for baseline measurement of oxygen uptake (VO_{2peak}) and peak power output (PPO). This test will require you to wear a heart rate monitor and have a mouthpiece inserted and a nose clip attached in order to collect information on how your body uses oxygen during exercise. The test will be performed on an electronically-braked bicycle ergometer and will consist of a gradual incremental phase until fatigue.

This test follows the same procedure explained above. The same criteria to stop the test apply. The incremental phase will commence at a low intensity (0 watts), and slowly increase (30 watts per minute).

Session 3-5: Familiarisation to Exercise protocol (5km TT) (approximately 45min duration)

These sessions are undertaken to ensure you become accustomed to the demands of a 5km time-trial, and comfortable with completing the task a quickly as possible. For each TT session a standardised 5-min warm-up prior to exercise will be administered, and then a 5km time-trial will be conducted. This will be performed on a cycle ergometer as quickly as possible. You will be asked to remain seated throughout all trials; you will be allowed to change up/down gear ratios as required. A heart rate monitor will be worn throughout the task. The only feedback to be provided will be work completed/to go, this will be presented as 'distance covered'.

In session 3, prior to conducting the time trial familiarisation you will be asked to complete a 10 item questionnaire to asses your attitude towards exercise.

Session 4-6: Performance testing (approximately 1hr duration)
The 3 sessions will be as follows (these will be conducted in a randomised order):

1 X Individual TT:
This session will be conducted in the exact same fashion as the familiarisation.
For this session you will conduct a warm up and then a 5 km TT. After this you will be asked to conduct a questionnaire that will assess motivation and pacing.

1 X competition TT with 1 competitor
Based on your physical capacity and performance in the TT familiarisations you will be matched with another participant, so that in this session you will compete, with the instruction to complete the 5km as quickly as possible. After this you will be asked to conduct a questionnaire that will assess motivation and pacing.

1 X competition TT with 3 competitors
Similar to the competition with one participant, in this session you will also conduct a 5 km TT with competition. Competition in this session will be provided by your matched participant and another group of two participants, overall you will compete with three other competitors. After this you will be asked to conduct a questionnaire that will assess motivation and pacing.

Brief description of the main procedures to be used:
All investigators are fully experienced in using these techniques.

Time-Trials
A standardised 5-min warm-up prior to exercise will be administered. Performance measures will comprise of a 5km time-trial. This will be performed on a cycle ergometer as quickly as possible. You will be asked to remain seated throughout all trials; you will be allowed to change up/down gear ratios as required. You will be asked to wear a heart rate monitor during these trials.

Responses to exercise:
Rate of perceived exertion (RPE): This measure will be obtained during and after exercise based on the 6-20 Borg scale, rating how hard the exercise "felt".

Feeling scale (FS): This measure of perceptions of exercise will be obtained during and after exercise using an 11 point scale [+5 (very good) to -5 (very bad)].

Sense of effort (SE): This measure will be obtained during and after exercise with a 0-10 [0 (no effort) to 10 (maximal effort)] scale.

Questionnaires:
Goal Orientations in Exercise Measure (GOEM): This measure is a 10 item questionnaire measuring your approach to exercise goals. This will be conducted in the familiarisation.

Intrinsic Motivation Inventory (IMI): this measure will be obtained after exercise, and will ask you to your motivation trends during the exercise.

Pacing Questionnaire: Post exercise you will be given a questionnaire (30 questions) to complete about the exercise just undertaken.

Important things to understand and what are the potential risks of participating in this project? Before you volunteer to this study, make sure you read carefully the items below:

1. You are free to withdraw from this study at any time without any consequences or need for explanation
2. You are required to complete a risk factor questionnaire. It is important to be truthful as this will help researchers determine if participating in this study is appropriate for you.
3. All exercise sessions involve risks of fainting, soft-tissue injury, muscle soreness and stiffness. The risk of such events is relatively low.
4. All exercise activity carries a risk of injury and risks of suffering a heart attack or stroke. It is important that you tell us if you have any medical condition**.**
5. For any medical emergencies a call to 000 will be made. The researchers will also commence appropriate first aid methods while waiting for the emergency team to arrive.
6. Furthermore, the exercise protocols involve the possibility for mood changes such as irritability and depression. To minimise the risk of any psychological stress, your results will remain confidential. If you become stressed as a result of your participation please feel free to consult Professor Tony Morris a registered psychologist, who is not involved in the study but knows about it on 0430 511 543 or at tony.morris@vu.edu.au (free of charge).

What will I gain from participating?

We cannot guarantee or promise that you will receive any direct benefit from your participation. However, from participating in this study you may expect to increase your understanding of fitness tests used by sport scientists, which will be performed in a state-of-the-art purpose-built testing facility.; however, once all testing sessions are completed you will receive free information about your own physical capabilities (i.e. Peak power output or VO_{2peak}) and an overview of your performance in the various trials.

