Teleoanticipation and its effect on pacing strategy

James Wiltshire

A thesis in fulfillment of the requirement for the degree of

Master of Research (Health Science)





University of South Australia

Allied Health and Human Performance – IIMPACT

17 December 2022

Originality Statement

I, James Wiltshire, hereby declare that this submission is my own work and that it contains no material previously published or written by another person except where acknowledged in the text. Nor does it contain material which has been accepted for the award of another degree.



Date: 17 December 2022

Table of Contents

Originality Statement ii

Table of Contents iii

Acknowledgments vi

Preface vii

1 Chapter One 1

Introduction 1

1.1 Introduction 2

1.2 Background 2

The path from Descartes dualism to the neuromatrix 2

The Central Governor Theory and beyond 4

Pacing Strategies in Athletes 6

Heat effects on performance and pacing 7

1.3 Thesis Aims 7

Research questions and hypothesis 8

2 Chapter Two 9

Pacing of athletes in a novel hot environment: a systematic review and meta-analysis 9

2.1 Abstract 10

2.2 Introduction 11

2.3 Methods 13

Eligibility Criteria 13

Information Sources 14

Selection Process 14

Data Collection 15

Data Items 15

Risk of Bias Assessment 17

Synthesis Methods for MA 17

Deviation from study protocol 18

2.4 Results 18

Study Selection Outcome 18

Risk of Bias Outcome 19

Results from Meta-analyses 20

Result of transformation of pace to a percentage of the 50% time completion value for the mild ambient temperature 27

Result of transformation of pace to a percentage of the 50% time completion value for each trial 28
Result of Secondary Analysis of Core Temperature Variables 30
2.5 Discussion 31
Comparison of *absolute* pace 31
Comparison of *relative* pace 33
Teleoanticipation 34
The 'end spurt' 36
Limitations 37
2.6 Conclusion 38
2.7 Funding support 39
2.8 Conflicts of Interest Statement 39
3 Chapter Three 40
The influence of an external factor (deception of environmental heat) on short time trial performance and pacing – an exploratory study 40
3.1 Abstract 41
3.2 Introduction 42
3.3 Methods 43
Participants 43
Study Design and Methodology 44
Familiarisation trial 46
Experimental trials 47
Deception implementation 48
Statistical Analysis 48
3.4 Results 49
Primary outcome: Time to completion during Time Trial 49
Secondary outcomes: Thermal, perceptual, and cardiovascular outcomes 49
3.5 Discussion 55
3.6 Conclusion 57
3.7 Funding support 57
3.8 Conflicts of Interest Statement 57
4 **Chapter Four** 58
Summary Discussion 58
4.1 Overview of Thesis 59
Systematic Review and Meta-analysis Findings 59
Randomised Cross-over Trial Findings 60

4.2 Implications of Thesis Findings 60
Systematic Review and Meta-analysis 61
Randomised Cross-over Trial 62
4.3 Future Research 63
4.4 Conclusions 66
References 67
Appendices 84
Appendix A. Medline Search Strategy 85
Appendix B: Cricket Australia Rehydration Guidelines 88
Appendix C: Consent Form 89
Appendix D: Data Collection Sheet – Familiarisation 91
Appendix E: Data Collection Sheet – Trial 2 and 3 99
Appendix F: Participant Information Sheet 108
Appendix G: Pre-session guidelines 114
Appendix H: Run Sheet – Trial 1 (familiarisation trial) 116
Appendix I: Run Sheet – Trial 2 and 3 118
Appendix J: Screening Questionnaire 120
Appendix K: Example Screenshot of Temperature Display 122

Acknowledgments

There are many people that I would like to thank and share the completion of this thesis with. Firstly, is my wife and children who put up with most weekends of me sitting in front of a computer screen muttering to myself. Without their support and encouragement, this would not have happened. Secondly, to my two supervisors who guided me through this process. To Sam whose continued support and gentle guidance was immense. He prodded me and challenged me and ultimately made this project work. My gratitude for the many hours that Sam put in both in a face-to-face capacity and in a reading, re-reading, and re-reading again cannot be expressed enough. To Lorimer who has inspired me in my professional life from very early on and whom I admire and respect as a researcher, as a teacher and as a guider of people. To have worked with Lorimer has been a fulfilment of a goal and has lived up to my expectations. Thank you to you both.

To the staff at the SACA who have helped me with recruitment, with hearing my ideas expressed and with encouraging the exploration of this area, thank you all. Finally, to my subjects who openly and willingly subjected themselves to the process of running in a heat chamber and accepting putting things in places that they never thought they would be asked to, thank you all.

Finally, I acknowledge the support from the Australian Government through a Research Training Program.

This process has been enjoyable, challenging and time consuming but has ultimately made me keen to explore more and to use this knowledge base to open up sports science further into the fatigue sciences. I look forward to the years to come of making furthering this area.

Preface

This thesis is arranged in four chapters, such that each chapter can be read independently.

For years, I have followed closely the research that has been done in the advancement of the pain sciences. I have read of the evolution of pain from being a purely input-based theory through to the beautiful complexity that it encompasses today involving the central cortical neuromatrix and the concept that the experience of pain is a product of the threat value placed on a situation by an individual. Through the course of my work in an elite sports arena, I have come across numerous examples of a parallel between this concept of peripheral input when viewing feelings of fatigue. Within sport, there is a heavy emphasis of pushing limits of physiological capacity and as such, it is heavily geared towards tracking changes in physiology and demanding testing of these limits to explore avenues to advance athletic progress. Within this testing, athletes are commonly tested for their aerobic capacity by testing of running to fatigue over set distances. Experience has shown me that, often, the results of these tests are somewhat outside of what has been predicted from an athlete when considering their individual training base and immediate training performance. Within a week, we have seen significant changes in performance that is unexplainable by pure physiology when testing these limits of endurance. In exploring this incongruence, it has become increasingly apparent that fatigue science has heavy parallels with the pain sciences. This parallel is where this Masters has originated from.

Chapter one delves into the origins of fatigue research, then explores this course of research with similarities within the pain sciences. It then finishes by providing an overview of the aims and hypotheses of this Masters. Chapter two is a systematic review and meta-analysis exploring the impact of the unfamiliar environmental ‘threat’ of heat on pacing as a means of looking at central cortical control of fatigue and behavioural regulation. It is formatted for

publication in *Sports Medicine*. Chapter three is a randomized control trial using deception to explore the impact of future perceived and real environmental heat 'threats' on pacing, performance and perceptual outcomes. It is formatted for publication in *Medicine & Science in Sports & Exercise*. For consistency within the thesis overall, these manuscripts are submitted with referencing styled for formatting in *Medicine & Science in Sports & Exercise*. This thesis uses conventions of Australian English, and all tables and figures are embedded in the text for ease of reading. Some tables and figures have been enlarged for ease of reading within this manuscript. This study was approved by the ethics board of the University of South Australia. Chapter four is the final summary drawing on the conclusions of these studies. Each chapter contains its own reference list and supplementary material is attached at the conclusion of the chapters or at the conclusion of the Thesis as appropriate.

1 Chapter One

Introduction

1.1 Introduction

Winners of elite sport competitions, whether individual or team sports, are often determined by who can succeed in pushing closest to the boundaries of their body's abilities in a given situation. The hypothesis of a central neuromatrix controller of fatigue stipulates that there is a reserve physical capacity held during the pacing of an event to ensure safe body homeostasis (1). It is the balancing act, of pushing this reserve but limiting injury, that guides sporting training regimes. Often an athlete is able to train for most situations they will encounter and can push into this reserve to attain greater performance benefits. However, frequently, an athlete will be confronted with an unfamiliar situation for which they have not trained. The hypothesised reaction of the central neuromatrix would be to hold a greater amount in reserve given the unknown outcome of the situation (2). Temperature fluctuations have been shown to cause significant negative effects on performance in endurance athletes (3). These fluctuations present potentially unfamiliar situations which an athlete must navigate through the course of an endurance event. The implications of exploring aspects of pacing, when confronted with future heat environments or unfamiliar environments, is that aspects of acclimatisation, past experience, education and mental strategies can be examined. The outcome would aim to improve performance in endurance athletes when confronted by these conditions.

1.2 Background

The path from Descartes dualism to the neuromatrix

The concept of peripherally derived inputs being the cause of perceptions has a long history as the basis for our understanding of how the body interacts with its environment (4). This

peripherally focused mechanism, as described by Descartes (4) in the 17th century, with a dualistic cause and effect relationship between afferent nerve input and perception, was initially challenged in the pain sciences by Melzack and Wall (5). They proposed that rather than being a purely sensory process, pain was modulated at the spinal cord and brain stem level. This challenging of the traditional concept of pain being a 'fixed, direct line communication system from the skin to the brain'(5) has created further theoretical considerations around the brain being the centre for the expression of *all* perceptions. This has been further refined over more recent times into the current hypothesis of a cortical neuromatrix (6-8). A significant step forward for the pain sciences occurred in the consideration of the pain experience reflecting a protective feeling modifiable by any cue or stored data related to the merits or otherwise of protection. Pain, then, is a truly 'biopsychosocial' feeling (9). The concept of a central cortical neuromatrix acknowledges the influence of 'context, company, competitive stimuli and meaning' (8).

Research into fatigue has since undergone a trajectory similar to that in the pain sciences. Early fatigue research by Hill (10-13) focused on the accumulation of lactate in the circulatory system as a by-product of glycogen metabolism. The concentration of lactate in the muscles was seen as being the limiter of exercise and Hill's theory proposed that oxygen was then needed to assist in the 'release of energy' for the removal process of this lactate (10-13). This peripheral fatigue model fundamentally suggested that limitation in the oxygen delivery system caused a point in exercise at which lactate production outpaced oxygen delivery and caused a critical build-up of lactate, and consequently, an associated reduction in systemic pH. This accumulation of lactate and systemic acidosis was thought to then cause a cessation of exercise. The limitation of this model of fatigue was the failure to include psychological and behavioural modifiers of exercise performance or to incorporate the sensory aspects associated with fatigue. Similar to research in the pain sciences, more recent

research into the experience of fatigue has also challenged the concept of a purely peripheral driver as the mechanism for fatigue (2, 14-17).

The Central Governor Theory and beyond

Due to the limitations of the peripheral fatigue model and its inability to fully explain a relationship between the limitation of oxygen delivery to exercising muscle and exercise performance in his studies, Ulmer (14) postulated a central 'black box' controller in the brain. Ulmer proposed that this 'black box' received peripheral feedback from the body, then incorporated both endogenous and exogenous reference signals and consequently created feedforward alterations in skeletal muscle drive and thereby modulated performance (14). Following from this research, Noakes proposed the Central Governor Model for fatigue (2, 15, 18-20). Originally this theory postulated that a 'central governor', which regulates the mass of skeletal muscle that is recruited during exercise, acts to protect the heart from developing myocardial ischaemia during maximal exercise' (2). This subsequent output was to protect the body from a threat to homeostasis (i.e., prior to a catastrophic system failure occurring) rather than the body being limited by reaching an endpoint of resources (i.e., a catastrophic systemic failure occurring). By 2004, Noakes had expanded this model, in an acknowledgement of the complexity of fatigue and concluded more broadly 'that it may be more correct to understand fatigue as a sensory perception that results from the complex integration of physiological, biochemical, and other sensory feedback from the periphery and that may or may not be associated with any alteration in muscle force production' (20). The breadth of this statement acknowledges that fatigue is a somatic experience that can be influenced by such a variety of areas that in their singular action, each area may or may not create a change in performance of muscular activation. Rather, it is the summing and

individual weighing that creates the final outcome of the feeling of fatigue. Importantly, Noakes further went on to point out that this feeling of fatigue was a protective functioning of the brain to prevent *perceived and predicted* threats to homeostasis (20). This model of fatigue has continued to evolve into a hypothesis that inputs are derived from various systems in the body including the oxygen saturation levels in the cardiac blood vessels, the circulatory glucose levels, the acid-base balance, core temperature, and plasma osmolarity (21). As with pain, the central theory suggests that fatigue, then, is an output feeling that is a summary of the processing of these peripheral signals that is weighed against emotional state, prior experience, mental health state and expectation of future effort (21).

The limitation of the Central Governor Model to account for higher centres of cortical input into exercise cessation and pacing has led to other models of fatigue being proposed. Notably, the *motivational-intensity theorem* of effort (22) focusing on the resultant cortical neural discharge associated with afferent drive weighed against the motivation to continue exercising has been explored through perceived effort studies in time to exhaustion trials (23). Further models of exercise cessation, pacing and fatigue have also been explored including the *dual processing model* as described by Micklewright et al., (24) incorporating intuitive and deliberative control mechanisms including such inputs as emotional state and social context as well as Renfree's (25) *decision-making theory* focussed on endurance athletes decision making early in an event and the implications of this on pacing and performance throughout an event. This historical progress therefore mirrors the pain sciences whereby both have moved to measuring threats to body health; whereby both pain and fatigue are defence signals that the organism uses to alter behaviour and thus prevent potential injury.

Pacing Strategies in Athletes

As a tenet of the cortical control of fatigue, it has been proposed that there is a set pacing strategy that is employed at the beginning of a exercise (14, 26-28). It has been proposed that this pacing of effort is determined in a feedforward method in which the athlete makes an approximation of the total exercise effort and sets the pace required to attempt to ensure optimal output while ideally protecting against a threat to body health (14, 26, 28, 29). This calculated pacing is termed teleo-anticipation which is derived from 'teleo' meaning end and the anticipation referring to the feedforward calculation that is undertaken (26).

For this theory to hold, in the event of an unusual environment, that is, an environment to which a body has yet to adapt, the central neuromatrix must make a calculation without the ability to utilise recent previous experience but still set a pacing strategy that will maximise performance but avoid injury throughout the exercise bout. Further, if there is a perceived more 'threatening environment' to occur at a future stage in the exercise bout, there would be expected to be either a reduced initial pacing strategy, or if exercise intensity is set, a faster onset of the feeling of fatigue. In relation to certain sports, this situation occurs when the duration of the event is such that the environmental conditions may change significantly over time or where travel to a new environment occurs, e.g., over the course of a two to five hour marathon. Under a model where threat is a mediator of performance, both conditions require a prediction to set a pacing strategy about a future unknown event to finish the event is the best possible time without creating catastrophic cellular harm.

Heat effects on performance and pacing

Very early studies (30, 31) showed the incredible ability of the human body to withstand temperatures of up to 127°C for short periods of time. Recent research from 1,791,972 marathon participants from 2001 to 2010 showed that air temperature caused the largest influence on running performance over all other climate parameters studied (3). A meta-analysis by Hancock, Ross and Szalma (32) demonstrated that high ambient heat caused significant athletic endurance performance degradation and was influenced by exposure duration and intensity. Importantly, a major finding was the large degree of individual variability of response to heat and the task dependency on the heat effect (32). This high variability and task dependency correlates with other stress mediated responses and reinforces the concept of a central cortical neuromatrix mediating responses based not purely on physiological feedback but rather on a ‘threat‘ grading to homeostasis. Further research demonstrating the performance benefits under hot conditions of mental skills training (33, 34), deception tasks (35, 36) or psychotropic drugs (37, 38) has demonstrated the influence of central mediators on performance.

1.3 Thesis Aims

In order to further examine a ‘threat neuromatrix’, this project will involve 2 studies: (i) systematic review and meta-analysis examining current evidence that predicted future environmental demands alter pacing behaviours; (ii) a randomised repeated measures deception experiment.

Research questions and hypothesis

Study 1	
Research Question	What effect does a novel high temperature ambient environment have on pacing strategies compared to a thermo-neutral environment
Study Design	Systematic Review
Hypothesis	It was hypothesised that when confronted with an unfamiliar, novel environmental demand, athletes would adopt a suboptimal pacing strategy.
Study 2	
Research Question	What are the independent and interactive effects of future perceived and true environmental threats to body homeostasis on human performance.
Study Design	Randomised Cross-over Cohort design
Hypotheses	Two hypotheses were identified. 1) It was hypothesised that being informed that a future 2kmTT will occur in a warmer environment than the first will increase completion time (relative to a milder deception) during the first 2kmTT. 2) It was hypothesised that being informed that the ambient temperature is high will result in a longer completion time than being told the ambient temperature is low, regardless of the true ambient temperature.

2 Chapter Two

Pacing of athletes in a novel hot environment: a systematic review and meta-analysis

2.1 Abstract

Background: Pacing strategies have been shown to be set at the beginning of an exercise bout and is thought to be determined in a feedforward mechanism. The impact of an unfamiliar hot environment of pacing is unclear.

Hypothesis/Purpose: The purpose of this study was to determine the current evidence on how pacing is altered when athletes are confronted by an unfamiliar hot environmental demand, and to quantify the changes in pace created.

Study Design: Systematic Review / Meta-analysis

Methods: Studies were included with adult participants (age > 18y.o) who had completed an endurance event > 4 minutes duration in hyperthermic conditions (>29℃) that was compared to a trial in mild conditions (8-29℃). Searches were conducted in Medline, Embase, Emcare, PsycINFO, Scopus, the Cochrane Central Register of Controlled Trials and in grey literature. Risk of bias assessments were conducted on all included studies. The following broad categories and outcome measures were collected: Pace (Power (Watts) or speed (Km/h) at a given time point), Physiology (Skin Temperature, Core Temperature, Heart Rate) and Perception (Rate of Perceived Exertion, Thermal Comfort, Thermal Sensation). Data points were then calculated at 5%, 10%, 30%, 50%, 70%, 90% and 100% of time completed for each trial and meta-analysed.

Results: From a total of 13,227 articles, 9 articles were included in the meta-analysis with 111 participants. A high risk of bias was found in 8 of the 9 studies. Participants in both trials started off at the same absolute pace but participants in the hyperthermic conditions significantly decreased their pace from the 10% mark onwards compared to the mild

condition. Both groups showed an ‘end spurt’ phenomenon of increased pace in the final 10% of the trials.

Conclusion: When confronted with an unfamiliar hot environment, participants will likely start with an unsustainably high initial pace compared to a mild environment. The impact of this is that a less efficient pacing strategy is adopted in the hot environment whereby a significant drop-off of pace occurs over the course of the event prior to an end spurt. This potentially then contributes to a poorer final finish time.

2.2 Introduction

Winners of elite endurance events are often determined by who can succeed in pushing closest to the boundaries of their body’s abilities while maintaining an optimal pacing strategy. If an athlete sets off too quickly, they will likely suffer a significant decline in pace during the event, ultimately resulting in a lower overall performance (39, 40). Conversely, if an athlete sets too slow a pacing strategy early in a race, they may not be able to make up time through the event, resulting in a lower overall performance (39, 40). Previous research by Ely (41) showed that marathon race winners tended to run at a more even pace throughout a race than slower runners did. The central (i.e. central nervous system) hypothesis of pacing models suggest there is a reserve physiological capacity held during the course of an event to ensure safe body homeostasis (1). It is the balancing act of pushing this reserve while preserving body protection from harm, real or perceived, that guides succesful pacing strategies (26, 42). Edwards and Polman (43) defined pacing as ‘an informed decision based on accurate knowledge of past and present factors, including intrinsic knowledge of our own physical capabilities.’ It has been proposed that a pacing strategy is set at the beginning of an exercise bout according to prior experience (14, 26-28). This pacing of effort is thought to be

determined in a feedforward method whereby the total exercise effort is estimated and the pace required to ensure that there is not a threat to body health is set (14, 26, 28). This calculated pacing is termed teleo-anticipation (26).

Athletes frequently face unfamiliar situations or environments. In such situations, the brain must make a calculation with less established strategies or with the absence of previous experience, and must set a pacing strategy that is predicted to be non-injurious by the end of the exercise bout (20, 28, 44). As the event proceeds through the early stages, the brain must integrate the varied information being generated from the environment and self (including both peripheral and brain generated information) regarding apparent threats to homeostasis, and adjust the pacing for the event accordingly (20, 28, 44, 45).

The initial pacing schema in the first 10% of the event has been shown to be a period of pace alteration as decisions around the estimation of the time remaining in the event and the rate of internal changes in the body are being made (20, 25, 44, 45). Environmental factors can be challenging to predict and ambient temperature has been found to have the biggest environmental effect on endurance performance (3). Although reductions in *performance* in hotter environments have been well researched (46-49), *pacing strategies* in unfamiliar hot environments is relatively unexplored (43). Previous research by Racinais (50) demonstrated larger changes in pacing strategies in unacclimated individuals during an endurance event in a hot ambient environment, than in a mild environment.

The impact of an unfamiliar hot environment on pacing in athletes is unclear. We undertook a systematic review and meta-analysis to determine current evidence on how pacing is altered when athletes are confronted by an unfamiliar hot environmental demand, and to quantify the changes in pace created. Further exploration of the first 10% of trials was undertaken to enhance understanding of changes in pacing behaviours during this time.

2.3 Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines were followed in preparing, conducting and reporting this systematic review (51). This review was pre-registered on the Open Science Framework (doi:10.17605/OSF.IO/MZV2S) on the 29/02/2020.

Eligibility Criteria

All English-language published and unpublished RCT's were eligible for inclusion in the study. To be eligible for inclusion in the review, study participants needed to be adults (age ≥ 18 years) and have any athletic background (recreational to professional). Studies in which participants reported any physical injury or limitations were excluded. All endurance-type events over 4 minutes in length were included. Participants needed to have undertaken a trial in hyperthermic conditions (defined as >29℃ (warm data)) (32) that was compared to a trial in mild conditions (8-29℃ (cool data)). All trials in the heat needed to be considered unfamiliar to the participants (i.e., participants were not acclimatised). Therefore, studies needed to detail any familiarisation sessions. Studies with any familiarisation trials with any form of heat were excluded. Further, all trials had to have self-directed pace or power output. Trials that were performed at a fixed power or pace or involved only partial body exposure to the hyperthermic conditions were excluded. In order to measure pacing strategies, studies needed to include a measure of power output or pace, taken at multiple time points across the trial with at least 1 time point in the first 10% of the trial, the middle 10-90% of the trial and the last 10% of the trial.

Information Sources

Searches were conducted in Medline, Embase, Emcare, PsycINFO, Scopus, and the Cochrane Central Register of Controlled Trials for eligible studies on the 31/03/2020 and updated on the 31/07/2022. Further, grey literature searches were performed on the 31/03/2020 and the 14/04/2020 and were again updated on the 31/07/2022. The databases searched were Web of Science, Informit, the Proquest Thesis registry, the DART-Europe Thesis registry, the British Library EThOS registry, the Canada Theses registry and the TROVE database. Hand searching of the Current Controlled Trials, the ISRCTN registry, the ANZCRT registry (Australian New Zealand Clinical Trials Registry), the Clinical Trials registry and the EU Clinical Trials registry was conducted to uncover missed trials on the 14/04/2020 and updated on the 31/07/2022. Search strategies can be found in Appendix 1.

Selection Process

All citations retrieved from the database searches were imported into EndNote and duplicates were removed. All remaining citations were then uploaded to Covidence. Three researchers (JW, LD, SC) independently reviewed all abstracts and titles twice and then collaborated to discuss and resolve any conflicts. Any unresolvable conflicts were pre-determined to be resolved by a fourth reviewer (LM). Three reviewers (JW, LD, SC) then screened the full text of the remaining studies twice according to the set eligibility criteria. Again, any conflicts were discussed and resolved.

Data Collection

Data were extracted from eligible studies by two reviewers (JW, LD). All data were extracted by both reviewers and then checked against each other for accuracy. Descriptive information regarding participant information and trial set-up from the selected articles were extracted into Covidence. Outcome data, in the form of means and standard deviations, were then extracted into an Excel spreadsheet. Where graph data needed to be extracted, WebPlotDigitiser (Version 4.4) (52, 53) was used to extract the data. Where any studies required clarification of data or if data were not available in the published article, the article's authors were contacted via email up to three times over a period of four weeks to obtain the missing data. If authors could not be contacted, the data were considered irretrievable.

Data Items

The following broad categories and outcome measures were collected from included articles: Pace (Power (Watts) or speed (Km/h) at a given time point), Physiology (Skin Temperature, Core Temperature, Heart Rate) and Perception (Rate of Perceived Exertion, Thermal Comfort, Thermal Sensation). All data that showed a power or speed output were eligible for inclusion. Means and standard deviations were extracted for all variables across each time trial. Due to the differences between studies in lengths of the time trials completed, temporal data were converted into a percentage of the duration of the time. This method has been employed in other studies on pacing data (54, 55). This method was then used to calculate data points at 5%, 10%, 30%, 50%, 70%, 90% and 100% of time completed for each trial. The aim of this meta-analysis was to examine a range of time points to allow precision of changes in pacing strategy. The 5% time point was included to allow more precision around

the initial pacing strategy chosen. Data from outside the identified time points were not considered, however, where the data extraction points did not align with the reported values, a calculation was made assuming a linear increase between the closest two time points. Where the 10% data point was the first point taken in a trial, the averaging method was unable to be applied to estimate the 5% data point. Where there were multiple trials with different ambient temperatures, the warm data were taken from the trial with the highest ambient temperature and the mild data were taken from the trial with the ambient temperature closest to 25˚C to reduce heterogeneity of temperature differences between studies.

Due to the different time trial activities (cycling, rowing or running) and different outcomes (power or speed) for the pacing data, it was necessary to transform the data to allow meta-analysis. To better analyse the pacing data from each study, we used two methods of transformation. Firstly, all pace data were converted into a percentage of the 50% time point from each trial and analysed. Therefore, data from the hotter ambient temperature trials were converted to a percentage of the 50% time point from the hot data and the same method was applied to the mild ambient temperature trials. The use of the comparison within the individual trials allowed for a comparison to be made regarding the *relative* pacing strategy adopted at the beginning and end of the event because data were compared *relative* to the individual trials. Secondly, all pace data were converted into a percentage of the 50% time point of the mild trial and analysed. This allowed for a comparison of the *absolute* change in power output over the duration of the event due to the common *absolute* reference point. The choice of the 50% time point as the comparator was to decrease the influence of the ‘fast start’ and the ‘end spurt’ (56). The middle period of an endurance event has been shown to be the most consistent period and was determined to be the most stable point to compare across studies (55).

Risk of Bias Assessment

Each study was assessed independently by two reviewers (JW, LD) for risk of bias utilising the Cochrane 'Risk of Bias' tool for randomised trials (RoB 2.0) (57). Additional guidance was utilised for crossover trials (58). The RoB 2.0 addresses five specific domains: (1) bias arising from the randomisation process; (2) bias due to deviations from intended interventions; (3) bias due to missing outcome data; (4) bias in measurement of the outcome; and (5) bias in selection of the reported result. Each domain was ranked according to the level of concern of bias (low; some concerns; high). Any discrepancies between reviewers were resolved by consensus. An overall summary 'risk of bias' judgement (low; some concerns; high) for the main outcome was then determined.

Synthesis Methods for MA

For the meta-analyses, a random-effects model was chosen for analysis due to the expected heterogeneity of study design, ambient temperatures, time trial methodology, and the intervention. Standardised mean differences (SMD) were calculated using Hedges' g (59) and a restricted maximum likelihood random-effects variance estimator was used to estimate between study variance (60). Cohen (61) described the following guidelines for interpreting the magnitude of the SMD: small, SMD = 0.2; medium, SMD = 0.5; and large, SMD = 0.8. Test statistics and confidence intervals were adjusted utilising the Hartung and Knapp (62) method because simulation studies (62-64) show better coverage probabilities with this method than with the classic random effects method. Forest plots were produced for each time point with tau-squared and I-squared calculated to estimate study heterogeneity. An I-

squared proportion threshold of 25% was considered to represent low heterogeneity, 50% to represent moderate heterogeneity and 75% was considered to represent considerable heterogeneity (65). To assess for small-study biases, funnel plots were created for each time point and were visually inspected for symmetry. If asymmetry was found, individual studies were inspected to assess for biases in publication or other areas of heterogeneity. All analyses were run using R version 4.2.1.

Deviation from study protocol

For each of the secondary variables, all data were transformed into a percentage of either the 100% time point of the hot or mild trial, depending on which was higher. This was done due to previous research showing linear increases over time for this data (66) so a conversion to the 100% time point aimed to reduce the influence of differences in length of event between trials. These data were analysed as per the protocol but are not presented in this review due to size constraints. A graph of Core Temperature analysis has been included to visualise changes within this variable and to stimulate further study. This non-reporting was a deviation from our a priori protocol (doi:10.17605/OSF.IO/MZV2S).

2.4 Results

Study Selection Outcome

A total of 13,227 articles resulted from the initial search. After removing duplicates, 9,694 articles were reviewed by title and abstract. Following removal of a further 9,539 articles, 147 articles were eligible for full-text screening. 135 articles were excluded during the final

screen due to inappropriate study design (53), fixed exercise strategy (20), no thermoneutral control (15), intermittent sprinting protocol (9), pre-load exercise (9), fixed RPE/exercise strategy (8), duplicate sample (6), incorrect intervention (6), no pacing strategy recorded (4), incorrect population (3) and non-heat acclimated (2). There were no conflicts between reviewers that required resolution with a fourth reviewer. Of the 12 remaining articles, 3 (67-69) were excluded due to an inability to recover data. This left 9 studies to be included in the meta-analysis. A flow chart detailing the result of the search process is presented in Figure 1.

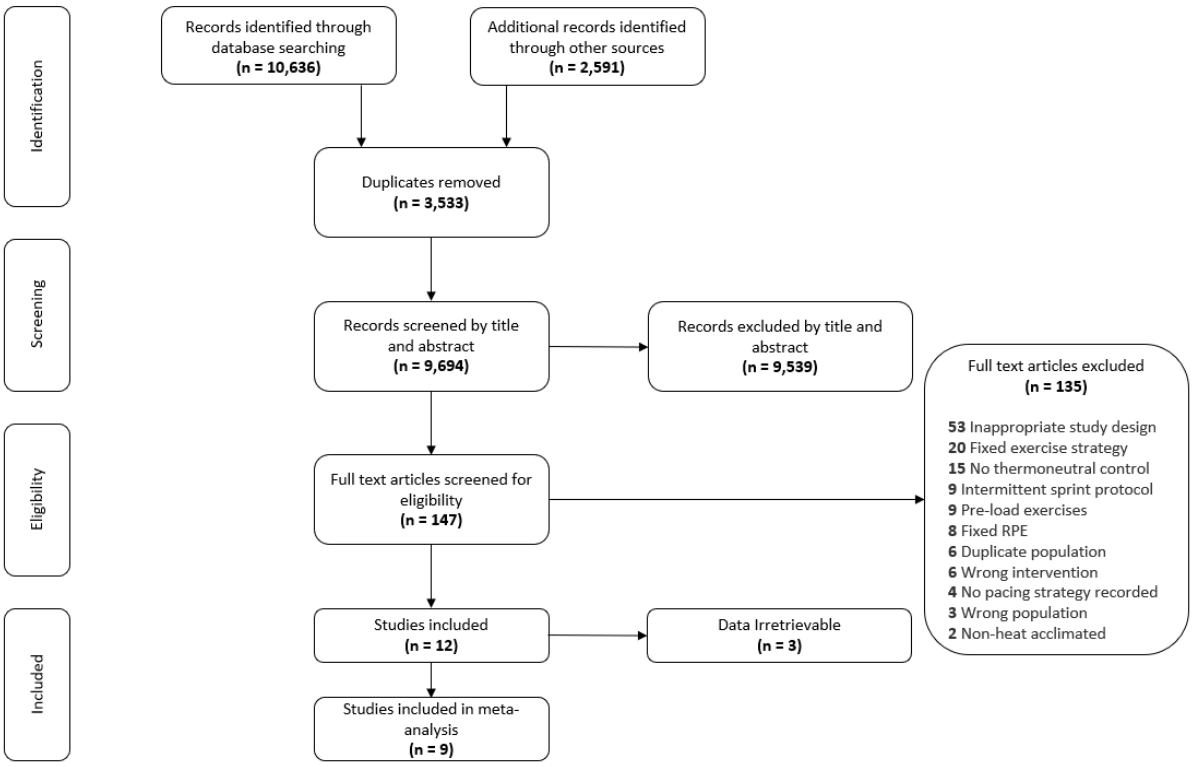


Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

Risk of Bias Outcome

A high risk of bias was determined to exist in 8 (35, 50, 70-75) of the 9 included studies (Table 1). The remaining study[48] was found to have a medium risk of bias. The most common

cause of a high risk of bias was a lack of reporting regarding deviations from intended interventions in Domain 2 (8 of 9 studies). Specifically, this was mostly around blinding of participants and assessors, due to the difficulty in blinding participants to different ambient environments. This lack of blinding would potentially lead to larger performance decreases in the experimental group (hot environment) due to the possible increased perception of effort required in the heat (57), and therefore create larger effect sizes of performance differences.

Results from Meta-analyses

111 participants from 9 studies were included in the meta-analysis. Table 2 outlines the characteristics of each included study. All included studies had the means for the main outcome measures (power/speed) pooled and meta-analysed at each of the pre-determined time points (5%, 10%, 30%, 50%, 70%, 90% and 100%). Only 4 of the included studies reported power in the first 5% of the trials (70, 73-75). This resulted in 4 studies having data available at the 5% point (70, 73-75) and 9 studies having data available at each of the remaining points (35, 50, 70-76). The results of the forest plots for each time point are shown in Figures 2 and 3. Figures 4 and 5 plot the combined means and standard deviations at each timepoint to visually represent the changes in pacing adopted during the trials in the different ambient environments.

References	Experimental Condition	Comparator	Outcome	Randomisation process	Deviations from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall
Abbiss et al., 2010	Hot (34˚C / 44%RH)	Mild (11˚C / 65%RH)	Power (W)	!	-	+	+	!	-
Bright et al., 2021	Hot (36˚C / 72%RH)	Mild (20˚C / 70%RH)	Power (W)	+	+	+	+	!	!
Castle et al., 2012	Hot (31˚C / 64%RH)	Mild (22˚C / 43%RH)	Power (W)	!	-	+	+	!	-
Periard et al., 2011	Hot (35˚C / 60%RH)	Mild (20˚C / 40%RH)	Power (W)	!	-	+	+	!	-
Periard & Racinais, 2016	Hot (35˚C / 60%RH)	Mild (18˚C / 40%RH)	Power (W)	!	-	+	+	!	-
Racinais et al., 2015	Hot (36˚C / 30%RH)	Mild (8˚C / 13%RH)	Power (W)	-	-	+	+	!	-
Schmit et al., 2016	Hot (35˚C / 50%RH)	Mild (21˚C / 50%RH)	Power (W)	-	-	+	+	!	-
Taylor et al., 2014	Hot (35˚C / 60%RH)	Mild (20˚C / 40%RH)	Power (W)	!	-	+	+	!	-
Tucker et al., 2004	Hot (35˚C / 60%RH)	Mild (15˚C / 60%RH)	Power (W)	!	-	+	+	!	-

Table 1. Risk of Bias Assessment. D1, Domain 1 - Randomisation process; D2, Domain 2 - Deviations from the intended interventions; D3, Domain 3 - Missing outcome data; D4, Domain 4 - Measurement of the outcome; D5, Domain 5 - Selection of the reported result; + Low Risk; ! Some Concerns; - High Risk.

References	**Study Type**	**No. / Gender**	**Age (Years)**	**Athletic Background**	**Event Characterisitcs**	**Intervention**	**Outcomes collected**
Abbiss et al., 2010	Randomised cross-over design	9 Male	31 ± 6	Amateur Cyclists 397 ± 93 km/week	Cycling on ergometer in climate chamber	100km self-paced time trials *1km sprints at 10, 32, 52, 72 and 99km *4km sprints at 20, 40, 60 and 80km	- Time and power output at 10 semi-regular points throughout trial - HR every 15 sec - T_{re} and T_{sk} taken midway through each sprint and each self-paced interval - RPE and thermal sensation 'recorded throughout'
Bright et al., 2021	Randomised cross-over design	14 Male	41 ± 10	Amateur Cyclists	Cycling on ergometer in climate chamber	30km self-paced time trials	- Power output every 3km - T_{re} and T_{sk} at rest, 4, 10, 16, 22, 28, and 30 km - RPE, thermal comfort, and thermal sensation were measured at rest (except for RPE), 4, 10, 16, 22, 28, and 30km
Castle et al., 2012	Randomised cross-over design	7 Male	20 ± 1	Amateur Cyclists Train x 3/wk	Cycling on ergometer in climate chamber	30 min self-paced time trials	- Power output recorded every minute

							- T_{re}, T_{sk}, HR, RPE and thermal sensation initially and at 3 min intervals
Periard et al., 2011	Randomised cross-over design	8 Male	31 ± 4	Amateur Cyclists >250 km/wk	Cycling on ergometer in climate chamber	40km self-paced time trials	- Power output every 5 mins of elapsed time - T_{re}, T_{sk}, HR, thermal comfort and RPE every 10 mins of elapsed time and at completion
Periard & Racinais, 2016	Randomised cross-over design	12 Male	35 ± 4	Amateur Cyclists >250 km/wk	Cycling on ergometer in climate chamber	750kJ self-paced time trials	- Power output every 10% of elapsed time - T_{re}, T_{sk}, HR, RPE, thermal comfort at 10, 30, 50, 70, 90 and 100% of elapsed time
Racinais et al., 2015	Randomised cross-over design	9 Male	33 ± 7	Amateur Cyclists Trained 14 h 40 min +/- 4 h 40 min per week	Cycling on flat outdoor track (Cool – Denmark) (Hot – Qatar)	43.4km self-paced time trials	- Power output every 10% of elapsed time - T_{re}, HR every 10% of elapsed time
Schmit et al., 2016	Non-randomised, Case - Control study	Control 22 Male Case 12 Male	Control 30 ± 4 Case 31 ± 5	Experienced, competitive Triathletes Trained x 7/wk	Cycling on ergometer in climate chamber	20km self-paced time trials	- Power output every km through trial

Taylor et al., 2014	Randomised cross-over design	8 Female	20 ± 2	Nil prior experience rowers >5 hours exercise per week	Rowing on rower in climate chamber	2km self-paced time trials	- Power output, T_{re}, T_{sk} every 100m - T_{re}, HR, RPE at 0, 1, 5, 10, 15 and 20km
Tucker et al., 2004	Randomised cross-over design	10 Male	25 ± 5	Amateur Cyclists	Cycling on ergometer in climate chamber	20km self-paced time trials	- Power output every 5% of elapsed time

Table 2. Study Characteristics. Values given in Mean ± SD's when available. T_{re}, Rectal Temperature; T_{sk}, Skin Temperature; HR, Heart Rate; RPE, Rate of Perceived Exertion

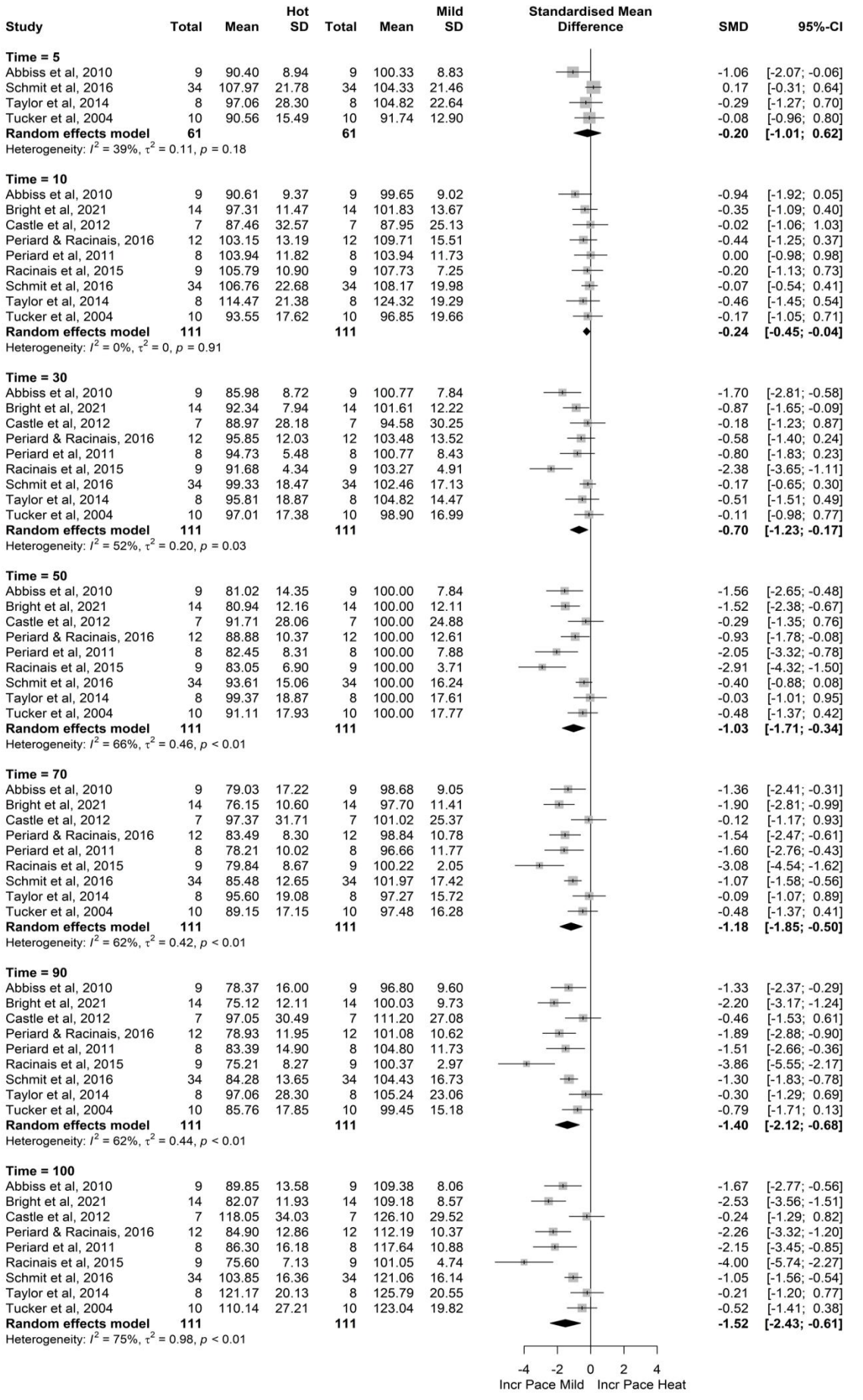


Figure 2. Forest plots of meta-analysis of pacing data (with conversion of Pace to be a percentage of the 50% time completion value for the mild value)