How will the information I give be used?

The information you provide to the researchers will be kept strictly confidential, data you provide will be coded and stored (i.e. without your name or personal details) which only the researchers will be able to identify.
The data that will be collected throughout the study will be used for the purpose of Mr. Andrew Hibbert completing his PhD thesis. Data will also be published as group data in peer-reviewed journals and conference presentations by Mr. Andrew Hibbert. No personal details will be revealed without your consent, any at no time will you be personally identifiable in the presentation of these results.

Who is conducting the study?

This study is being conducted by Victoria University, College of Sport and Exercise Science, Institute of Sport, Exercise and Active Living.
For further information regarding this study, please contact the Principal or Student Investigator.

Investigators:
Dr. Matthew Varley **-** Principal investigator email: matthew.varley@vu.edu.au
Mr. Andrew Hibbert - Student investigator mob: 0400772879 email: andrew.hibbert1@live.vu.edu.au
Professor Remco Polman - Associate investigator
A/Prof François Billaut - Associate investigator
Dr. Aaron Petersen - Associate investigator

If you have any queries or complaints about the way you have been treated, you may contact the Ethics and Biosafety Coordinator, Victoria University Human Research Ethics Committee, Victoria University, PO Box 14428, Melbourne, VIC, 8001 phone (03) 9919 4148.

APPENDIX B: CONSENT FORMS

B.1 Study 1 - Consent form

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:
We would like to invite you to be a part of a study into the….

The role of task familiarity on the development and reproducibility of pacing within exercise testing.

This project aims to examine the efficacy of different familiarisation sessions on subsequent performance testing, and the possible effectiveness of reducing learning effects and increasing reliability of testing. Although knowledge of endpoint and effects of learning are known to play a role in pace determination, the effect of familiarisation on pacing has not been extensively studied. Therefore, the results of this research will have significant and direct application for further investigations into determining the appropriate number of familiarisation sessions and performance trials needed to produce a reliable pacing profile in exercise testing.

This study will investigate the effect of different familiarisation sessions on repeated sprint (RS) and time-trial (TT) performance. The study will consist of two parts Part A will investigate repeated sprint performance and Part B will investigate time trial performance. Prior to beginning the testing sessions, you will be randomly allocated to either a repeat-sprint (RS) or time-trial (TT) protocol, and to either a full familiarisation (FF), modified familiarisation (HF) or equipment familiarisation (EF).
Therefore, you will be allocated to one of six groups;

- RS-FF
- RS-MF
- RS-EF
- TT-FF
- TT-MF
- TT-EF

In the first session you will be required to perform your allocated familiarisation session after this you will be required to complete four (4) to five (5) testing sessions consisting of either repeat sprint exercises (i.e. ten 10-second sprints, interspersed with 30s of passive recovery between repetitions) or a time trial (i.e. 20km) performance (dependent on your group allocation). Prior to and throughout exercise there will be a number of neuromuscular tests (i.e. maximal voluntary contraction & electromyography recording).

Prior to taking part in this study, all participants will be required to complete a Risk Factor Assessment Questionnaire, which will identify those with suspected cardiovascular complications, ventilatory restrictions and/or musculoskeletal conditions or injuries. This questionnaire will help to minimise the risk of physical complications, if you do not pass this process you will not be included in this research.

Before you volunteer to this study, make sure you read carefully the items below:

1. You are free to withdraw from this study at any time without any consequences or need for explanation
2. All exercise activity carries a risk of injury and risks of suffering a heart attack or stroke. It is important that you tell us if you have any medical condition**.**
3. For any medical emergencies a call to 000 will be made. The researchers will also commence appropriate first aid methods while waiting for the emergency team to arrive.
4. All exercise sessions involve risks of fainting, soft-tissue injury, muscle soreness and stiffness. The risk of such events is relatively low.
5. Furthermore, the exercise protocols involve the possibility for mood changes such as irritability and depression. To minimise the risk of any psychological stress, your results will remain confidential. If you become stressed as a result of your participation, please feel free to consult Dr Harriet Speed a registered psychologist free of charge on (03) 99195412 or at harriet.speed@vu.edu.au

CERTIFICATION BY SUBJECT

I, _____ (name)

of

(address/suburb) _____

certify that I am at least 18 years old* and that I am voluntarily giving my consent to participate in the study: "Effect of task familiarisation upon the development and reproducibility of pacing within exercise testing" which is being conducted at Victoria University by: Andrew Hibbert

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Andrew Hibbert

and that I freely consent to participation involving the below mentioned procedures:

Repeat sprint exercise – (RS groups only)

Time-Trials – (TT groups only)

Maximal voluntary contraction (MVC) test (non-invasive)

Electromyography (EMG) recording (non-invasive)

PPO testing– (RS groups only)

Graded exercise test – (TT groups only)

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:
Any queries about your participation in this project may be directed to the researchers

Professor Remco Polman ph: (03) 9919 5974 email: remco.polman@vu.edu.au
Dr. Matthew Varley ph: (03)9919 5275 email: matthew.varley@vu.edu.au
Mr. Andrew Hibbert mob: 0400772879 email: andrew.hibbert1@live.vu.edu.au

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4781.