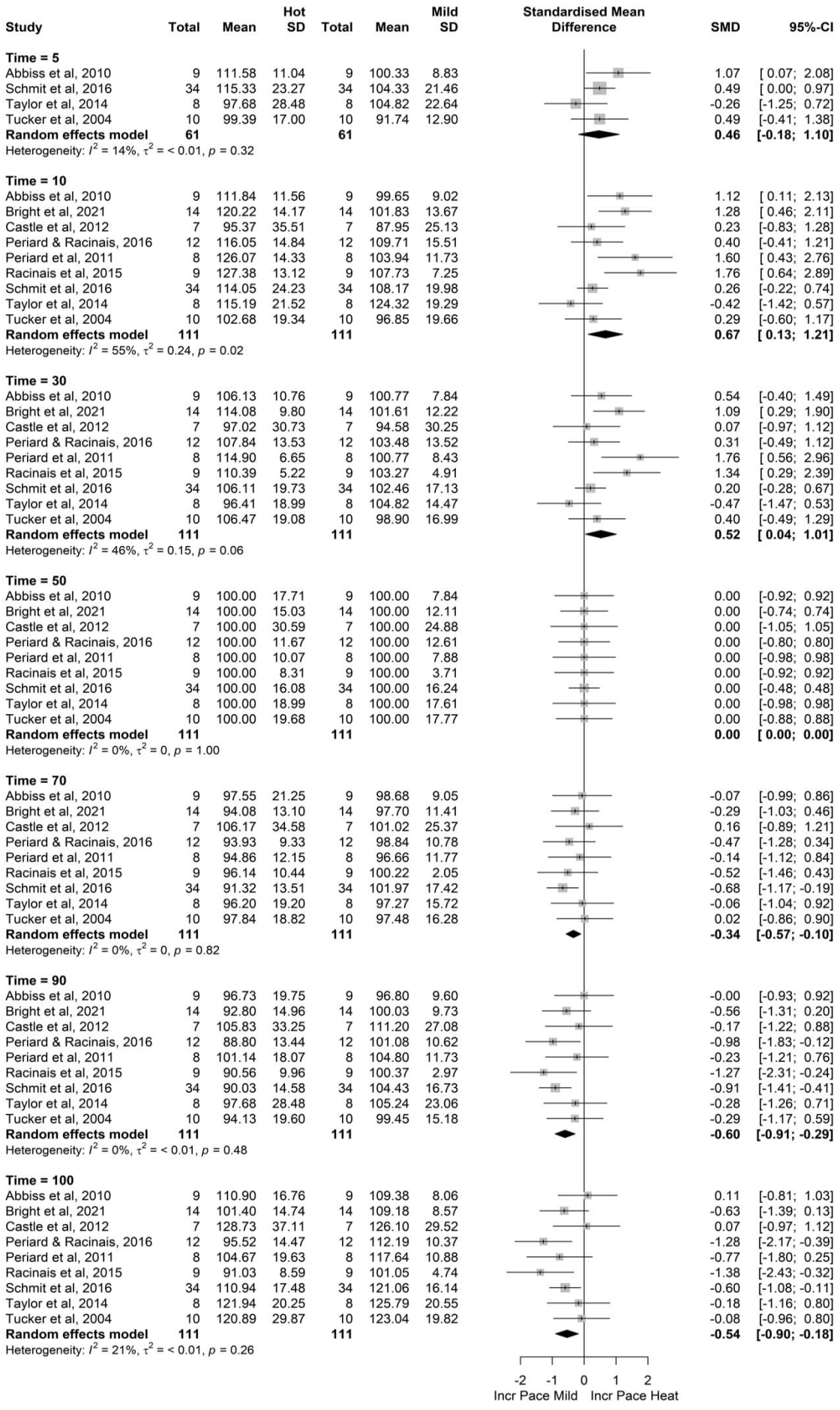


Figure 3. Forest plots of meta-analysis of pacing data (with conversion of pace to be a percentage of the 50% time completion value)

Result of transformation of pace to a percentage of the 50% time completion value for the mild ambient temperature

The use of the 50% point of the mild trial as a reference point allowed for a comparison of the *absolute* change in power output over the duration of the event between the two environments. Figures 2 and 4 represent the results of the comparison between the pace of the hot and mild ambient temperature trials. The 5% time completion point demonstrated no significant difference (SMD=0.20 [95% CI -0.62–1.01], p=0.49, I^2=39%). From this time point onwards there was a significant difference found between the pace in the two different environments. This difference increased over time (all $p<0.05$). The average pace of the trials (when compared to the pace at 50% time completion value of the mild ambient temperature) was 92.5% ± 19.3% in the hot group and 104.1% ± 16.9% in the mild group. There was a significant difference between the average pace of the trials of 11.6% (± 1.9%, $p<0.001$). Heterogeneity also increased between studies as the completed time increased such that there was low heterogeneity in the 5% and 10% time points, moderate heterogeneity at the 30% time point, moderate-considerable heterogeneity in the 50% - 90% time points and considerable heterogeneity in the 100% time point.

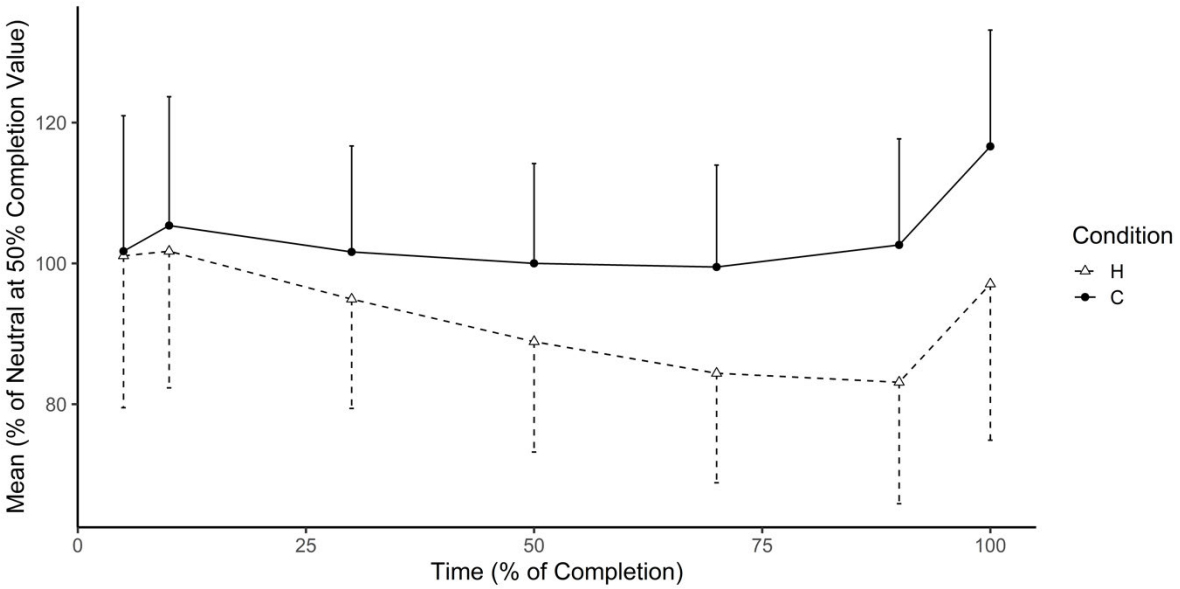


Figure 4. Graph of combined means (± SD's) of the result of conversion of pace to an *absolute* percentage of the 50% time completion value for the mild ambient temperature. H, hot group; C, mild group.

Result of transformation of pace to a percentage of the 50% time completion value for each trial

The use of a within trial reference point allowed for a comparison to be made regarding the *relative* pacing strategy adopted at the beginning and end of the event within the same environment. Figures 3 and 5 represent the results of the comparison between the pace of the hot and mild ambient temperature trials. At 5% completion, there was no significant increase (SMD=0.46 [95% CI -0.18–1.10], p=0.11, I^2=14.4%) in the pace of the hot group as compared to the mild group. At 10% completion, there was a *large* significant difference in pacing (SMD=0.67 [95% CI=0.13-1.21], p=0.02, I^2=55%) with the hot group 9.3% greater than the mild group. By 30% completion, there remained a *medium* significant increased

comparative pace of the hot group (SMD=0.52 [95% CI=0.04-1.01], p=0.04, I^2=46%) although this had diminished to a 5.4% difference between the groups. As the 50% point was the reference point for each trial, this value was 100% for each trial. At 70% completion, there was a *small* but significant (SMD=0.34 [95% CI=0.10-0.57], p=0.01, I^2=0%) increase in the pace of the mild group compared to the hot group by 4.5%. This increased to a *medium* significant difference in pace at 90% (SMD=0.60 [95% CI=0.29-0.91], p<0.01, I^2=0%) favouring the mild group by 9.1%. Finally, by the end of the trial, at 100% completion, there was a *medium* significant difference (SMD=0.54 [95% CI=0.18-0.90], p=0.01, I^2=21%) of 7.8% favouring an increase in the mild group. The average pace (compared to the pace at 50% time completion value of each trial) in this comparison was 103.7% ± 20.3% in the hot group. Heterogeneity was significantly lower in this comparison with moderate heterogeneity at the 10% and 30% time points but very low heterogeneity at all other time points.

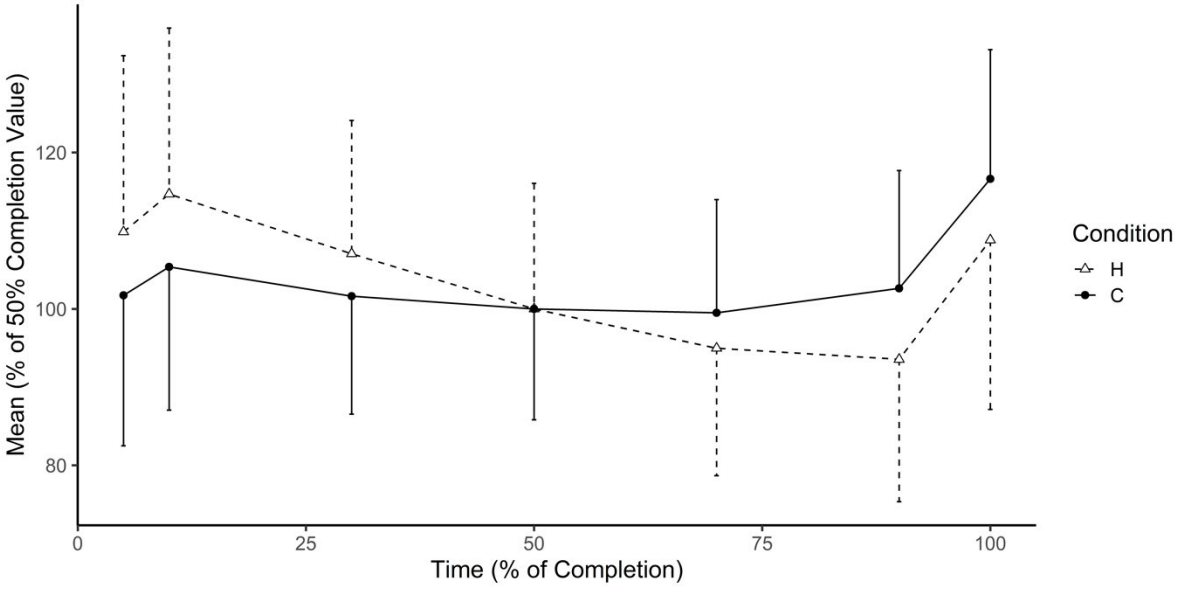


Figure 5. Graph of combined means (± SD's) of the result of conversion of pace to a *relative* percentage of the 50% time completion value for each trial. H, hot group; C, mild group.

Result of Secondary Analysis of Core Temperature Variables

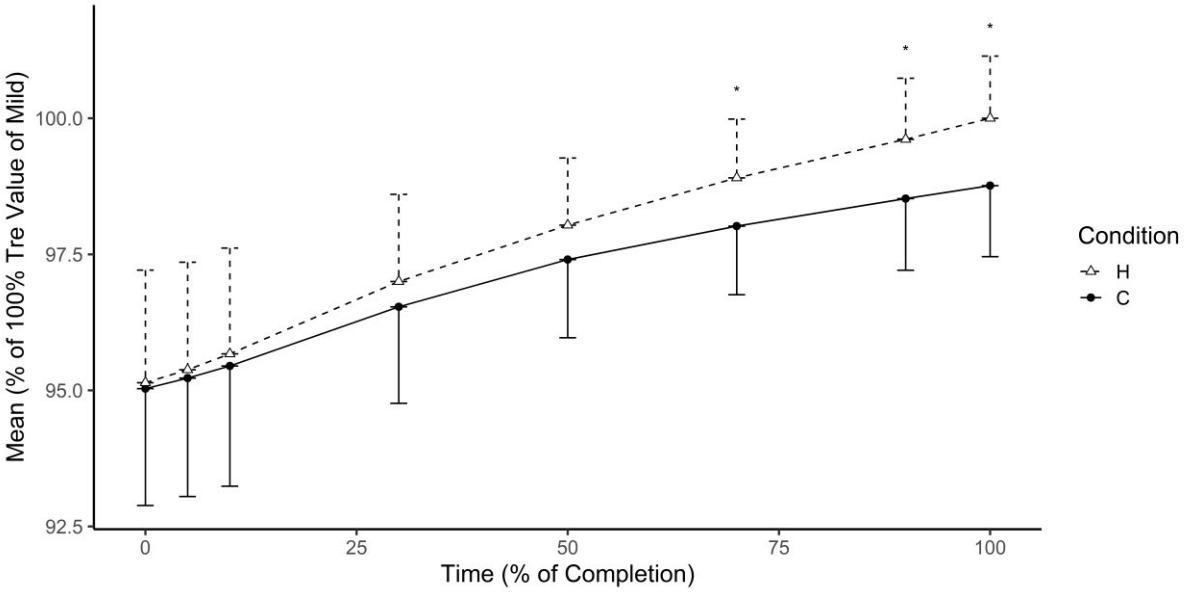


Figure 6. Graph of combined means (± SD's) of the result of conversion of Tre to a *relative* percentage of the 100% mild Tre value for each trial. * indicates statistical significant difference ($p < 0.05$); H, hot group; C, mild group; Tre, Core (Rectal) Temperature.

An in-depth analysis of core temperature differences is beyond the scope of this review. However, this data has been produced to illustrate the differences in rates of core temperature increase between the groups. This analysis indicates that after the 70% completion point, there is a significant difference in the core temperatures recorded between the groups ($p > 0.05$) with the group exposed to the higher ambient temperatures recording higher core temperatures.

2.5 Discussion

Through this systematic review and meta-analysis, we aimed to understand how pacing is altered when athletes are confronted by an unfamiliar hot environmental demand and to quantify the changes in pace created. Of special interest was the initial pacing schema in the first 10% of the event. We found that athletes tend to adopt a different pacing strategy when exercising in an unacclimated state in a hot environment, as compared to when exercising in a mild environment. Examination of the first 5% of the event showed no significant difference of *absolute* pace between the different environments at the start of the trials (Figure 4). In a hot environment, athletes demonstrated a *relative* fast start, followed by a large decrease in pace before an final end spurt (Figure 3). This is distinct from the performance of the athletes in the mild environment who had a much more stable period between the 30^{th} to 90^{th} percentile of the event. This finding is in line with previous findings from several key studies within this field which demonstrate these different strategies across different ambient temperatures (28, 77, 78).

Comparison of *absolute* pace

The results of the comparison of *absolute* pace, with both trials referenced to the same value, showed that there was no significant difference between starting points despite being confronted with an unfamiliar, hyperthermic environment (Figures 2 and 4). This is in line with previous literature that has shown a lack of altered pacing in the initial period of an endurance event under different environmental conditions. In a recent meta-analysis on cycling performance during endurance events in the heat, Davies et al., (79) found a comparable result whereby participants in both the hot and mild conditions started at a similar

pace during the initial 10–15-minute period. Tatterson et al., (80) also found that non-acclimated cyclists did not alter their performance at the start of an event when starting a trial in a hot versus mild ambient environment. Of interest is that research into endurance events in hypoxic environments have shown a similar initial pace at the start of trials in comparison to a sea-level environment (79, 81, 82). However, these results are not universal: Abel et al., (83) found that cyclists in a hypoxic environment started slower when in a hypoxic environment than at sea level. Abel et al., (83) however, also found that the starting times of both groups reverted to being the same as the mild group when the 'threat' of future demand was taken away, by deceiving participants that there was no hypoxia. This highlights the decision making that occurs at the beginning of the race around future demands in endurance events (25). The influence of the starting pace has been suggested to then influence the development of the resultant pacing strategy for the remainder of an event (39, 84). In fact, Renfree (29), after a series of studies investigating decision-making in running pacing, proposed that the pacing strategy chosen, and the subsequent relative performance achieved through the race, was dictated by the quality of the athletes' decision-making regarding running speeds during the initial stages of the race. Heterogeneity increased throughout the course of the trials during this meta-analysis. This potentially demonstrates the increasing variability in the pace of individuals as the trials progressed. An explanation for this would be that participants have a consistent starting pace according to a relatively stable internal schema of pacing. This would make sense given the athletes had good experience at the given trials in mild conditions. As the updating of individual pacing strategies occur, this then creates uniquely different changes to pacing strategies for the remainder of the trial based as individuals chose slightly different strategies and these differences were then exacerbated as the trials continued.

Comparison of *relative* pace

The comparison of *relative* pacing values, where each trial was compared to its own middle 50% time point, primarily allowed an exploration of the different pacing strategies adopted during the first and last 10% segments. The results of this meta-analysis show that when confronted with a neutral environment, participants employed a modest fast start followed by an even pace before exhibiting an end spurt. In contrast, the participants in the hot, unfamiliar environment, began with a significantly faster relative start during the first 10% of the events before dramatically reducing their pace until the final 10% where they again exhibited an end spurt phenomenon. Several reviews have described multiple different pacing strategies adopted during competitive events (39, 85). Although an 'all-out' effort (where output likely decreases over time) is ideal for very short events of less than 4 minutes duration, a more even pacing strategy is seen to be ideal for longer endurance-type events (39, 85). It has been contended that this allows for the greatest efficiency in pace and will therefore allow for the fastest finish times for a given athlete (39, 85). In agreement with this model for optimal pacing, Ely et al., (41) found that marathon participants who finished the event the quickest ran with the most even pacing strategies while participants who finished with a slower overall time ran with a fast-starting pace which then diminished significantly over the course of the event. In a study by Adams et al., (86) investigating the pacing strategy of an 11.3km (7 miles) road race, participants were grouped into finishing time quartiles with each runner then referenced around deviations from pre-determined goal race times and pace. They found that the goal pace deviations in the first and second mile were not significantly different between those finishing close to the end goal time and those that finished outside the goal time. They concluded that the initial stages of the event were characterized by a similar pace but those who failed to achieve their goal time fell away significantly during the middle to late portion of the event. Similarly, the study of major marathons allows for a comparison between

recreational runners and elite runners, as differentiated by finish times. Santos et al., (87) in a study of 190 228 New York marathon finishers, found that elite runners tended to run with a more even pacing strategy whereas recreational runners ran with a higher variability in the pacing strategy chosen. Note that the evenness of the pacing strategy in elite runners does not necessarily point to being the only determinant of success. Faster finishers are much more likely to have better physiological and mental resources, however, a more economical pacing strategy likely aids in a better finish time in two equally physiologically and mentally matched individuals. This trend has also been seen across time with the evolution of pacing. In a study of pacing throughout world record marathon races, Diaz et al., (88) found that 'classic' runners displayed a significant 'positive' running strategy with a large drop-off from the initial fast pace compared with 'contemporary' runners who ran at a more even pace before the end spurt which was the fastest 5km split. Of interest is that the contemporary runners, in breaking previous world records of classic runners, did not simply hold onto the fast pace throughout the world record but rather started with a slower pace which was maintained (88). As demonstrated in our meta-analyses, the correct pacing strategy in the first 5-10% of an endurance event is important for overall performance and the ability to sustain an optimal pacing strategy.

Teleoanticipation

Given that the initial pace is a significant determinant of subsequent pacing strategy, Ulmer (26), coined the term teleoanticipation in reference to the setting of the pace according to the anticipated distance of the upcoming event. This model has been subsequently expanded to explain pacing strategies including the *Central Governor Model* with a subconscious controller of effort (20), the *Perception Based Model* incorporating RPE as a moderator of

pace (56), the *Pacing Awareness Model* citing conscious and subconscious brain control of pacing (43), the *Psychobiological Model* incorporating perception of effort with experience / knowledge of the event (89) and then, more recently, the *Dual Processing Model* as described by Micklewright et al., (24) incorporating intuitive and deliberative control mechanisms including such inputs as emotional state and social context. One of the constants in all of these models is the idea that previous experience of the upcoming event is a key component of being able to set an appropriate pace in the early stages. When confronted with a situation where there is limited current familiarity of the upcoming events environmental demands, the outcomes of this meta-analysis reinforce the concept that there is a poor judgement of starting pace. Based on the above models, this would occur until such a time as the information from the new environment can be modulated against the internal schemas which then would update the pacing strategy. As seen in our meta-analysis, this correction appears to occur after the first 5-10% of the event. However, the correction appears to occur in a continual manner where there is not a sudden drop of running intensity but rather a gradual decline in pace. This reinforces the idea of a continual updating of the pacing schema anchored around anticipation of future demands (24, 56, 89).

Recent research in the field of fatigue has focussed on perceptual control of behaviour. A study by Van Cutsem et al., (90) found a decrease of 9% in time to exhaustion when participants were subjected to an increased perception of thermal strain. During this study, participants cycled in a 20˚C ambient environment with or without a hot pack on their back to increase the perception of thermal strain. The outcome of the trials showed that the *perception* of thermal strain was likely a significant modifier of exercise performance and the reason for premature cessation of the exercise in the experimental group. This study was performed in a fixed exercise protocol which does not allow for observations around how an athlete would change pace according to these increasing perceptions. The authors focused on the late stage

increase in RPE observed in the experimental group and suggested that this was likely due to increased activity in the premotor cortex due to exercising in an unpleasant environment (90). Interestingly, the reduction in overall performance of 9% closely matches that found by our meta-analysis of *absolute* pace and suggests that at least some of the influence of the reduction in performance found may have been due to perceptions of future threat and the need to protect from cellular harm.

The 'end spurt'

This meta-analysis showed that, during the final 10% of both trials, an 'end spurt' can be noted, associated with an increase in pace. During the hot trials, this end spurt occurs despite having an increasingly slower pace after the first 10% of time completed and a higher core temperature. This end spurt phenomenon has been purported to be caused by the knowledge that the finish line is close and this in turn causes a reduction in the 'motivators' that contribute to the body protecting from cellular harm (40, 56). The appearance of this fast finish in both trials supports the notion of higher center control of pacing and was critical in the initial proposals of pacing as set out by Noakes (2). This fast finish has been noted in contemporary marathon runners despite the movement towards a more even pacing schema for the race as mentioned previously (88). This end spurt has been thought of as an indicator that athletes are still to move towards the perfect pacing of endurance races whereby the event is run at an even pace throughout (88). The idea that this phenomenon is also an error in pacing judgement is seen in this meta-analysis in that even with a steadily decreasing pace in the novel hot environment, there remained the ability for participants to have a large increase in pace during the final 10% of the trial. This would suggest there was a significant reserve left, as predicted by the various models described above.

The average pace was 11% lower in the hot environment than in the mild environment. This is in line with a previous meta-analysis by Hancock et al., (32) which showed the same reduction in performance in endurance events when comparing ambient temperature above 29˚C with temperatures below this threshold. The outcome of this meta-analysis, therefore, shows that when an athlete is presented with an unfamiliar hot environment, with no heat acclimation, that there is tendency towards a fast relative start, at a similar pace to what would be expected in milder conditions. This likely then contributes to a comparatively greater reduction in pacing over the course of an event and ultimately to poorer performance. A reduced pacing in the initial stages would allow the brain time to update the inherent pacing schema such that a more stable pace can be sustained throughout the run and assist with a faster relative finish time. Further research utilizing intra-subject designs exploring how different pacing strategies in the first 5-10% of an endurance event affects performance would help to improve this concept.

Limitations

The main limitation for this meta-analysis was the wide range of event times across the studies as well as the range of event characteristics (cycling, rowing and running). In order to overcome this, outputs (power or speed) were referenced against themselves to create a uniform ‘percentage of completion’. This method depends on the heterogeneity of the trial lengths and event characteristics not having an impact on the pacing strategy adopted. Visual observation of the plots of the outcomes of each of the contributing studies did, however, indicate that the observed pacing changes were similar between the different exercise modalities. Also, as described by Davies et al., (79) in a meta-analysis investigating environmental and feedback interventions on the pacing profiles in cyclists, the influence of

the amount of time spent in warming up in a hot ambient environment needs to be taken into account as this impacts starting core temperature. None of the included studies had differences observed in the starting core temperatures between environmental conditions but the inter-study differences in the starting core temperatures was not considered. Rates of heat storage were unlikely to be significantly affected by mild differences in the starting core temperatures. The high risk of bias in 8 of the 9 studies involved reduces the confidence in the data used and reduces the ability to draw strong conclusions from this analysis. Further, limiting the search strategy to English-language papers only increases the chances that studies were missed in the analysis. Differences in wind speed, athletic clothing, participant characteristics (gender, experience levels) and environment (indoor / outdoor) were also not accounted for in the study. Despite this heterogeneity in the study designs and participant characteristics, the analyses did not show significant heterogeneity in their outcomes. This gives confidence in the validity of the novel approach used to combine study outcomes according to a reference point.

2.6 Conclusion

This meta-analysis showed that when confronted with an unfamiliar hot environment, participants will likely start with an unsustainably high initial pace which is significantly higher than in a mild environment relative to the average pace of the event. The impact of this is that a less efficient pacing strategy is adopted in the hot environment whereby a significant drop-off of pace occurs over the course of the event prior to an end spurt. This potentially then contributes to a poorer final finish time.

2.7 Funding support

GLM was supported by a Leadership Investigator Grant from the National Health & Medical Research Council of Australia (ID 1178444).

2.8 Conflicts of Interest Statement

James Wiltshire: JW works as a full-time sports physiotherapist with the South Australian Cricket Association.

G. Lorimer Moseley: GLM has received support from: Reality Health, ConnectHealth UK, Institutes of Health California, AIA Australia, Workers' Compensation Boards and professional sporting organisations in Australia, Europe, South and North America. Professional and scientific bodies have reimbursed him for travel costs related to presentation of research on pain and pain education at scientific conferences/symposia. He has received speaker fees for lectures on pain, pain education and rehabilitation. He receives royalties for books on pain and pain education.

Lachlan Darch: LW has no known conflicts of interest

Ashley Grant: AG has no known conflicts of interest

Samuel Chalmers: SC has no known conflicts of interest

3 Chapter Three

The influence of an external factor (deception of environmental heat) on short time trial performance and pacing – an exploratory study

3.1 Abstract

Hypothesis/Purpose: We aimed to determine the influence of a future perceived threat to homeostasis on pacing strategy and performance in repeated 2kmTT's. First, we hypothesised that being informed that a future 2kmTT will occur in a warmer environment than the first increases completion time (relative to the milder deception) during the first 2kmTT. Second, we hypothesised that being informed that the ambient temperature is high will result in a longer completion time than being told the ambient temperature is low, regardless of true ambient temperature.

Study Design: Randomised Cross-over Trial

Methods: Seventeen adults (age > 18y.o) were recruited from a domestic high performance cricket program. Participants ran two consecutive 2kmTT's separated by a 25-minute walk in a heat-controlled chamber set at 32℃ (30% RH) on three occasions. The first session was a control session and during the second two sessions, participants were deceived that the second 2kTT was at either 36℃ (30% RH) or 28℃ (30% RH). Time to completion for each 2kTT was recorded. Secondary analysis was carried out on thermal, perceptual and cardiovascular variables.

Results: There was no significant difference between time taken to complete the trials in each group. There was a *large* and significant main effect during Time Trial 2 on both thermal comfort ($p = 0.012$, $\eta p^2 = 0.335$) and TS ($p = 0.028$, $\eta p^2 = 0.266$) and a large but not significant effect on RPE ($p = 0.06$, $\eta p^2 = 0.204$). There were no main effects on thermal or cardiovascular variables.

Conclusion: This exploratory study showed that when elite cricket players ran a 2kmTT performance was unaffected by external feedback in the form of a future threat.

3.2 Introduction

The concept of ‘teleoanticipation’ arose almost three decades ago (26), and seeks to explain that for any endurance exercise, an athlete chooses a pacing strategy based on predictions of finishing in the best possible time while keeping a buffer of available physiological reserves and therefore protecting the self from real, or perceived, ‘harm’. Although originally being based on a somatosensory and metabolic control basis, this anticipatory concept has been evolved over time to include cortical input (24, 29, 78). Recent research has also demonstrated that external influences such as music (91) and competition (92) have also been shown to influence pacing strategy and performance, as have strategies such as self-talk (33). Further demonstration of the influences of these ‘central factors’ (as distinct from peripheral physiological limiters) has been achieved through deception trials (35, 93, 94).

Tucker and Noakes (56) suggest that pacing strategies are influenced by event duration. The authors contend that pacing during events of duration less than 4 mins are characterised by a strong effort followed by a gradual diminishing of pace whereas events of duration greater than 4 mins are typically characterised by an elongated ‘U-shaped’ pace whereby participants have a fast start then settle into a consistent mid-race pace and then finish with an end spurt. The distinctive shape of longer duration events has been posited to be due to the increased influence of external factors affecting teleoanticipation (95) and have been found across multiple sports (96, 97). However, it is important to note that team sport activities are rarely performed in a continuous, evenly paced manner but are rather an accumulation of repeat efforts (98). During repeated sprints, Billaut et al., (99) asserted that future anticipation of the number of sprint efforts still to occur, as well as the task duration of the current effort, influenced the pacing strategy of participants. There has been limited research to date which

has examined the influence of teleo-anticipation across repeated endurance efforts such as those that occur in most team sport events.

The assessment of endurance capacity forms an integral part of determining players' physical preparation. One method used to assess endurance in elite team sports is the 2-kilometre time trial (2kmTT). To our knowledge, no studies to date have examined the influence of external factors on 2kmTT performance. We aimed to determine the influence of a future perceived threat to homeostasis on pacing strategy and performance in repeated 2kmTT's. Environmental ambient heat can be considered a threat, given that individuals report greater perceptual discomfort and experience greater cardiovascular strain, and ultimately demonstrate a reduction in physical performance during exercise in the heat (50, 100, 101). We had two hypotheses. First, we hypothesised that being informed that a future 2kmTT will occur in a warmer environment than the first increases completion time (relative to the milder deception) during the first 2kmTT. Second, we hypothesised that being informed that the ambient temperature is high will result in a longer completion time than being told the ambient temperature is low, regardless of true ambient temperature.

3.3 Methods

Participants

Participants were recruited from state-based high-performance teams during the cricket pre-season from August 2021 to September 2021. Eligible participants were those aged 18 years and over and currently selected in a senior elite domestic cricket program. Participants were excluded if they had a current injury which limited their ability to perform the 2kmTT, were suffering from an acute episode of pain, had a psychiatric or neurological condition, or

suffered from a cardiac condition. Participants were recruited on a volunteer basis and provided written informed consent form. This study was approved by a local Human Ethics Committee (#202265). To detect a medium effect size (in line with research by Castle et al. (35)) with a 5% significance level, a power of 80%, four measurements per time trial, and a correlation among repeated measures of 0.5, a total sample size of 24 participants was required (G Power software version 3.1.9.2). All eligible, and available, participants within the high-performance system were approached. A total of 18 participants volunteered for the study and underwent the familiarisation trial which fell just short of the power requirements. One participant subsequently dropped out of the study due to an inability to commit to the study timeframes. Seventeen participants (10 females, 7 males, mean ± SD: age 21.5 ± 4.0 years, height 175.1 ± 8.7 cm, weight 74.5 ± 9.9 kg) were subsequently recruited and analysed in this study. All participants had regularly run 2kmTT's within the last year.

Study Design and Methodology

The study design was a randomised, cross-over, single-blinded deception trial. All participants attended three sessions comprising a familiarisation session followed by two subsequent cross-over trials (Fig. 1). All sessions were 7-10 days apart and were at the same time of day to standardise the effect of circadian variation upon physiological and performance measures (102). Simple randomisation of experimental trial order was performed using a computer random number generator by the principal researcher with nine participants allocated to start in the warm deception group. Prior to all sessions, participants were instructed to abstain from alcohol and to follow the same caffeine and exercise routine for 48 hours prior to each trial.

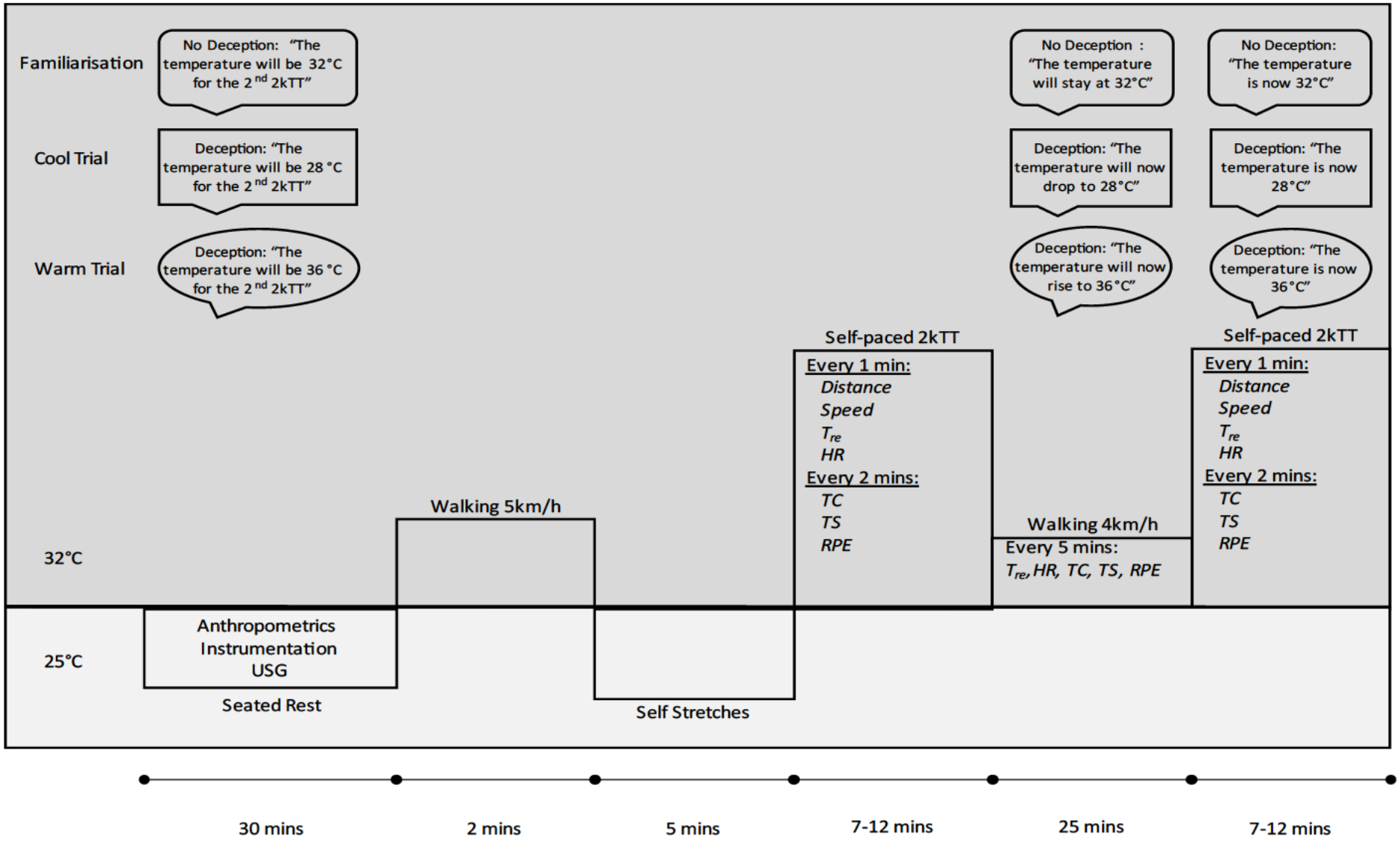


Figure 1. Study Design and Methodology. USG, Urine Specific Gravity; T_{re}, Rectal Temperature; HR, Heart Rate; TC, Thermal Comfort, TS, Thermal Sensation; RPE, Rate of Perceived Exertion

Familiarisation trial

Participants initially entered a temperature-controlled room set at an air temperature of ~23℃. Participants were screened for medical issues in line with the exclusion criteria, anthropometric and demographic data were collected, and informed written consent was obtained. Urine specific gravity (USG; Pocket Refractometer PAL-10S, Atago, USA) was tested from a mid-stream urine sample. Three participants tested greater than 1.020 g/ml and were provided with a predetermined rehydration strategy (Cricket Australia Hydration Guidelines). A heart rate monitor (Polar M400, Finland) was fitted, and skin temperature sensors (iButton DS1922L, iButtonlink, USA) were taped to the skin over the right biceps, chest wall, thigh and calf. Mean skin temperature (T_{Sk}) and was calculated using the equation of Ramanathan (103). After all instrumentation was complete, participants entered the environment chamber which was set to an air temperature of 32℃ and 30% relative humidity (RH). Throughout the trials, participants were blinded to the true air temperature which remained constant for the duration of all trials. Initially on entering the environment chamber, participants were instructed in the use of the 6-20 Borg scale for rating of perceived exertion (RPE) (104). They were then asked to rate their thermal comfort on the 7-point Bedford Thermal Comfort Scale (ranging from 'much too warm' through to 'much too cool') and thermal sensation (TS) on the 7-point Ashrae Thermal Sensation Scale (ranging from 'Hot' through to 'Cold') (105). Participants then performed a 2 min warm-up on a motorised treadmill at 5 km/h before exiting the environmental chamber and performing 5 min of self-stretching (Fig. 1).

Participants then re-entered the environment chamber and stayed in the chamber for the remainder of the trial. For the main segment of the trial, participants ran two x 2kmTT's as

fast as possible with a 25-min recovery walk on the treadmill between the trials. Immediately before beginning the 2kmTTs while in the environmental chamber, baseline thermal comfort, TS and heart rate (HR), were recorded. Throughout the 2kmTT's, distance covered, running speed, HR and T_{Sk} were recorded every min and thermal comfort, thermal sensation and RPE were recorded every 2 mins. Each 2kmTT was started with a rolling start of 10 km/h for the familiarisation. During each 2kmTT, the speed of the treadmill was able to be freely manipulated by the participant whilst being blinded to the numerical value but not blinded to distance travelled. At the completion of the first 2kmTT, participants completed a 25-min walk on the treadmill at 4 km/h. Throughout the recovery walk, HR, T_{Sk}, thermal comfort, thermal sensation, and RPE were recorded every 5 mins. At the completion of the walking segment, participants again had a 10 km/h rolling start for the second 2kmTT which was completed with an identical protocol to the first 2kmTT.

Experimental trials

On arrival at the trial, participants were seated in the temperature-controlled room set at an air temperature of ~23°C. USG was collected according to the previously described process. In order to improve measurement reliability, participants were then asked to self-insert a CorTemp Pill (HQ, Inc., USA) 10 cm past the anal sphincter to collect rectal temperature (T_{re}) (106). All warm-up procedures were the same as the familiarisation trial mentioned above. The initial 2kmTT speed of the treadmill during the trials was set at 20% lower than the average familiarisation time-trial speed. The data collection procedure for distance covered, running speed, HR, T_{Sk}, thermal comfort, thermal sensation, and RPE during the 2kmTT was identical to the familiarisation trial with the addition of T_{re} collection every 1 min.

Deception implementation

Throughout the trials, participants were able to view a computer screen with a readout of air temperature. Participants were informed that this was the true air temperature of the room. For the deception trials, participants were instructed that during the mid-trial walking either the temperature would rise to 36℃ (Warm trial) or that it would fall to 28℃ (Mild trial) (with relative humidity remaining the same). This deception was displayed on the computer screen with the temperature gradually changing to the desired value over the course of the walking segment. It was communicated to participants that the initial 2kmTT would be operated in the same environmental conditions each time and that the air temperature would only change for the second 2kmTT.

Statistical Analysis

A one-way ANOVA with a factor of Condition (Warm or Mild) was performed on completion time for each Time Trial (1 and 2) to determine the effect of deception upon time to completion (primary outcome). To standardise the data for time taken, all time points were converted into percentages of the finish time. Outcomes for each time point were calculated at 25% increments (25%, 50%,75%, 100%) by assuming a linear increase between the closest two time points (for 25%, 50%, and 75%). This allowed for direct comparison across participants with different completion times. Two-way repeated measures ANOVAs with factors of Time (4 levels: 25%, 50%, 75%, and 100%) and Condition (2 levels: Warm and Mild) were performed on all secondary outcome variables (HR, T_{re}, T_{sk}, RPE, thermal comfort, and thermal sensation) for each time trial. All main effects were followed up by pairwise comparisons between conditions to explore effect sizes and guide future research directions. Significant Time by Condition interactions were followed up by simple main

effects analysis. All analyses were performed using R version 4.1.0. Statistical significance was accepted at the level of $P < 0.05$ with mean and 95% confidence intervals obtained. Effect sizes from the ANOVAs were measured using partial eta squared (ηp^2) which were interpreted as small (0.01), medium (0.06), and large (0.14) effects (107).

3.4 Results

Primary outcome: Time to completion during Time Trial

The time taken to complete the first 2kmTT for the Mild and Warm trials were 529.8 ± 91.9 and 531.7 ± 97.7 respectively. Participants completed the second 2kmTT for Mild and Warm respectively in 551.0 ± 93.1 and 553.6 ± 91.5. There was no statistical difference between conditions for Time Trial 1 ($p = 0.953$, $\eta p^2 < 0.001$) or Time Trial 2 ($p = 0.935$, $\eta p^2 < 0.001$) for the time taken to complete each time trial.

Secondary outcomes: Thermal, perceptual, and cardiovascular outcomes

3.4.1.1 Thermal and cardiovascular outcomes

All variables showed a *large* significant main effect over Time (all $p < 0.05$, $\eta p^2 > 0.14$) across each Time Trial (Table. 1). There was a *large* significant main effect of Condition on HR in Time Trial 2 with pairwise comparisons demonstrating an increase in HR in the Warm Condition (Mild = 171.2 ± 29.9, Warm = 173.1 ± 28.0; $p = 0.037$, $\eta p^2 = 0.276$). No other main effects of Condition on each variable across each Time Trial were found (all $p > 0.05$). There was no significant two-way interaction between Condition and Time for each of the secondary outcomes for each Time Trial (all $p > 0.05$) except for T_{Sk} in Time Trial 1 (p =

0.033, $\eta p^2 = 0.216$). Follow-up simple main effects demonstrated no significant differences between conditions at each time point for T_{Sk} (all $p > 0.05$) however, plot lines showed a (non-significant) increase in T_{Sk} at the beginning of Time Trial 1 (Table 1).