[*please note: Where the participant/s are aged under 18, separate parental consent is required; where the participant/s are unable to answer for themselves due to mental illness or disability, parental or guardian consent may be required.]

B.2 Study 2 - Consent form

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:
We would like to invite you to be a part of a study into the….

The use of Transcutaneous Electrical Nerve Stimulation (TENS) to reduce the perceptions of fatigue in exercise.

Prior to taking part in this study, all participants will be required to complete a Risk Factor Assessment Questionnaire, which will identify those with suspected cardiovascular complications, ventilatory restrictions and/or musculoskeletal conditions or injuries. This questionnaire will help to minimise the risk of physical complications, if you do not pass this process you will not be included in this research.

Project explanation

This project aims to examine the use of transcutaneous electrical nerve stimulation (TENS) to reduce the perceptions of fatigue and therefore influence performance in exercise. TENS is a method of low-voltage electrical currents to the skin via surface electrodes commonly used for the treatment of chronic and acute pain.

All exercise naturally involves a level of discomfort associated with fatigue (i.e. fatigue induced soreness), this information is important in determining exercise performance. Investigation into exercise has established that fatigue and the associated responses can be identified as a negative emotion in an individual's sense of effort. Essentially performance is determined by the level of negative emotions (discomfort) an individual is willing to encounter. Therefore, the use of TENS in this setting is planned to be used to 'mask' the sensations and therefore the perception of fatigue during a cycling time trial. Prior to taking part in this study, all participants will be required to complete a risk factor assessment questionnaire, which will identify any issues that may influence your ability to participate. This questionnaire will help to minimise the risk of physical complications, if you do not pass this process you will not be included in this research.
If you choose to volunteer, you will be randomly allocated to one of two groups either TENS application during exercise (TENSduring) or TENS application prior to exercise (TENSprior). You will be required for six sessions (approximately 1.5 hour each). This will involve one familiarisation to the exercise protocol, familiarisation to the maximal voluntary contraction and magnetic stimulation and familiarisation to TENS, one familiarisation session to the exercise protocol, one pre testing session for baseline testing and three experimental testing sessions which involve a control (no TENS application), and two intervention (TENS application) sessions.

Before you volunteer to this study, make sure you read carefully the items below:

1. You are free to withdraw from this study at any time without any consequences or need for explanation
2. There is a slight chance you will experience discomfort associated with the TENS, any discomfort will be quickly disappear following the removal of stimulation. If you feel at any stage that the discomfort associated with any technique is unbearable you can choose to withdraw from the research.
3. You are required to complete a risk factor questionnaire. It is important to be truthful as this will help researchers determine if participating in this study is appropriate for you.
4. All exercise sessions involve risks of fainting, soft-tissue injury, muscle soreness and stiffness. The risk of such events is relatively low.
5. All exercise activity carries a risk of injury and risks of suffering a heart attack or stroke. It is important that you tell us if you have any medical condition**.**
6. For any medical emergencies a call to 000 will be made. The researchers will also commence appropriate first aid methods while waiting for the emergency team to arrive.
7. Furthermore, the exercise protocols involve the possibility for mood changes such as irritability and depression. To minimise the risk of any psychological stress, your results will remain confidential. If you become stressed as a result of your participation please feel free to consult Professor Tony Morris a registered psychologist, who is not involved in the study but knows about it on (03) 9919 5353 or at tony.morris@vu.edu.au (free of charge).

CERTIFICATION BY SUBJECT

I, _____ (name)

of

(address/suburb) _____

Certify that I am at least 18 years old and that I am voluntarily giving my consent to participate in the study*:*

"Use of Transcutaneous Electrical Nerve Stimulation (TENS) to reduce the perceptions of fatigue in exercise."