3.4.1.2 Perceptual outcomes

The amount of time completed showed a *large* and significant main effect on each variable across each Time Trial ($p < 0.05$, $\eta p^2 > 0.14$). There was no significant main effect due to Condition on any variable during Time Trial 1 (all $p > 0.05$). Condition showed a *large* and significant main effect during Time Trial 2 on both thermal comfort ($p = 0.012$, $\eta p^2 = 0.335$) and TS ($p = 0.028$, $\eta p^2 = 0.266$) and a large but not significant effect on RPE ($p = 0.06$, $\eta p^2 = 0.204$). Pairwise comparisons showed a significant increase in values in the Warm condition versus the Mild condition for both thermal comfort (Mild = 1.7 ± 1.0, Warm = 1.9 ± 0.9, $p = 0.001$) and thermal sensation (Mild = 1.8 ± 1.0, Warm = 2.0 ± 0.9, $p < 0.001$). There was a significant interaction between Condition and Time during Time Trial 1 for thermal sensation ($p = 0.029$). Simple main effects for thermal sensation showed a *large* and significant difference at the 100% time point for Time Trial 1 for thermal sensation (Mild = 2.6 ± 0.6, Warm = 2.4 ± 0.8, $p = 0.04$, $\eta p^2 = 0.235$). There were no other interactions found across all other variables in either Time Trial 1 or 2 (all $p > 0.05$) between Condition and Time (Table 2).

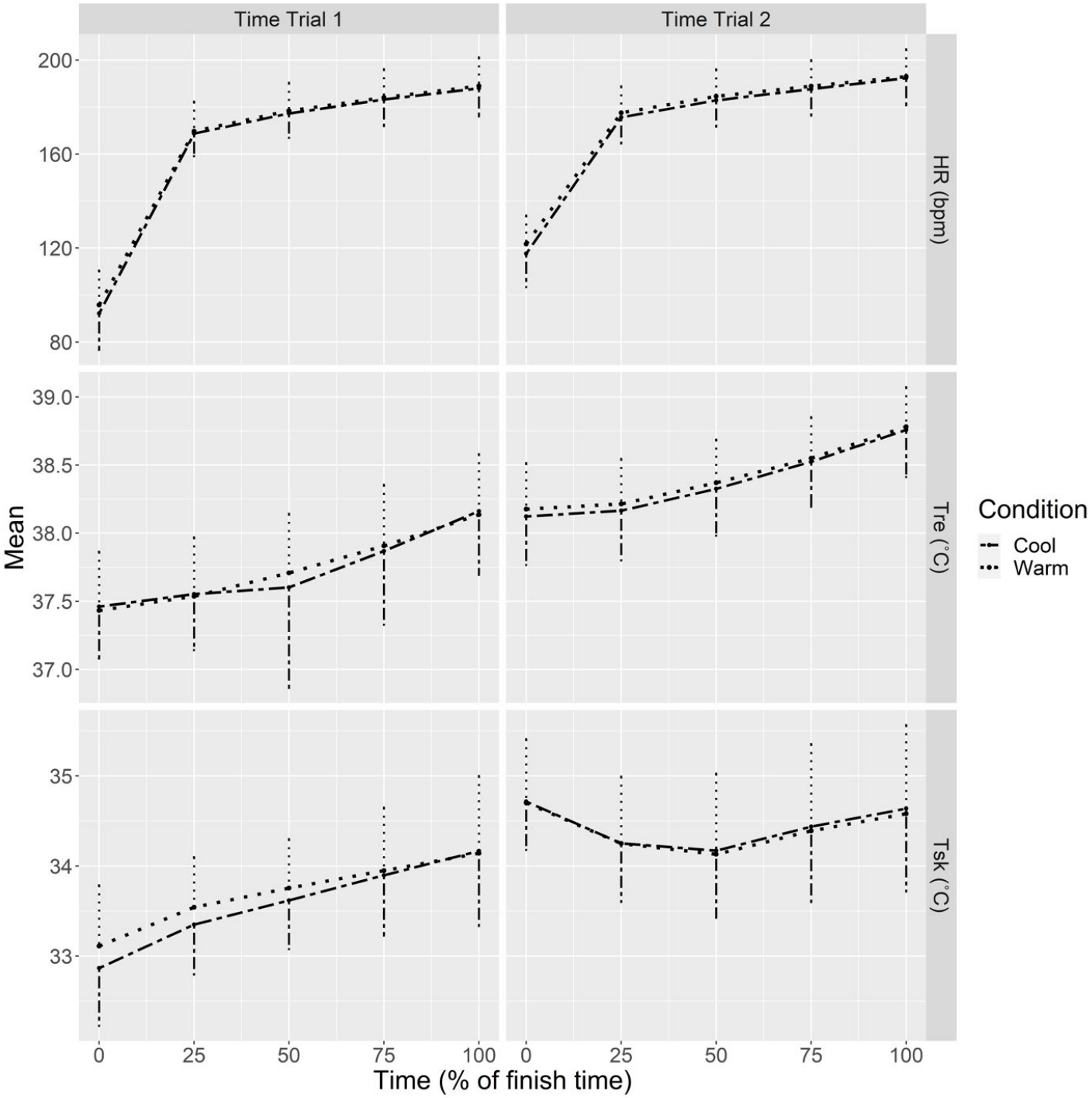


Figure 2. Physiological variables for each Time Trial. Mean and 95% confidence intervals. HR, Heart Rate; T_{re}, Rectal Temperature; T_{Sk}, Skin Temperature.

		Time Trial 1		Time Trial 2	
Variables	**Time**	**Mild**	**Warm**	**Mild**	**Warm**
HR (bpm)	0	92.2 (15.5)	95.8 (14.7)	117.7 (14.2)	121.7 (12.1)
	25	168.7 (9.6)	169.7 (12.6)	175.6 (11.1)	177.6 (11.3)
	50	177.3 (10.4)	178.4 (11.9)	182.8 (11.2)	184.6 (11.5)
	75	183.3 (11.3)	184.1 (12.0)	187.7 (11.3)	188.9 (11.0)
	100	188.0 (12.0)	189.0 (12.2)	192.4 (11.6)	192.9 (11.7)
Time (0↔100%)		$p<0.001$*** $\eta p^2=0.968$	$p<0.001$*** $\eta p^2=0.986$	$p<0.001$*** $\eta p^2=0.986$	$p<0.001$*** $\eta p^2=0.984$
T_{re} (˚C)	0	37.5 (0.4)	37.4 (0.4)	38.1 (0.4)	38.2 (0.3)
	25	37.6 (0.4)	37.5 (0.4)	38.2 (0.4)	38.2 (0.3)
	50	37.6 (0.7)	37.7 (0.4)	38.3 (0.3)	38.4 (0.3)
	75	37.9 (0.5)	37.9 (0.4)	38.5 (0.3)	38.5 (0.3)
	100	38.2 (0.5)	38.1 (0.4)	38.8 (0.3)	38.8 (0.3)
Time (0↔100%)		$p<0.001$*** $\eta p^2=0.647$	$p<0.001$*** $\eta p^2=0.924$	$p<0.001$*** $\eta p^2=0.927$	$p<0.001$*** $\eta p^2=0.935$
T_{sk} (˚C)	0	32.9 (0.6)	33.1 (0.7)	34.7 (0.5)	34.7 (0.7)
	25	33.4 (0.6)	33.5 (0.6)	34.3 (0.7)	34.3 (0.7)
	50	33.6 (0.5)	33.8 (0.5)	34.2 (0.7)	34.1 (0.9)
	75	33.9 (0.7)	33.9 (0.7)	34.4 (0.8)	34.4 (1.0)
	100	34.2 (0.8)	34.1 (0.9)	34.6 (0.9)	34.6 (1.0)
Time (0↔100%)		$p<0.001$*** $\eta p^2=0.800$	$p<0.001$*** $\eta p^2=0.696$	$p<0.001$*** $\eta p^2=0.534$	$p<0.001$*** $\eta p^2=0.521$

Table 1. Physiological Data with Mean (SD). HR, Heart Rate; T_{re}, Rectal Temperature; T_{Sk}, Skin Temperature. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

		Time Trial 1		Time Trial 2	
Variables	**Time**	**Mild**	**Warm**	**Mild**	**Warm**
RPE (Borg)	25	13.5 (1.9)	14.1 (1.5)	13.5 (1.9)	14.1 (1.8)
	50	16.1 (1.4)	16.1 (1.6)	16 (1.4)	16.5 (1.6)
	75	17.7 (1.3)	17.8 (1.4)	18 (1.2)	18.4 (1.3)
	100	19.1 (1.1)	19.4 (0.8)	20 (0)	20 (0)
Time (0↔100%)		$p<0.001$*** $\eta p^2=0.866$	$p<0.001$*** $\eta p^2=0.904$	$p<0.001$*** $\eta p^2=0.889$	$p<0.001$*** $\eta p^2=0.878$
TC (Bedford)	0	0.5 (0.5)	0.4 (0.5)	0.6 (0.5)	1 (0.7)
	25	1.2 (0.7)	1.2 (0.6)	1.2 (0.7)	1.4 (0.7)
	50	1.6 (0.6)	1.6 (0.7)	1.7 (0.8)	1.9 (0.8)
	75	2.2 (0.7)	2.1 (0.7)	2.2 (0.8)	2.3 (0.8)
	100	2.5 (0.7)	2.3 (0.8)	2.5 (0.8)	2.6 (0.6)
Time (0↔100%)		$p<0.001$*** $\eta p^2=0.814$	$p<0.001$*** $\eta p^2=0.725$	$p<0.001$*** $\eta p^2=0.788$	$p<0.001$*** $\eta p^2=0.782$
TS (Ashrae)	0	0.5 (0.5)	0.6 (0.5)	0.7 (0.8)	1 (0.7)
	25	1.3 (0.6)	1.5 (0.7)	1.5 (0.7)	1.6 (0.9)
	50	2 (0.7)	1.9 (0.8)	2 (0.7)	2.2 (0.8)
	75	2.3 (0.7)	2.2 (0.7)	2.4 (0.7)	2.5 (0.7)
	100	2.6 (0.6)	2.4 (0.8)	2.5 (0.9)	2.6 (0.7)
Time (0↔100%)		$p<0.001$*** $\eta p^2=0.792$	$p<0.001$*** $\eta p^2=0.715$	$p<0.001$*** $\eta p^2=0.806$	$p<0.001$*** $\eta p^2=0.817$

Table 2. Perceptual data with Mean (SD). RPE, Rate of Perceived Exertion; TC, Thermal Comfort; TS, Thermal Sensation. *** $p < 0.001$

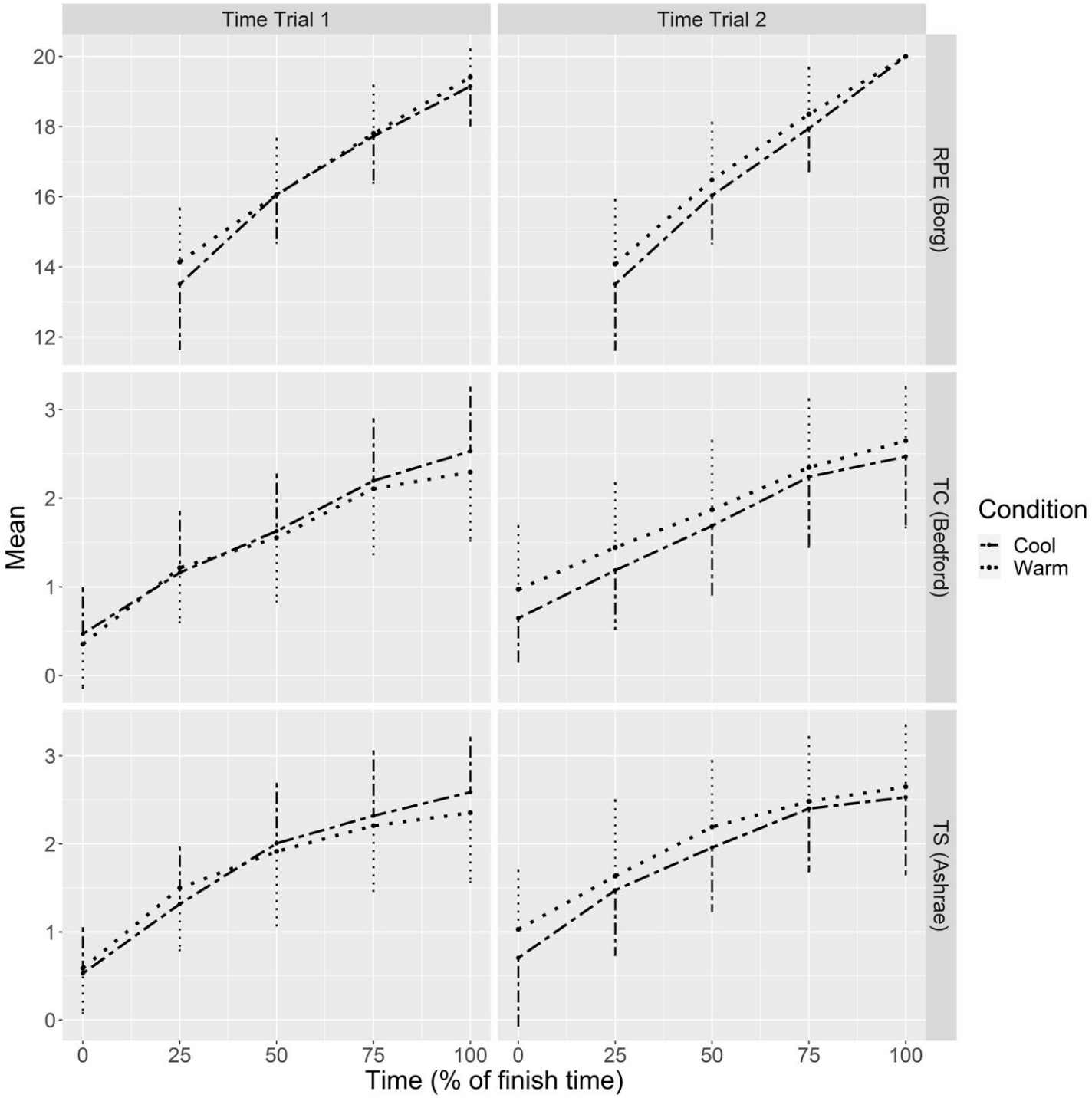


Figure 3. Perceptual variables for each Time Trial. Mean and 95% confidence intervals. RPE, Rate of Perceived Exertion; TC, Thermal Comfort; TS, Thermal Sensation.

3.5 Discussion

The main hypothesis of this exploratory study was not supported based on the observation that the deception of temperature did not cause a difference in the completion time of either, or both, of the 2kmTT's. While previous research using deception trials have investigated the impact of external factors (e.g. music, competition) during time trials on performance (27, 91, 97), this is the first study (to our knowledge) to look at both the prior influence of a future threat on a trial in combination with the performance of a prior trial.

Models describing the role of central fatigue (27, 56, 101) lend suggestion that there would be a modification of current performance if an individual felt a threat to finishing an aerobic event. Within hyperthermia-induced fatigue, this was investigated by Castle et al. (35), where the decrease in exercise performance due to ambient heat was ameliorated by deceiving participants that air (environment) and core (individual) temperature had not risen. Although previous studies have found significant effects on performance with the introduction of external feedback during exercise greater than 30 minutes (35, 36, 108), Tucker and Noakes (56) suggest that modulation of pacing by central factors (e.g. perceived environmental stress) likely occurs in events of greater than 4 minutes duration, and can be evidenced by the tell-tale 'end spurt' (increased performance at the end of the event). Although the pacing strategy of participants in the current study did show an end spurt, there was no significant pacing difference (and only 'trivial' differences) found between the Warm and Mild deception conditions throughout the trials. The findings of this study indicate a lack of effect of future threat and teleo-anticipation over a brief aerobic endurance event (~8 min).

Exploratory analysis of the physiological and perceptual data showed significant differences in the perceptual variables during Time Trial 2 while showing no statistical difference in the thermal and cardiovascular variables. Both thermal comfort and thermal sensation showed significantly higher values in the Warm deception condition of *large* effect while RPE fell just outside of a statistical difference ($p = 0.06$) while also showing a *large* effect of an increase in values in the Warm deception condition. This is in direct contrast to the lack of statistical difference and *trivial* effect sizes in the cardiovascular (HR) and thermal (core and skin temperature) variables. Tentatively, this raises the possibility that sustaining the same level of

work and physiological strain is perceptually more challenging when the participants believe they had an increased environmental demand. Over an increased length of time, or given a larger perceptual challenge, this has the potential to start to impact performance.

Ely et al. (109), found that experience with running over a certain known distance allows for a more 'ingrained pacing schema' and is therefore more robust to the moderating effect of external factors (110). Given this study was conducted on elite cricket players who have repeatedly completed prior 2kmTT efforts, it may be that an ingrained pacing schema in combination with the time trial methodology reduced the amount of influence on variability of the deception feedback. Other researchers have also shown a decreased outcome variability in shorter duration time trials when compared to longer durations or time to exhaustion trials (111, 112). It is possible that over time, these increased perceptual stressors would over-ride the pacing schema and start to cause a performance effect as is noted in events greater than 30 minutes (36). However, given the exploratory nature of the study, these observations must be treated with caution. Further research is needed to explore the timeframes around when central factors start to play a significant role in reducing performance.

The primary limitation of the study is the confidence in the participants' beliefs that the environmental conditions in the second time trial were different from the first. Previous deception research in this area has stated that the participants' acceptance of the deception is imperative for allowing valid findings to be taken from these types of study (35). A follow-up question at the conclusion of the trial exploring the validity of the deception would increase confidence that the deception was accepted. The consistently lower reporting of TC and TS throughout the second 2kmTT in the Mild deception group does add some level of validity to the acceptance of the deception of the study. Further to this limitation, given the use of heat as an external threat, there may have been a stronger result if the ambient temperatures used caused the core temperature to elevate further. Previous research has shown that increases in temperature cause greater pacing and performance changes (76).

3.6 Conclusion

Deception of air temperature throughout the duration of the study explored a novel approach to the influence of teleo-anticipation on pacing strategies during a common time trial. In conclusion, this exploratory study showed that when elite cricket players ran a 2kmTT, despite tending to show typical signs (i.e., an end spurt) associated with an event thought to be influenced by teleo-anticipation, performance was unaffected by external feedback in the form of a future threat.

3.7 Funding support

GLM was supported by a Leadership Investigator Grant from the National Health & Medical Research Council of Australia (ID 1178444).

3.8 Conflicts of Interest Statement

James Wiltshire: JW works as a full-time sports physiotherapist with the South Australian Cricket Association.

G. Lorimer Moseley: GLM has received support from: Reality Health, ConnectHealth UK, Institutes of Health California, AIA Australia, Workers' Compensation Boards and professional sporting organisations in Australia, Europe, South and North America. Professional and scientific bodies have reimbursed him for travel costs related to presentation of research on pain and pain education at scientific conferences/symposia. He has received speaker fees for lectures on pain, pain education and rehabilitation. He receives royalties for books on pain and pain education.

Samuel Chalmers: SC has no known conflicts of interest

4 Chapter Four

Summary Discussion

4.1 Overview of Thesis

The aim of this thesis was to examine the impact of a future 'threatening' environment on pacing and performance in medium distance endurance events. This was achieved firstly through a systematic review and meta-analysis of the literature to determine the impact of unfamiliar environmental demands on pacing. This analysis was followed up with a randomised cross-over control trial which sought to investigate the pacing of two consecutive two-kilometre time-trials when participants were deceived into believing the second two-kilometre time-trial would be run with a higher or lower environmental temperature.

Systematic Review and Meta-analysis Findings

The systematic review and meta-analyses aimed to investigate the impact a future unfamiliar hot environment would have on the pacing of participants when compared to a thermo-neutral environment. Overall, the studies that were included in the meta-analysis were of a low quality with a high risk of bias. The findings of the analysis indicate that there is a similar *actual* pace in the first 5-10% in both environments, however, following this, there is a significant decrease in the pace of participants in the hot environment relative to the thermo-neutral environment. This potentially points to an unsustainable pacing strategy that is adopted by participants in the initial stages of an unfamiliar hot environment that is then corrected due to central cortical process aiming to protect from cellular harm that may occur if a similar pace was sustained. All studies included in this review were of endurance events greater than 30 minutes in duration. There was a lack of evidence around endurance events of short to medium duration.

Randomised Cross-over Trial Findings

Using a randomised cross-over trial design, this pilot study used a deception of environmental temperature to investigate two separate goals. The first goal was to explore the impact of a perceived future environmental demand on the pacing of a medium duration endurance event while the second goal was to investigate how the perception of the environment alters pacing and performance outcomes, as well as perceptual and physiological measures. The results of this study showed that over the course of a medium distance event of 7-12 minutes duration, despite showing the signs typically associated with teleo-anticipation during an endurance event (i.e., an end spurt), there was no significant impact of a future threat, via an expected change in environmental temperature, on pacing and performance. However, there was an indication, through large effect size differences, that perceptual measures of exertion and thermal sensation may be influenced by the belief of immediate environmental demands as well as the actual demands.

4.2 Implications of Thesis Findings

The systematic review and meta-analyses demonstrated the need for further investigation into the impact of future ‘threats’ to perceived or real harm and the impact this has on pacing and performance. This review and analyses helped to direct future research toward the cortical processes involved with fatigue and the impact this could have on pacing strategies. This review also demonstrated that there was a gap in the literature exploring the impact of unfamiliar environmental challenges on events that are of a short-to-medium duration (4-30 minutes). The randomised cross-over trial aimed to investigate this short-to-medium time period and the impact of perceived versus real environmental demands on pacing strategies to explore cortical involvement over events of this duration.

Systematic Review and Meta-analysis

The results of the systematic review and meta-analyses demonstrated the significant changes in both the performance outcome and the adopted pacing strategy when athletes are confronted with an unfamiliar hot environment. The meta-analyses further highlighted the importance of the initial pacing during the first 5-10% of the event that has been shown by previous research to dictate the pacing strategy used for the remainder of the event (29, 39). It was hypothesised that during this initial period of time, the brain must calculate the wealth of information regarding the intra- and extra- body environments and then adjust pacing accordingly to ideally avoid cellular harm.

Given that overall performance is influenced by the pacing strategy adopted (39), understanding the brain's interpretation of the environment and how this influences pacing is essential for optimising performance. The results of this systematic review and the meta-analyses expand on the concept that the setting of pace is determined by the anticipated distance of the upcoming event, termed teleoanticipation by Ulmer (26). The setting of an unsustainable pace when confronted with an unfamiliar hot environment shows that there are other factors that influence pace setting then just the distance remaining. Our initial pace appears to be based on some form of calculation of future effort expenditure and in an unfamiliar environment, this must be estimated prior to disturbances in physiology to allow for more accurate predicting of demands, both environmental and physical. When faced with future 'threats', it seems athletes tend towards an over optimism of their sustainable pace. This expanded concept of anticipation is in line with later models of fatigue such as the *pacing awareness model* citing conscious and subconscious brain control of pacing (43), the *psychobiological model* incorporating perception of effort with experience / knowledge of the event (89) and then, more recently, the *dual processing model* as described by Micklewright

et al., (24) incorporating intuitive and deliberative control mechanisms including such inputs as emotional state and social context.

The implications for these findings demonstrate the need for athletes to ensure the pacing strategy chosen during the initial stages of an endurance event is well thought out and encompasses the real challenges that will occur in the upcoming event (i.e., environmental, physical terrain, etc). Optimal pacing strategies in endurance events are considered to be one where there is a minimal of change of pace throughout the duration of the event (39-41). Given that participants in an unfamiliar hot environment self-selected a starting pace that was not different from a known thermo-neutral environment, this suggests a lack of ability of the brain to forward plan in the initial stages of an event prior to updated information being obtained from sensory and perceptual cues following physiological disturbance during exercise. During this initial time period, without an internal plan, or 'schema', for how to pace, an athlete must rely on forward planning from known variables and should adopt pacing according to a pre-determined race plan to avoid the pitfalls of relying on cortical processing of an appropriate pace and playing 'catch-up' during the remainder of the event.

Randomised Cross-over Trial

The main outcome of this study showed that there was no impact on performance or pacing when participants were exposed to a perceived future threat during a medium (7-12min) endurance event. This builds on the gap in the literature around this length of event that was identified in the previous systematic review and meta-analysis. The outcomes of this study show that it is likely that participants were able to set off with a similar pacing strategy and that the future impact of threat from the environment was not enough to cause a performance change over this length of event. Using deception within the study design of the randomised cross-over trial also allowed for the exploration of cortical processing of perception and its

impact on pacing and performance. Exploratory analysis of the perceptual results of this study found that there was a significantly increased perception of thermal discomfort (raised thermal comfort and thermal sensation values) and a non-significant, but *large* increased effect size on RPE when participants were deceived that they were running in a warmer environment than the actual temperature. While this did not change performance or pacing, this demonstrated that perception of effort may be influenced by cortical processes.

4.3 Future Research

One of the main themes of this thesis was the exploration of cortical processing involved in fatigue when faced with a future 'threat'. Further consideration of the impact of the brains influence as the moderator of pacing and performance would provide valuable information and allow for targeted interventions within elite sports for optimising performance in endurance events. In exploring avenues for future research directions, fatigue research can look to other science arenas that explore threats to cellular homeostasis.

An area that has led the way with researching central cortical involvement in human behaviour is the pain sciences. In the movement from a historical view of pain being directly related to tissue damage (4), to now incorporating the whole cortical neuromatrix in the experience of pain (6-8), the pain sciences have opened up new and exciting areas of research. The concept of a central cortical neuromatrix acknowledges the influence of 'context, company, competitive stimuli and meaning' (8) and follows the hypothesis that perceived pain levels are a measure of the threat to the person based on the outcome of these interactive elements. This conceptualisation of pain being a defensive measure to protect draws striking similarities to the study of fatigue, as fatigue can be viewed as the protective output from the brain in response to perceived or real harm. The concept of fatigue being a

protective mechanism is not new and in fact was postulated by Mosso in 1891 (113) but until recently has not been used in popular definitions of fatigue (114). It then follows that future research should be targeted at the same influences as those that shape pain – context, company, competitive stimuli and meaning (8).

In assessing the elements of fatigue, the initial defining of fatigue created challenges due to the numerous competing models of fatigue (115). This created complexities in refining the search strategy for the systematic review as well as creating an appropriate deception task for the randomised cross-over trial. Further to these design implementation challenges, the interpretation of results was muddied due to the numerous models of fatigue. An example of this is that the lack of performance change in the randomised cross-over trial can be interpreted as a proving of a physiological model of peripheral-based fatigue. Under this model, the lack of performance change in both deception groups would be explained due to both groups having similar physiological demands despite the perceptual differences. Conversely, using the motivational intensity model, it could be argued that the motivation to continue outweighed the increased perceptual challenges brought about by the deception and hence created a lack of change in performance over this duration of event. To further the study of fatigue, therefore, the definition of fatigue must be addressed adequately.

Within the elite sports setting, fatigue is commonly studied at the neuromuscular level with the definition of fatigue being described as the decrease in performance that occurs after prolonged vigorous exercise (114). Recently, exploration of cortical aspects of fatigue have included elements of motivational theory. In a paper on defining fatigue, Kuppuswamy (116) described fatigue as a decrease in the activational system of motivation and described fatigue as a sensory percept. This describes fatigue as being a decrease in the self-initiated ability to act or perform an activity despite having the interest to do so. In exploring motivational aspects of fatigue definitions, research has started to push towards emotional influences on

fatigue in athletes. Further, with the recent shift towards central cortical definitions of fatigue, 'mental fatigue' has had increasing interest with multiple studies and reviews exploring this aspect of fatigue on aerobic performance and skill execution (117-119). This evolution of fatigue definitions has allowed for the ongoing exploration into these areas and needs to be further refined to include the 'threat neuromatrix' and continue to drive future research into avenues to enhance performance in elite sports settings.

With the evolution of our understanding of central cortical influences on fatigue in elite sports settings, the complex and potentially bidirectional relationship between mood and fatigue has come under increasingly scrutiny in the past decade. The impact of depression (120, 121), anxiety (122, 123) and stress (124, 125) have been reported in the literature as having a bi-directional relationship with *pain* in the neuromatrix model. However, the direct influence of mental health issues on *fatigue* and performance appears to have had limited research. Golding et al, (126) estimated that one-in-four high performance athletes (23.7%) may be suffering from depression. In a study of elite rugby league players in Australia, Du Preez et al, (127) found that generalized anxiety disorder had a prevalence of 14.6% and depression 12.6% in the pre-season. Within a 'threat' neuromatrix model of fatigue, this area of research warrants further attention. A study by Govus et al, in 2018 (128), found that subjective wellness measures taken prior to training sessions could predict the amount of perceived effort throughout a session as rated on an RPE scale. In a review on broad 'performance outcomes' in sports, Lochbaum et al, (129) found a negative impact of mental health on performance. Due to the performance-based nature of elite sports, a direct, causal link between mood state and performance outcome would be of significant interest. Combined with a general lack of research into the direct relationship between the key pillars of depression, anxiety and stress on fatigue states and therefore performance outcomes, there remains significant scope for future research into this field of study.

4.4 Conclusions

This thesis demonstrates the impact of environmental challenges on pacing and performance. This builds on previous models of fatigue that centre around perceived threats to cellular harm, and explores impacts on short-to-medium distance events. Through this thesis, it was observed that unfamiliar hot environments led to inefficient changes in pacing strategies. Further, it was found that perceptual influences could be modified through deception without an influence on overall performance and it was hypothesised that over longer distances, these influences would likely start to modify performance.

References

1. Swart J, Lamberts RP, Lambert MI, St Clair Gibson A, Lambert EV, Skowno J, et al. Exercising with reserve: evidence that the central nervous system regulates prolonged exercise performance. Br J Sports Med. 2009;43(10):782-8. Epub 20081203. doi: 10.1136/bjsm.2008.055889. PubMed PMID: 19052141.

2. Noakes TD, Peltonen JE, Rusko HK. Evidence that a central governor regulates exercise performance during acute hypoxia and hyperoxia. Journal of Experimental Biology. 2001;204(18):3225-34.

3. El Helou N, Tafflet M, Berthelot G, Tolaini J, Marc A, Guillaume M, et al. Impact of environmental parameters on marathon running performance. PLoS One. 2012;7(5):e37407. Epub 20120523. doi: 10.1371/journal.pone.0037407. PubMed PMID: 22649525; PubMed Central PMCID: PMC3359364.

4. Descartes's R. The treatise of man (De homine) by rené descartes. JR Coll Physicians Edinb. 2009;39:375-6.

5. Melzack R, Wall PD. Pain Mechanisms: A New Theory: A gate control system modulates sensory input from the skin before it evokes pain perception and response. Science. 1965;150(3699):971-9.

6. Melzack R. Phantom limbs and the concept of a neuromatrix. Trends in neurosciences. 1990;13(3):88-92.

7. Moseley GL, Gallace A, Spence C. Bodily illusions in health and disease: physiological and clinical perspectives and the concept of a cortical 'body matrix'. Neuroscience & Biobehavioral Reviews. 2012;36(1):34-46.

8. Moseley GL. A pain neuromatrix approach to patients with chronic pain. Manual therapy. 2003;8(3):130-40.

9. Moseley GL, Butler DS. Fifteen years of explaining pain: the past, present, and future. The Journal of Pain. 2015;16(9):807-13.

10. Hill AV, Long C, Lupton H. Muscular exercise, lactic acid and the supply and utilisation of oxygen.—Parts VII–VIII. Proceedings of the Royal Society of London Series B, Containing Papers of a Biological Character. 1924;97(682):155-76.

11. Hill AV, Long C, Lupton H. Muscular exercise, lactic acid, and the supply and utilisation of oxygen.—Parts IV-VI. Proceedings of the Royal Society of London Series B, containing papers of a biological character. 1924;97(681):84-138.

12. Hill AV, Long C, Lupton H. Muscular exercise, lactic acid, and the supply and utilisation of oxygen.—Parts l-lll. Proceedings of the Royal Society of London Series B, Containing Papers of a Biological Character. 1924;96(679):438-75.

13. Hill AV. Croonian Lecture:—The laws of muscular motion. Proceedings of the Royal Society of London Series B, Containing Papers of a Biological Character. 1926;100(701):87-108.

14. Ulmer HV. Perceived Exertion as a Part of a Feedback System and its Interaction with Tactical Behaviour in Endurance Sports. In: Borg G, Ottoson D, editors. The Perception of Exertion in Physical Work: Proceedings of an International Symposium held at The Wenner-Gren Center, Stockholm, October 3rd – 5th, 1985. London: Palgrave Macmillan UK; 1986. p. 317-26.

15. Noakes TD. Challenging beliefs: ex Africa semper aliquid novi. Medicine and Science in Sports and Exercise. 1997;29:571-90.

16. Lamb KL, Eston RG, Corns D. Reliability of ratings of perceived exertion during progressive treadmill exercise. British journal of sports medicine. 1999;33(5):336-9.

17. Chen MJ, Fan X, Moe ST. Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: a meta-analysis. Journal of sports sciences. 2002;20(11):873-99.

18. Noakes TD. Maximal oxygen uptake:" classical" versus" contemporary" viewpoints: a rebuttal. Medicine and science in sports and exercise. 1998;30:1381-98.

19. Noakes T. Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. Scandinavian Journal of Medicine & Science in Sports: Review Article. 2000;10(3):123-45.

20. Noakes TD, St Clair Gibson A, Lambert EV. From catastrophe to complexity: a novel model of integrative central neural regulation of effort and fatigue during exercise in humans. Br J Sports Med. 2004;38(4):511-4. doi: 10.1136/bjsm.2003.009860. PubMed PMID: 15273198; PubMed Central PMCID: PMC1724894.

21. Lambert E, Gibson ASC, Noakes T. Complex systems model of fatigue: integrative homoeostatic control of peripheral physiological systems during exercise in humans. British journal of sports medicine. 2005;39(1):52-62.

22. Wright RA. Refining the prediction of effort: Brehm's distinction between potential motivation and motivation intensity. Social and Personality Psychology Compass. 2008;2(2):682-701.

23. Marcora SM, Staiano W. The limit to exercise tolerance in humans: mind over muscle? European journal of applied physiology. 2010;109(4):763-70.

24. Micklewright D, Kegerreis S, Raglin J, Hettinga F. Will the conscious–subconscious pacing quagmire help elucidate the mechanisms of self-paced exercise? New opportunities in dual process theory and process tracing methods. Sports Medicine. 2017;47(7):1231-9.

25. Renfree A, Martin L, Micklewright D, St Clair Gibson A. Application of decision-making theory to the regulation of muscular work rate during self-paced competitive endurance activity. Sports Med. 2014;44(2):147-58. doi: 10.1007/s40279-013-0107-0. PubMed PMID: 24113898.

26. Ulmer HV. Concept of an extracellular regulation of muscular metabolic rate during heavy exercise in humans by psychophysiological feedback. Experientia. 1996;52(5):416-20. doi: 10.1007/BF01919309. PubMed PMID: 8641377.

27. Baden DA, Warwick-Evans L, Lakomy J. Am I nearly there? The effect of anticipated running distance on perceived exertion and attentional focus. Journal of Sport and Exercise Psychology. 2004;26(2):215-31.

28. Tucker R, Marle T, Lambert EV, Noakes TD. The rate of heat storage mediates an anticipatory reduction in exercise intensity during cycling at a fixed rating of perceived exertion. J Physiol. 2006;574(Pt 3):905-15. Epub 20060223. doi: 10.1113/jphysiol.2005.101733. PubMed PMID: 16497719; PubMed Central PMCID: PMC1817748.

29. Renfree A. Determinants of Pacing Decisions in Competitive Endurance Activity: University of Worcester; 2017.

30. Blagden C. XII. Experiments and observations in an heated room. Philosophical transactions of the Royal Society of London. 1775(65):111-23.

31. Blagden C. XLVII. Further experiments and observations in an heated room. Philosophical Transactions of the Royal Society of London. 1775(65):484-94.

32. Hancock PA, Ross JM, Szalma JL. A meta-analysis of performance response under thermal stressors. Human factors. 2007;49(5):851-77.

33. Wallace PJ, McKinlay BJ, Coletta NA, Vlaar JI, Taber MJ, Wilson PM, et al. Effects of Motivational Self-Talk on Endurance and Cognitive Performance in the Heat. Med Sci Sports Exerc. 2017;49(1):191-9. doi: 10.1249/MSS.0000000000001087. PubMed PMID: 27580154.

34. Barwood M, Thelwell R, Tipton M. Psychological skills training improves exercise performance in the heat. Medicine+ Science in Sports+ Exercise. 2008;40(2):387.

35. Castle PC, Maxwell N, Allchorn A, Mauger AR, White DK. Deception of ambient and body core temperature improves self paced cycling in hot, humid conditions. Eur J Appl Physiol. 2012;112(1):377-85. Epub 20110515. doi: 10.1007/s00421-011-1988-y. PubMed PMID: 21573777.

36. Jones HS, Williams EL, Bridge CA, Marchant D, Midgley AW, Micklewright D, et al. Physiological and psychological effects of deception on pacing strategy and performance: a review. Sports Med. 2013;43(12):1243-57. doi: 10.1007/s40279-013-0094-1. PubMed PMID: 24002790.

37. Roelands B, Meeusen R. Alterations in central fatigue by pharmacological manipulations of neurotransmitters in normal and high ambient temperature. Sports Medicine. 2010;40(3):229-46.

38. Cordery P, Peirce N, Maughan R, Watson P. Dopamine/noradrenaline reuptake inhibition in women improves endurance exercise performance in the heat. Scandinavian Journal of Medicine & Science in Sports. 2017;27(11):1221-30.

39. Abbiss CR, Laursen PB. Describing and understanding pacing strategies during athletic competition. Sports Med. 2008;38(3):239-52. doi: 10.2165/00007256-200838030-00004. PubMed PMID: 18278984.

40. Capostagno B. 'Endurance Training - Science and Practice' - Iñigo Mujika. South African Journal of Sports Medicine. 2012;24:131.

41. Ely MR, Martin DE, Cheuvront SN, Montain SJ. Effect of ambient temperature on marathon pacing is dependent on runner ability. Med Sci Sports Exerc. 2008;40(9):1675-80. doi: 10.1249/MSS.0b013e3181788da9. PubMed PMID: 18685522.

42. Marino FE. Reduced power output in self-paced exercise in the heat is due to thermal and cardiovascular strain but improvements are not? J Appl Physiol (1985). 2022;132(5):1318. doi: 10.1152/japplphysiol.00156.2022. PubMed PMID: 35587116.

43. Edwards AM, Polman RC. Pacing and awareness: brain regulation of physical activity. Sports Med. 2013;43(11):1057-64. doi: 10.1007/s40279-013-0091-4. PubMed PMID: 23990402.

44. Noakes TD, Calbet JA, Boushel R, Søndergaard H, Rådegran G, Wagner PD, et al. Central regulation of skeletal muscle recruitment explains the reduced maximal cardiac output during exercise in hypoxia. Am J Physiol Regul Integr Comp Physiol. 2004;287(4):R996-9; author reply R9-1002. doi: 10.1152/ajpregu.00608.2003. PubMed PMID: 15371281.

45. St Clair Gibson A, Noakes TD. Evidence for complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans. Br J Sports Med. 2004;38(6):797-806. doi: 10.1136/bjsm.2003.009852. PubMed PMID: 15562183; PubMed Central PMCID: PMC1724966.

46. Periard JD, Eijsvogels TMH, Daanen HAM. Exercise under heat stress: thermoregulation, hydration, performance implications, and mitigation strategies. Physiological Reviews. 2021;101(4):1873-979. doi: 10.1152/physrev.00038.2020. PubMed PMID: WOS:000697337800009.

47. Cheuvront SN, Kenefick RW, Montain SJ, Sawka MN. Mechanisms of aerobic performance impairment with heat stress and dehydration. J Appl Physiol (1985). 2010;109(6):1989-95. Epub 20100805. doi: 10.1152/japplphysiol.00367.2010. PubMed PMID: 20689090.

48. Girard O, Brocherie F, Bishop DJ. Sprint performance under heat stress: A review. Scand J Med Sci Sports. 2015;25 Suppl 1:79-89. doi: 10.1111/sms.12437. PubMed PMID: 25943658.

49. Junge N, Jørgensen R, Flouris AD, Nybo L. Prolonged self-paced exercise in the heat - environmental factors affecting performance. Temperature (Austin). 2016;3(4):539-48.

Epub 20160815. doi: 10.1080/23328940.2016.1216257. PubMed PMID: 28090557; PubMed Central PMCID: PMC5198812.

50. Racinais S, Périard JD, Karlsen A, Nybo L. Effect of heat and heat acclimatization on cycling time trial performance and pacing. Med Sci Sports Exerc. 2015;47(3):601-6. doi: 10.1249/MSS.0000000000000428. PubMed PMID: 24977692; PubMed Central PMCID: PMC4342312.

51. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann T, Mulrow CD, et al. Mapping of reporting guidance for systematic reviews and meta-analyses generated a comprehensive item bank for future reporting guidelines. J Clin Epidemiol. 2020;118:60-8. Epub 20191115. doi: 10.1016/j.jclinepi.2019.11.010. PubMed PMID: 31740319.

52. Drevon D, Fursa SR, Malcolm AL. Intercoder Reliability and Validity of WebPlotDigitizer in Extracting Graphed Data. Behav Modif. 2017;41(2):323-39. Epub 20161022. doi: 10.1177/0145445516673998. PubMed PMID: 27760807.

53. Aydin O, Yassikaya MY. Validity and Reliability Analysis of the PlotDigitizer Software Program for Data Extraction from Single-Case Graphs. Perspect Behav Sci. 2022;45(1):239-57. Epub 20210331. doi: 10.1007/s40614-021-00284-0. PubMed PMID: 35342869; PubMed Central PMCID: PMC8894524.

54. Périard JD, Racinais S. Heat stress exacerbates the reduction in middle cerebral artery blood velocity during prolonged self-paced exercise. Scand J Med Sci Sports. 2015;25 Suppl 1:135-44. doi: 10.1111/sms.12379. PubMed PMID: 25943664.

55. Périard JD, Racinais S. Performance and Pacing during Cycle Exercise in Hyperthermic and Hypoxic Conditions. Med Sci Sports Exerc. 2016;48(5):845-53. doi: 10.1249/MSS.0000000000000839. PubMed PMID: 26656777.

56. Tucker R, Noakes TD. The physiological regulation of pacing strategy during exercise: a critical review. Br J Sports Med. 2009;43(6):e1. Epub 20090217. doi: 10.1136/bjsm.2009.057562. PubMed PMID: 19224909.