Which is being conducted at Victoria University by: Andrew Hibbert

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by: **Mr. Andrew Hibbert** and that I freely consent to participation involving the below mentioned procedures:

5-km Time-Trials

Graded exercise test

Transcutaneous electrical nerve stimulation (TENS)

Pressure Algometry

EMG

Maximal Voluntary Contraction

Peripheral Magnetic Stimulation

Responses to scales and Questionnaires:

- **Rate of Perceived exertion (RPE)**
- **Feeling Scale (FS)**
- **Sense of Effort (SE)**
- **Skeletal Discomfort (SD)**
- **Questionnaire about exercise**

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:

Any queries about your participation in this project may be directed to the researchers

Dr. Matthew Varley ph: (03) 9919 5275 email: matthew.varley@vu.edu.au
Mr. Andrew Hibbert mob: 0400772879 email: andrew.hibbert1@live.vu.edu.au **Professor Remco Polman**

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4781.

B.3 Study 3 - Consent form

VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

CONSENT FORM FOR PARTICIPANTS INVOLVED IN RESEARCH

INFORMATION TO PARTICIPANTS:
We would like to invite you to be a part of a study into the….

Influence of competition on cycling time trial performance

This project is being conducted by a student researcher Andrew Hibbert as part of a PhD study at Victoria University under the supervision of Professor Remco Polman, Dr. Matthew Varley from the College of Sport and Exercise Science; Institute of Sport Exercise and Active Living and A/Prof François Billaut from Université Laval, Département de kinesiology, Québec, Canada.

Often exercise is conducted with competition, this may include one other individual (head to head) or often exercise may be undertaken with many competitors (such as a marathon or cycling race). This project aims to examine the influence of competition both against 1 participant and in a group, and how this effects pacing and performance in cycling time trials.

Outline: 8 sessions

- Session 1: This involves an a practice of the incremental test to measure aerobic fitness (Graded exercise test, GXT)
- Session 2: This involves the GXT testing session
- Session 3: Involves a 5 km cycling time-trial (TT) familiarisation
- Session 4: Involves a 5 km TT familiarisation
- Session 5: Involves a 5 km TT familiarisation
- Sessions 6-8: 3 time-trial testing sessions
  - 1 x individual 5 km TT
  - 1 x 5 km TT with 1 competitor
  - 1 x 5 km TT with 3 competitors

Before you volunteer to this study, make sure you read carefully the items below:

1. You are free to withdraw from this study at any time without any consequences or need for explanation
2. You are required to complete a risk factor questionnaire. It is important to be truthful as this will help researchers determine if participating in this study is appropriate for you.
3. All exercise sessions involve risks of fainting, soft-tissue injury, muscle soreness and stiffness. The risk of such events is relatively low.
4. All exercise activity carries a risk of injury and risks of suffering a heart attack or stroke. It is important that you tell us if you have any medical condition**.**
5. For any medical emergencies a call to 000 will be made. The researchers will also commence appropriate first aid methods while waiting for the emergency team to arrive.
6. Furthermore, the exercise protocols involve the possibility for mood changes such as irritability and depression. To minimise the risk of any psychological stress, your results will remain confidential.

If you become stressed as a result of your participation please feel free to consult Professor Tony Morris a registered psychologist, who is not involved in the study but knows about it on 0430 511 543 or at tony.morris@vu.edu.au (free of charge).

CERTIFICATION BY SUBJECT

I, _____ (name)

of
(address/suburb) _____

certify that I am at least 18 years old and that I am voluntarily giving my consent to participate in the study*:* *"***Influence of competition on cycling time trial performance***"*
which is being conducted at Victoria University by: Andrew Hibbert

I certify that the objectives of the study, together with any risks and safeguards associated with the procedures listed hereunder to be carried out in the research, have been fully explained to me by:

Andrew Hibbert

and that I freely consent to participation involving the below mentioned procedures:

Cycling Time-Trials

Graded exercise test

Responses to scales
- **Rate of Perceived exertion (RPE)**
- **Feeling Scale (FS)**
- **Sense of Effort (SE)**

Questionnaire about exercise
- **Goal Orientations in Exercise Measure (GOEM)**
- **Intrinsic Motivation Inventory (IMI)**
- **Experiencing a Pacing Exercise Research Trial Questionnaire (EXPERT-Q)**

I certify that I have had the opportunity to have any questions answered and that I understand that I can withdraw from this study at any time and that this withdrawal will not jeopardise me in any way.

I have been informed that the information I provide will be kept confidential.

Signed:

Date:

Any queries about your participation in this project may be directed to the researchers

Investigators:
Dr. Matthew Varley **-** Principal investigator email: matthew.varley@vu.edu.au
Mr. Andrew Hibbert - Student investigator mob: 0400772879 email: andrew.hibbert1@live.vu.edu.au

Professor Remco Polman - Associate investigator
A/Prof François Billaut - Associate investigator
Dr. Aaron Petersen - Associate investigator

If you have any queries or complaints about the way you have been treated, you may contact the Ethics Secretary, Victoria University Human Research Ethics Committee, Office for Research, Victoria University, PO Box 14428, Melbourne, VIC, 8001 or phone (03) 9919 4781.