57. Cumpston M, Li T, Page MJ, Chandler J, Welch VA, Higgins JP, et al. Updated guidance for trusted systematic reviews: a new edition of the Cochrane Handbook for Systematic Reviews of Interventions. Cochrane Database Syst Rev. 2019;10(10.1002):14651858.

58. Flemyng E, Dwan K, Moore TH, Page MJ, Higgins JP. Risk of bias 2 in Cochrane reviews: a phased approach for the introduction of new methodology. Cochrane Database of Systematic Reviews. 2020(10).

59. Hedges LV. Distribution theory for Glass's estimator of effect size and related estimators. journal of Educational Statistics. 1981;6(2):107-28.

60. Viechtbauer W. Bias and efficiency of meta-analytic variance estimators in the random-effects model. Journal of Educational and Behavioral Statistics. 2005;30(3):261-93.

61. Cohen J. The effect size. Statistical power analysis for the behavioral sciences. 1988:77-83.

62. Hartung J, Knapp G. A refined method for the meta-analysis of controlled clinical trials with binary outcome. Statistics in medicine. 2001;20(24):3875-89.

63. IntHout J, Ioannidis J, Borm GF. The Hartung-Knapp-Sidik-Jonkman method for random effects meta-analysis is straightforward and considerably outperforms the standard DerSimonian-Laird method. BMC medical research methodology. 2014;14(1):1-12.

64. Langan D, Higgins JP, Jackson D, Bowden J, Veroniki AA, Kontopantelis E, et al. A comparison of heterogeneity variance estimators in simulated random-effects meta-analyses. Research synthesis methods. 2019;10(1):83-98.

65. Egger M, Higgins JP, Smith GD. Systematic reviews in health research: Meta-analysis in context: John Wiley & Sons; 2022.

66. Stewart C, Whyte DG, Cannon J, Wickham J, Marino FE. Exercise-induced dehydration does not alter time trial or neuromuscular performance. International journal of sports medicine. 2014;35(09):725-30.

67. de Paula Viveiros J, Amorim F, Alves M, Passos R, Meyer F. Run performance of middle-aged and young adult runners in the heat. International journal of sports medicine. 2012;33(03):211-7.

68. Barwood MJ, Corbett J, White D, James J. Early change in thermal perception is not a driver of anticipatory exercise pacing in the heat. British journal of sports medicine. 2012;46(13):936-42.

69. Faulkner S, Hupperets M, Hodder S, Havenith G. Conductive and evaporative precooling lowers mean skin temperature and improves time trial performance in the heat. Scandinavian journal of medicine & science in sports. 2015;25:183-9.

70. Abbiss CR, Burnett A, Nosaka K, Green JP, Foster JK, Laursen PB. Effect of hot versus cold climates on power output, muscle activation, and perceived fatigue during a dynamic 100-km cycling trial. Journal of Sports Sciences. 2010;28(2):117-25.

71. Périard JD, Cramer MN, Chapman PG, Caillaud C, Thompson MW. Cardiovascular strain impairs prolonged self-paced exercise in the heat. Experimental physiology. 2011;96(2):134-44.

72. Periard JD, Racinais S. Performance and pacing during cycle exercise in hyperthermic and hypoxic conditions. Med Sci Sports Exerc. 2016;48(5):845-53.

73. Schmit C, Duffield R, Hausswirth C, Coutts AJ, Le Meur Y. Pacing adjustments associated with familiarization: heat versus temperate environments. International journal of sports physiology and performance. 2016;11(7):855-60.

74. Taylor L, Mauger AR, Watkins SL, Fitch N, Brewer J, Maxwell NS, et al. Precooling does not improve 2,000-m rowing performance of females in hot, humid conditions. The Journal of Strength & Conditioning Research. 2014;28(12):3416-24.

75. Tucker R, Rauch L, Harley YX, Noakes TD. Impaired exercise performance in the heat is associated with an anticipatory reduction in skeletal muscle recruitment. Pflügers Archiv. 2004;448(4):422-30.

76. Bright FM, Clark B, Jay O, Périard JD. The effect of minimal differences in the skin-to-air vapor pressure gradient at various dry-bulb temperatures on self-paced exercise performance. J Appl Physiol (1985). 2021;131(3):1176-85. Epub 20210729. doi: 10.1152/japplphysiol.01059.2020. PubMed PMID: 34323591.

77. Marino FE, Lambert MI, Noakes TD. Superior performance of African runners in warm humid but not in cool environmental conditions. Journal of applied physiology. 2004;96(1):124-30.

78. Tucker R. The anticipatory regulation of performance: the physiological basis for pacing strategies and the development of a perception-based model for exercise performance. British journal of sports medicine. 2009;43(6):392-400.

79. Davies MJ, Clark B, Welvaert M, Skorski S, Garvican-Lewis LA, Saunders P, et al. Effect of environmental and feedback interventions on pacing profiles in cycling: a meta-analysis. Frontiers in Physiology. 2016;7:591.

80. Tatterson AJ, Hahn AG, Martini DT, Febbraio MA. Effects of heat stress on physiological responses and exercise performance in elite cyclists. Journal of Science and Medicine in Sport. 2000;3(2):186-93.

81. Rupp T, Saugy JJ, Bourdillon N, Millet GP. Brain-muscle interplay during endurance self-paced exercise in normobaric and hypobaric hypoxia. Frontiers in physiology. 2022:1683.

82. Bradbury KE, Coffman KE, Mitchell KM, Luippold AJ, Fulco CS, Kenefick RW. Separate and combined influences of heat and hypobaric hypoxia on self-paced aerobic exercise performance. Journal of Applied Physiology. 2019;127(2):513-9.

83. Abel A, Baron B, Grappe F, Francaux M. Effect of environmental feedbacks on pacing strategy and affective load during a self-paced 30 min cycling time trial. Journal of sports sciences. 2019;37(3):291-7.

84. Renfree A, Casado A. Athletic races represent complex systems, and pacing behavior should be viewed as an emergent phenomenon. Frontiers in physiology. 2018;9:1432.

85. Foster C, de Koning JJ, Bischel S, Casolino E, Malterer K, O'Brien K, et al. Pacing strategies for endurance performance. Endurance training, science and practice. 2012;1:85-97.

86. Adams WM, Hosokawa Y, Belval LN, Huggins RA, Stearns RL, Casa DJ. Deviation from goal pace, body temperature and body mass loss as predictors of road race performance. Journal of Science and Medicine in Sport. 2017;20(3):302-6.

87. Santos-Lozano A, Collado P, Foster C, Lucia A, Garatachea N. Influence of sex and level on marathon pacing strategy. Insights from the New York City race. International journal of sports medicine. 2014;35(11):933-8.

88. Díaz JJ, Fernández-Ozcorta EJ, Santos-Concejero J. The influence of pacing strategy on marathon world records. European journal of sport science. 2018;18(6):781-6.

89. Pageaux B. The psychobiological model of endurance performance: an effort-based decision-making theory to explain self-paced endurance performance. Sports Medicine. 2014;44(9):1319.

90. Van Cutsem J, Roelands B, De Pauw K, Meeusen R, Marcora S. Subjective thermal strain impairs endurance performance in a temperate environment. Physiology & behavior. 2019;202:36-44.

91. English T, Mavros Y, Jay O. Listening to motivational music mitigates heat-related reductions in exercise performance. Physiol Behav. 2019;208:112567. Epub 20190604. doi: 10.1016/j.physbeh.2019.112567. PubMed PMID: 31173785.

92. Corbett J, White DK, Barwood MJ, Wagstaff CRD, Tipton MJ, McMorris T, et al. The Effect of Head-to-Head Competition on Behavioural Thermoregulation, Thermophysiological Strain and Performance During Exercise in the Heat. Sports Med. 2018;48(5):1269-79. doi: 10.1007/s40279-017-0816-x. PubMed PMID: 29147922; PubMed Central PMCID: PMC5889783.

93. Hartley GL, Flouris AD, Plyley MJ, Cheung SS. The effect of a covert manipulation of ambient temperature on heat storage and voluntary exercise intensity. Physiol Behav. 2012;105(5):1194-201. Epub 20111229. doi: 10.1016/j.physbeh.2011.12.017. PubMed PMID: 22226992.

94. Williamson JW, McColl R, Mathews D, Mitchell JH, Raven PB, Morgan WP. Hypnotic manipulation of effort sense during dynamic exercise: cardiovascular responses and brain activation. J Appl Physiol (1985). 2001;90(4):1392-9. doi: 10.1152/jappl.2001.90.4.1392. PubMed PMID: 11247939.

95. Emanuel A. Perceived Impact as the Underpinning Mechanism of the End-Spurt and U-Shape Pacing Patterns. Front Psychol. 2019;10:1082. Epub 20190508. doi: 10.3389/fpsyg.2019.01082. PubMed PMID: 31139122; PubMed Central PMCID: PMC6519309.

96. de Koning JJ, Foster C, Bakkum A, Kloppenburg S, Thiel C, Joseph T, et al. Regulation of pacing strategy during athletic competition. PLoS One. 2011;6(1):e15863. Epub 20110120. doi: 10.1371/journal.pone.0015863. PubMed PMID: 21283744; PubMed Central PMCID: PMC3024328.

97. Waldron M, Villerius V, Murphy A. Augmenting performance feedback does not affect 4 km cycling time-trials in the heat. J Sports Sci. 2015;33(8):786-94. Epub 20141114. doi: 10.1080/02640414.2014.962579. PubMed PMID: 25397352.

98. Spencer M, Bishop D, Dawson B, Goodman C. Physiological and metabolic responses of repeated-sprint activities:specific to field-based team sports. Sports Med. 2005;35(12):1025-44. doi: 10.2165/00007256-200535120-00003. PubMed PMID: 16336007.

99. Billaut F, Bishop DJ, Schaerz S, Noakes TD. Influence of knowledge of sprint number on pacing during repeated-sprint exercise. Med Sci Sports Exerc. 2011;43(4):665-72. doi: 10.1249/MSS.0b013e3181f6ee3b. PubMed PMID: 20798658.

100. Sawka MN, Leon LR, Montain SJ, Sonna LA. Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. Compr Physiol. 2011;1(4):1883-928. doi: 10.1002/cphy.c100082. PubMed PMID: 23733692.

101. Nybo L, Rasmussen P, Sawka MN. Performance in the heat-physiological factors of importance for hyperthermia-induced fatigue. Compr Physiol. 2014;4(2):657-89. doi: 10.1002/cphy.c130012. PubMed PMID: 24715563.

102. Gabriel BM, Zierath JR. Circadian rhythms and exercise - re-setting the clock in metabolic disease. Nat Rev Endocrinol. 2019;15(4):197-206. doi: 10.1038/s41574-018-0150-x. PubMed PMID: 30655625.

103. Ramanathan NL. A new weighting system for mean surface temperature of the human body. J Appl Physiol. 1964;19:531-3. doi: 10.1152/jappl.1964.19.3.531. PubMed PMID: 14173555.

104. Borg G. Borg's perceived exertion and pain scales: Human kinetics; 1998.

105. Schweiker M, Fuchs X, Becker S, Shukuya M, Dovjak M, Hawighorst M, et al. Challenging the assumptions for thermal sensation scales Building Research & Information. 2017;45(5):572-89. doi: 10.1080/09613218.2016.1183185.

106. Wilkinson DM, Carter JM, Richmond VL, Blacker SD, Rayson MP. The effect of cool water ingestion on gastrointestinal pill temperature. Medicine & Science in Sports & Exercise. 2008;40(3):523-8.

107. Miles J, Shevlin M. Applying regression and correlation: A guide for students and researchers: Sage; 2001.

108. Tyler CJ, Reeve T, Hodges GJ, Cheung SS. The Effects of Heat Adaptation on Physiology, Perception and Exercise Performance in the Heat: A Meta-Analysis. Sports Med. 2016;46(11):1699-724. doi: 10.1007/s40279-016-0538-5. PubMed PMID: 27106556.

109. Ely BR, Cheuvront SN, Kenefick RW, Sawka MN. Aerobic performance is degraded, despite modest hyperthermia, in hot environments. Med Sci Sports Exerc. 2010;42(1):135-41. doi: 10.1249/MSS.0b013e3181adb9fb. PubMed PMID: 20010120.

110. Micklewright D, Papadopoulou E, Swart J, Noakes T. Previous experience influences pacing during 20 km time trial cycling. Br J Sports Med. 2010;44(13):952-60. Epub 20090412. doi: 10.1136/bjsm.2009.057315. PubMed PMID: 19364755.

111. Hopkins WG, Hewson DJ. Variability of competitive performance of distance runners. Med Sci Sports Exerc. 2001;33(9):1588-92. doi: 10.1097/00005768-200109000-00023. PubMed PMID: 11528349.

112. Jeukendrup A, Saris WH, Brouns F, Kester AD. A new validated endurance performance test. Med Sci Sports Exerc. 1996;28(2):266-70. doi: 10.1097/00005768-199602000-00017. PubMed PMID: 8775164.

113. Mosso A. L'educazione fisica ei giuochi nelle scuole. Nuova Antologia. 1891;120.

114. Marino FE. Human fatigue: Evolution, health and performance: Routledge; 2019.

115. Eichner ER. The faces of fatigue. Current Sports Medicine Reports. 2011;10(2):56-7.

116. Kuppuswamy A. The fatigue conundrum. Brain. 2017;140(8):2240-5.

117. Brownsberger J, Edwards A, Crowther R, Cottrell D. Impact of mental fatigue on self-paced exercise. International Journal of Sports Medicine. 2013;34(12):1029-36.

118. Pageaux B, Lepers R. The effects of mental fatigue on sport-related performance. Progress in brain research. 2018;240:291-315.

119. Russell S, Jenkins D, Rynne S, Halson SL, Kelly V. What is mental fatigue in elite sport? Perceptions from athletes and staff. European journal of sport science. 2019;19(10):1367-76.

120. Kroenke K, Wu J, Bair MJ, Krebs EE, Damush TM, Tu W. Reciprocal relationship between pain and depression: a 12-month longitudinal analysis in primary care. The Journal of Pain. 2011;12(9):964-73.

121. Bourke JH, Langford RM, White PD. The common link between functional somatic syndromes may be central sensitisation. Journal of psychosomatic research. 2015;78(3):228-36.

122. Louw A, Diener I, Butler DS, Puentedura EJ. The effect of neuroscience education on pain, disability, anxiety, and stress in chronic musculoskeletal pain. Archives of physical medicine and rehabilitation. 2011;92(12):2041-56.

123. Pinto PR, McIntyre T, Almeida A, Araújo-Soares V. The mediating role of pain catastrophizing in the relationship between presurgical anxiety and acute postsurgical pain after hysterectomy. Pain. 2012;153(1):218-26.

124. Burmistr I. Theories of pain, up to Descartes and after neuromatrix: what role do they have to develop future paradigms? Pain medicine. 2018;3(1):6-12.

125. Garland EL. Pain processing in the human nervous system: a selective review of nociceptive and biobehavioral pathways. Primary Care: Clinics in Office Practice. 2012;39(3):561-71.

126. Golding L, Gillingham RG, Perera NKP. The prevalence of depressive symptoms in high-performance athletes: A systematic review. The Physician and Sportsmedicine. 2020;48(3):247-58.

127. Du Preez EJ, Graham KS, Gan TY, Moses B, Ball C, Kuah DE. Depression, anxiety, and alcohol use in elite rugby league players over a competitive season. Clinical Journal of Sport Medicine. 2017;27(6):530-5.

128. Govus AD, Coutts A, Duffield R, Murray A, Fullagar H. Relationship between pretraining subjective wellness measures, player load, and rating-of-perceived-exertion training load in American college football. International journal of sports physiology and performance. 2018;13(1):95-101.

129. Lochbaum M, Zanatta T, Kirschling D, May E. The Profile of Moods States and athletic performance: A meta-analysis of published studies. European Journal of Investigation in Health, Psychology and Education. 2021;11(1).

Appendices

Appendix A. Medline Search Strategy

Line	Search Expression
#1	Hot Temperature/
#2	exp Heat Stress Disorders/
#3	Body Temperature/
#4	(environment* or ambient*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
#5	(temperature? or heat or heated or heating or hot or over?heat*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
#6	4 and 5
#7	(heat exhaust* or heat stroke or heat?stroke or sun stroke or sun?stroke).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept

word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]

#8 1 or 2 or 3 or 6 or 7

#9 Athletes/

#10 Sports/

#11 exp Exercise/

#12 (Exerci* or run or ran or running or physical* condition* or training or cool????down or warm????up or sport* or athlet*).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]

#13 9 or 10 or 11 or 12

#14 8 and 13

#15 (pacing or pace* or anticipat* or feed?forward or pre?emptive* or predict* or teleo?anticipat* or central governor model?).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary

concept word, rare disease supplementary concept word, unique identifier, synonyms]

#16 14 and 15

#17 limit 16 to animals

#18 limit 16 to humans

#19 16 not 17

#20 18 or 19

Appendix B: Cricket Australia Rehydration Guidelines

Hydration Leading into a Match

Evening Before:

- 600ml water with evening meal; AND an additional 600ml water with 3 x sachets of Hydralyte or with 1 x Shotz tablet before going to bed if you have a high sweat rate

Morning of the Match - Team Hotel / Changerooms:

- USG test and re-hydrate as per guidelines below.
- If your USG is 1.020 or over, you are dehydrated.

At Ground:

- Replace 1.5 x weight lost during warm-up (e.g. if 300 g lost during warm-up, consume 450 mL fluid before start of play)

1.020 - 1.023:

- Add 3 sachets Hydralyte or 1 x Shotz tablet to 600 ml water ***OR*** consume 600 ml of fluid while having breakfast containing moderate-high sodium foods* (e.g.: vegemite on toast or breakfast cereal e.g. weetbix, UT Antioxidant Plus, Plus Protein) & consume
- Drink (sip on) another 500 ml of fluid (any) before the match

1.024 - 1.031:

- Add 4 sachets of Hydralyte or 1.5 Shotz tablets to 800 ml water & consume
- Drink (sip on) another 700 ml of fluid (any) before the match

1.031 and above:

- Add 5 sachet Hydralyte, or 2 Shotz tablets to 1000 ml water & consume
- Drink (sip on) another 1000 ml of fluid (any) before the match

This fluid should be consumed over time (over a number of hours if necessary), not 'skulled down' quickly.

- *Consuming foods that contain sodium (salt) helps stimulate thirst and retains the consumed fluids e.g. bread, dairy such as low-fat milk and cheese, canned tuna, vegetable juice, pretzels, salted nuts, salty biscuits (Pekish, Sakatas).

SACA Nutrition 2018/19

Appendix C: Consent Form

This project has been approved by the University of South Australia's Human Research Ethics Committee. If you have any ethical concerns about the project or questions about your rights as a participant please contact

the Executive Officer of this Committee, Tel: +61 8 8302 3118; Email: humanethics@unisa.edu.au

SECTION 1: CONTACT AND PROJECT DETAILS

Researcher's Full Name:	James Wiltshire
[redacted]	[redacted]
Supervisor's Full Name:	Professor Lorimer Moseley
[redacted]	[redacted]
Protocol Number:	202265
Project Title:	Assessing the accuracy of human ambient temperature perception

SECTION 2: CERTIFICATION

Participant Certification

In signing this form, I confirm that:

- I have read the Participant Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part.
- I understand that this trial involves high intensity exercise in a heated environment and the risks associated with both high intensity exercise and as well as exercising in the heat.
- I understand the purpose of the research project and my involvement in it.
- I understand that participation in this study is voluntary and I am free to decline or withdraw from the research project without effecting my relationship with the researcher, the South Australian Cricket Association or the University of South Australia now or in the future. Withdrawal can occur anytime up to 14 days after a participation in a trial.

- I understand that while information gained during the study may be published, all efforts will be made to remove any information that might identify me, unless required by law. However, as the sample size is small, complete anonymity cannot be guaranteed.
- I understand that data will be securely stored for five years upon completion of the project, at the Body in Mind offices, City East Campus, RM C7-26A, University of South Australia. At the conclusion of the 5 year retention period, all data files stored on the Body in Mind server drive will be deleted. Physical files will be deleted once they have been scanned and saved securely onto the Body in Mind server drive.
- I understand that a full summary of results will be sent to me via electronic email at the completion of the project.

Participant Signature	*Printed Name*	*Date*

Researcher Certification		
I have explained the study to subject and consider that he/she understands what is involved.		
Researcher Signature	*Printed Name*	*Date*

Appendix D: Data Collection Sheet – Familiarisation

Participant number_____

Date_____

Data	**Collected**
Participant Information Sheet provided	Y / N
Consent Form Signed and collected	Y / N
APESS collected	Y / N
Demographics Questionnaire collected	Y / N
CorTemp Medical Questionnaire collected	Y / N

USG		
Weight		*3.2=
Height		
RPE (at rest) – should be 6		

On entering chamber

Thermal Comfort	
Thermal Sensation	

After self-stretches

Thermal Comfort	
Thermal Sensation	
HR	

At beginning of 1st 2kTT	**Time period**	**Data**
Distance	1 min	
Speed	1 min	
HR	1 min	
Distance	2 min	
Speed	2 min	
HR	2 min	
Thermal Comfort	2 min	
Thermal Sensation	2 min	
RPE	2 min	
Distance	3 min	
Speed	3 min	
HR	3 min	
Distance	4 min	
Speed	4 min	
HR	4 min	
Thermal Comfort	4 min	
Thermal Sensation	4 min	
RPE	4 min	
Distance	5 min	
Speed	5 min	
HR	5 min	
Distance	6 min	
Speed	6 min	
HR	6 min	

Thermal Comfort	6 min	
Thermal Sensation	6 min	
RPE	6 min	
Distance	7 min	
Speed	7 min	
HR	7 min	
Distance	8 min	
Speed	8 min	
HR	8 min	
Thermal Comfort	8 min	
Thermal Sensation	8 min	
RPE	8 min	
Distance	9 min	
Speed	9 min	
HR	9 min	
Distance	10 min	
Speed	10 min	
HR	10 min	
Thermal Comfort	10 min	
Thermal Sensation	10 min	
RPE	10 min	
Distance	11 min	
Speed	11 min	
HR	11 min	
Distance	12 min	
Speed	12 min	

HR	12 min	
Thermal Comfort	12 min	
Thermal Sensation	12 min	
RPE	12 min	
Thermal Comfort	Conclusion	
Thermal Sensation	Conclusion	
RPE	Conclusion	
Time to complete	Conclusion	

Amount to rehydrate	**3.2ml/Kg**	

Walk Interval	**Time period**	**Data**
HR	5 min	
Thermal Comfort	5 min	
Thermal Sensation	5 min	
RPE	5 min	
HR	10 min	
Thermal Comfort	10 min	
Thermal Sensation	10 min	
RPE	10 min	
HR	15 min	
Thermal Comfort	15 min	
Thermal Sensation	15 min	
RPE	15 min	
HR	20 min	
Thermal Comfort	20 min	
Thermal Sensation	20 min	
RPE	20 min	
HR	25 min	
Thermal Comfort	25 min	
Thermal Sensation	25 min	
RPE	25 min	

2nd 2kTT	**Time period**	**Data**
Distance	1 min	
Speed	1 min	
HR	1 min	
Distance	2 min	
Speed	2 min	
HR	2 min	
Thermal Comfort	2 min	
Thermal Sensation	2 min	
RPE	2 min	
Distance	3 min	
Speed	3 min	
HR	3 min	
Distance	4 min	
Speed	4 min	
HR	4 min	
Thermal Comfort	4 min	
Thermal Sensation	4 min	
RPE	4 min	
Distance	5 min	
Speed	5 min	
HR	5 min	
Distance	6 min	
Speed	6 min	
HR	6 min	

Thermal Comfort	6 min	
Thermal Sensation	6 min	
RPE	6 min	
Distance	7 min	
Speed	7 min	
HR	7 min	
Distance	8 min	
Speed	8 min	
HR	8 min	
Thermal Comfort	8 min	
Thermal Sensation	8 min	
RPE	8 min	
Distance	9 min	
Speed	9 min	
HR	9 min	
Distance	10 min	
Speed	10 min	
HR	10 min	
Thermal Comfort	10 min	
Thermal Sensation	10 min	
RPE	10 min	

Distance	11 min	
Speed	11 min	
HR	11 min	

Distance	12 min	
Speed	12 min	
HR	12 min	
Thermal Comfort	12 min	
Thermal Sensation	12 min	
RPE	12 min	
Thermal Comfort	Conclusion	
Thermal Sensation	Conclusion	
RPE	Conclusion	
Time to complete	Conclusion	

Post 2nd 2kTT

Weigh Out	

Appendix E: Data Collection Sheet – Trial 2 and 3

Participant number_____

Date_____

Data	**Collected**	
USG		
Weight		*3.2=
RPE (at rest) – should be 6		

On entering chamber

Thermal Comfort	
Thermal Sensation	

After self-stretches

Thermal Comfort	
Thermal Sensation	
HR	
CorTemp	

At beginning of 1st 2kTT	**Time period**	**Data**
Distance	1 min	
Speed	1 min	
HR	1 min	

CorTemp	1 min	
Distance	2 min	
Speed	2 min	
HR	2 min	
CorTemp	2 min	
Thermal Comfort	2 min	
Thermal Sensation	2 min	
RPE	2 min	
Distance	3 min	
Speed	3 min	
HR	3 min	
CorTemp	3 min	
Distance	4 min	
Speed	4 min	
HR	4 min	
CorTemp	4 min	
Thermal Comfort	4 min	
Thermal Sensation	4 min	
RPE	4 min	
Distance	5 min	
Speed	5 min	
HR	5 min	
CorTemp	5 min	
Distance	6 min	
Speed	6 min	
HR	6 min	

CorTemp	6 min	
Thermal Comfort	6 min	
Thermal Sensation	6 min	
RPE	6 min	
Distance	7 min	
Speed	7 min	
HR	7 min	
CorTemp	7 min	
Distance	8 min	
Speed	8 min	
HR	8 min	
CorTemp	8 min	
Thermal Comfort	8 min	
Thermal Sensation	8 min	
RPE	8 min	
Distance	9 min	
Speed	9 min	
HR	9 min	
CorTemp	9 min	
Distance	10 min	
Speed	10 min	
HR	10 min	
CorTemp	10 min	
Thermal Comfort	10 min	
Thermal Sensation	10 min	
RPE	10 min	

Distance	11 min	
Speed	11 min	
HR	11 min	
CorTemp	11 min	
Distance	12 min	
Speed	12 min	
HR	12 min	
CorTemp	12 min	
Thermal Comfort	12 min	
Thermal Sensation	12 min	
RPE	12 min	
Thermal Comfort	Conclusion	
Thermal Sensation	Conclusion	
RPE	Conclusion	
CorTemp	Conclusion	
Time to complete	Conclusion	

Amount to rehydrate	**3.2ml/Kg**	

Walk Interval	**Time period**	**Data**
HR	5 min	
Core Temp	5 min	
Thermal Comfort	5 min	
Thermal Sensation	5 min	
RPE	5 min	
HR	10 min	
Core Temp	10 min	
Thermal Comfort	10 min	
Thermal Sensation	10 min	
RPE	10 min	
HR	15 min	
Core Temp	15 min	
Thermal Comfort	15 min	
Thermal Sensation	15 min	
RPE	15 min	
HR	20 min	
Core Temp	20 min	
Thermal Comfort	20 min	
Thermal Sensation	20 min	
RPE	20 min	
HR	25 min	
Core Temp	25 min	
Thermal Comfort	25 min	

Thermal Sensation	25 min	
RPE	25 min	

2nd 2kTT	**Time period**	**Data**
Distance	1 min	
Speed	1 min	
HR	1 min	
CorTemp	1 min	
Distance	2 min	
Speed	2 min	
HR	2 min	
CorTemp	2 min	
Thermal Comfort	2 min	
Thermal Sensation	2 min	
RPE	2 min	
Distance	3 min	
Speed	3 min	
HR	3 min	
CorTemp	3 min	
Distance	4 min	
Speed	4 min	
HR	4 min	
CorTemp	4 min	
Thermal Comfort	4 min	
Thermal Sensation	4 min	
RPE	4 min	
Distance	5 min	
Speed	5 min	

HR	5 min	
CorTemp	5 min	
Distance	6 min	
Speed	6 min	
HR	6 min	
CorTemp	6 min	
Thermal Comfort	6 min	
Thermal Sensation	6 min	
RPE	6 min	
Distance	7 min	
Speed	7 min	
HR	7 min	
CorTemp	7 min	
Distance	8 min	
Speed	8 min	
HR	8 min	
CorTemp	8 min	
Thermal Comfort	8 min	
Thermal Sensation	8 min	
RPE	8 min	
Distance	9 min	
Speed	9 min	
HR	9 min	
CorTemp	9 min	
Distance	10 min	
Speed	10 min	

HR	10 min	
CorTemp	10 min	
Thermal Comfort	10 min	
Thermal Sensation	10 min	
RPE	10 min	
Distance	11 min	
Speed	11 min	
HR	11 min	
CorTemp	11 min	
Distance	12 min	
Speed	12 min	
HR	12 min	
CorTemp	12 min	
Thermal Comfort	12 min	
Thermal Sensation	12 min	
RPE	12 min	
Thermal Comfort	Conclusion	
Thermal Sensation	Conclusion	
RPE	Conclusion	
CorTemp	12 min	
Time to complete	Conclusion	

Post 2nd 2kTT

Weigh Out	

Appendix F: Participant Information Sheet

PROJECT TITLE: Assessing the accuracy of human perception during exercise -

HUMAN RESEARCH ETHICS COMMITTEE APPROVAL NUMBER: 202265

PRINCIPAL INVESTIGATOR: James Wiltshire

PRINCIPAL SUPERVISOR: Professor Lorimer Moseley

CO-SUPERVISOR: Dr Samuel Chalmers

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?

Winners of elite sport competitions, whether individual or team sports, are often determined by who can succeed in pushing closest to the boundaries of their body's abilities in a given situation. It is the balancing act of pushing the 'physiological' reserve but limiting injury that guides sporting training regimes. Early research into fatigue focused on the build-up of lactic acid in the circulatory system as a by-product of glycogen metabolism in the production of muscular contractions. The concentration of lactic acid in the muscles was seen as being the limiter of exercise. This theory proposed that oxygen was then needed to assist in the release of energy for the removal process of this lactic acid. This peripheral fatigue model fundamentally suggested that limitation in the oxygen delivery system caused a point in exercise at which lactic acid production outpaced oxygen delivery and caused a catastrophic build-up of lactic acid. This 'catastrophic' accumulation of lactic acid was thought to then cause a cessation of exercise and generate the feeling of fatigue. More recent research into the experience of fatigue has challenged the concept of a purely peripheral driver as the mechanism for fatigue. The aim of this research project is to further explore the perceptive ability of humans while exercising under

fatigue. This will be achieved by investigating the effect of subtle interventions during exercise on a treadmill.

Who is undertaking the project?

This project is being conducted by James Wiltshire. This research will form the basis for the degree of a Master of Research (Population Health Practice) at the University of South Australia under the supervision of Professor Lorimer Moseley and Dr Samuel Chalmers.

Why am I being invited to participate?

Participants have been drawn from the elite playing squads within the South Australian Cricket Association. Participants have been selected based on meeting eligibility criteria for age, medical fitness and physical fitness via a screening questionnaire. The specific eligibility criteria for this study are:

Inclusion Criteria • Elite cricketers aged 18 – 40years • Be proficient in the English language • Self-assessed ability to run for 8 minutes on a treadmill at a very high intensity • Read and signed a consent form
Exclusion Criteria • Currently suffering an episode of acute pain or injury • Poor circulation/peripheral vascular disease • Psychiatric or neurological condition • Cardiac condition e.g., Hypertension • Inability to commit to study timetable

What am I being invited to do?

You are being invited to participate in 3 sessions over the course of 3 weeks. During each of these sessions you will be required to run on a treadmill for a total of approximately 45 minutes duration. This

run will consist of two 8-10 minute blocks of running at a high intensity interspersed with 25 minutes recovery walk. The trial will be conducted in an environment controlled chamber at the University of South Australia City East Campus. Through the course of the trial, the temperature within the environment chamber will be elevated compared to normal temperatures and may range from 27 degrees Celsius up to 36 degrees Celsius in some trials. On first arriving, participants will be screened for medical issues and a questionnaire will then be provided to obtain background data to review genetic factors, fitness levels and previous heat experience. At this time, participants will be asked to provide a urine sample in order to check hydration status. As you will be exercising in the heat, it is important that you are hydrated on entering the chamber. The urine will immediately be discarded and will not be stored. Participants will then enter an environmental chamber and, after being instructed on the use of the treadmill, perform a warm-up and then complete the 45-minute trial on the treadmill. Water will be allowed to be consumed during the recovery walk as needed.

How much time will my involvement in the project take?

The total time is anticipated to take approximately 1.5 - 2 hours per session. There will be a requirement to attend weekly sessions over 3 weeks for a total of 3 sessions.

Are there any risks associated with participating in this project?

The main risk to participants will be heat stress or musculoskeletal injury. The risks associated with heat stress are mitigated by participant screening, the maximum temperature and humidity coupling kept at a safe level for exercise and ad liburtum fluid intake throughout the exercise session. The risk from running on the treadmill will be mitigated from the screening process and also from the protocol involving an adequate warm-up segment.

COVID-19 Precautions

Due to the current COVID-19 pandemic, there are a number of precautions that are being undertaken to ensure the safety of participants.

- All participants are required to have signed into the University Campus via MySA Gov App using the appropriate QR Code.
- All equipment and contact surfaces will be cleaned before and after each participant use.
- Disposable gloves will be worn by researchers whenever there is a need for close contact (i.e. the handling of the participant questionnaires).
- Hand sanitisation will be encouraged throughout the trial (where appropriate).

What are the potential benefits of the research project?

Although there are no direct benefits for participants, the outcomes of this research may improve the understanding of fatigue perception among the general population and in the athletic community.

Can I withdraw from the project?

While we would be pleased to have you participate, we respect your right to decline. Participation in this study is voluntary and participants are free to decline or withdraw from the research project without effecting their relationship with the researcher, South Australian Cricket Association or the University of South Australia now or in the future. Withdrawal can occur anytime up to 14 days after a participant performs a trial after which time all data will be de-identified and collated.

What will happen to my information?

Confidentiality and privacy: All data collected will be de-identified by removal of any names or identifiers. While all efforts will be made to remove any information that might identify you, as the sample size is small, complete anonymity cannot be guaranteed. However, the utmost care will be taken to ensure that no personally identifying details are revealed.

Storage: Physical records will be scanned and stored in an electronic format. Research Data, Primary Materials and Research Records will be stored on the Body in Mind server drive. Throughout the course of the research project, password protection will be utilized to keep data confidential and restricted to the research team. At the conclusion of the 5 year retention period, all data files stored on the Body in

Mind server drive will be deleted. Physical files will be deleted once they have been scanned and saved securely onto the Body in Mind server drive.

Publishing: A summary of the findings will be provided to the participants via electronic mail. Summary findings will be used as part of the Principal Investigator's Master's thesis and may be used in presentations.

Your information will only be used as described in this participant information sheet and it will only be disclosed according to the consent provided, except as required by law.

Who do I contact if I have questions about the project?

If you have any further questions regarding this project, please contact the Principal Investigator:

Phone: +61 8 8300 3800 (South Australian Cricket Association – request James Wiltshire)

Email: James.Wiltshire@mymail.unisa.edu.au

What if I have a complaint or any concerns?

This project has been approved by the University of South Australia's Human Research Ethics Committee. If you have any ethical concerns about the project or questions about your rights as a participant please contact the Executive Officer of UniSA HREC:

Phone: +61 8 8302 3118

Email: humanethics@unisa.edu.au

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

If I want to participate, what do I do?

In order to participate in the above research, a signed consent form will need to be filled out.

Yours sincerely,

James Wiltshire – Principal Investigator

School of Health Sciences,

University of South Australia

Professor Lorimer Moseley – Principal Supervisor

School of Health Sciences,

University of South Australia

Professor Kevin Norton – Co-Supervisor

School of Health Sciences,

University of South Australia

Dr Samuel Chalmers – Co-Supervisor

School of Health Sciences,

University of South Australia

Appendix G: Pre-session guidelines

A number of variables need to be controlled in order to obtain precise and accurate measurements during the testing sessions. Please adhere to the following guidelines before attending each simulation trial.

24 hours before:

-No alcohol should be consumed 24 hours before the trial.

-No vigorous (strenuous) exercise should be the day of the trial.

8+ hours before:

-No caffeine should be consumed 8 hours before the trial.

2 hours before:

-Consume the provided 600mL of water with 1 sachet of Hydralyte. This can be consumed either chilled or tepid (room temperature). Any fluid consumed less than 2 hours before the session must be tepid (room temperature).

-Consume a meal/snack that you would deem 'typical' before playing a cricket match. Try to be as consistent as possible with this choice of meal/snack before each trial.

30min before:

-Please do not rush to attend the session. This will cause your core temperature to naturally increase, potentially confounding the results gained during the testing sessions. Therefore, it is recommended that you provide ample time to find a parking space nearby and walk in a relaxed manner to the laboratory.

What to bring to each session:

-Running shoes (please wear the same shoes each time)

-Comfortable running shorts and shirt (please wear the same clothes each time)

-Water (plenty)

-Towel

-Come ready to pee! We will be collecting a urine sample for USG sampling before each session.

-Full length compression garments / skins are not permitted.

Appendix H: Run Sheet – Trial 1 (familiarisation trial)

Run Sheet – Trial 1 Running component (familiarisation trial)

Time	Event	Equipment	Data collected
0000 – 0010 (10mins)	Collect participant information with participant lying (to allow to collect blood pressure)	Participant Information Sheet (pre-sent) Consent Form (pre-sent) Adult Pre-Exercise Screening System (pre-filled) Demographic questionnaire (pre-filled) CorTemp Medical Questionnaire (pre-filled) Clipboards and pens Alco-wipes	Consent Form Signature Demographics APSS form CorTemp Medical Questionnaire
0010 – 0020 (10mins)	Collect anthropometric data	Auto Blood Pressure Machine USG Height chart	Blood Pressure USG Height
0020 – 0035 (15mins)	Put sensors on players	HR monitor Skin Temp sensors Disposable Razors Scales	Weight / BMI
0035 – 0040 (5mins)	Explain procedure prior to entering chamber Enter Chamber Familiarise to treadmill	Data Collection Sheet	RPE Thermal comfort Thermal sensation HR Core Temperature
0040 – 0140 (60mins)	Run trial on treadmill (Warm-up and running)	Treadmill Data collection Sheet	RPE Thermal comfort Thermal sensation HR Core Temperature
(5 mins) 0140 – 0145	Weigh out	Scales	Weight

Time	Event	Instructions
0030 – 0034 (4mins)	Enter chamber and warm-up at 5kph for 2 mins	"Please step onto the treadmill and you will begin a steady walk to warm-up for 2 mins"
0034 – 0039 (5 mins)	Self-stretching <u>outside</u> the enviro-chamber	"Please step off the treadmill and perform any stretches you would like to do. You have 5 minutes to perform these."
0039 – 0040 (1 min)	Start treadmill at 10kph for rolling start	"Please step onto the edges of the treadmill to begin the trial. I will be turning up the treadmill for a 'rolling start' at a reasonable jogging pace. Once the timer hits the 100 metre mark, please jump onto the treadmill belt and the trial will begin. Remember, you can manipulate the speed as often as you like once the trial has started. This is a maximal test so push yourself as hard as you can. At the completion of the 2kTT you will have 30 seconds where you can regain your breathe by putting your feet on either side of the treadmill."
0040 – 0050 (10mins)	1st 2kTT	
0050 – 0115 (25mins)	Walk interval Treadmill set to 4kph	Immediately on finishing – "Now we will turn the treadmill down to a steady walking pace so you can have an active recovery and regain your baseline levels. You have 25 minutes of steady walking to recover your breath and be ready to go again for your final 2kTT effort. You have been given an amount of fluid at room temperature to ensure you remain hydrated. Please drink the entire amount over the next 20 minutes at your own pace." 2:30 minutes before the start of the 2nd 2kTT – "In 2 minutes we will be doing a rolling start again into the second 2kTT. Please step onto the edges of the treadmill at that time. I will be turning up the treadmill for a 'rolling start' at a reasonable jogging pace. Once the timer hits the 100 metre mark, please jump onto the treadmill belt and the trial will begin. Remember, you can manipulate the speed as often as you like once the trial has started. This is a maximal test so push yourself as hard as you can."
0115 – 0125 (10mins)	2nd 2kTT	

Appendix I: Run Sheet – Trial 2 and 3

Run Sheet – Trial 2 and 3 Running component

Time	Event	Equipment	Data collected
0000 – 0010 (10mins)	Collect anthropometric data	Auto Blood Pressure Machine USG Height chart	Blood Pressure USG Height
0010 – 0025 (15mins)	Put sensors on players	HR monitor Skin Temp sensors Disposable Razors Scales	Weight / BMI
0025 – 0030 (5mins)	Explain procedure prior to entering chamber Enter Chamber Familiarise to treadmill	Data Collection Sheet	RPE Thermal comfort Thermal sensation HR Core Temperature
0030 – 0130 (60mins)	Run trial on treadmill (Warm-up and running)	Treadmill Data collection Sheet	RPE Thermal comfort Thermal sensation HR Core Temperature
(5 mins) 0130 – 0135	Weigh out	Scales	Weight

Time	Event	Instructions
0030 – 0034 (4mins)	Enter chamber and warm-up at 5kph for 2 mins	"Please step onto the treadmill and you will begin a steady walk to warm-up for 2 mins"
0034 – 0039 (5 mins)	Self-stretching outside the enviro-chamber	"Please step off the treadmill and perform any stretches you would like to do. You have 5 minutes to perform these."
0039 – 0040 (1 min)	Start treadmill at 10kph for rolling start	"Please step onto the edges of the treadmill to begin the trial. I will be turning up the treadmill for a 'rolling start' at a reasonable jogging pace. Once the timer hits the 200 metre mark, please jump onto the treadmill belt and the trial will begin. Remember, you can manipulate the speed as often as you like once the trial has started. This is a maximal test so push yourself as hard as you can. At the completion of the 2kTT you will have 30 seconds where you can regain your breathe by putting your feet on either side of the treadmill."
0040 – 0050 (10mins)	1st 2kTT	
0050 – 0115 (25mins)	Walk interval Treadmill set to 4kph	Immediately on finishing – "Now we will turn the treadmill down to a steady walking pace so you can have an active recovery and regain your baseline levels. You have 25 minutes of steady walking to recover your breath and be ready to go again for your final 2kTT effort. You have been given an amount of fluid at room temperature to ensure you remain hydrated. Please drink the entire amount over the next 20 minutes at your own pace." <u>If told temp rising</u> – "It is definitely warming up in here", "I'm feeling the heat" <u>If told temp falling</u> – "It is nicer in here now". "That temperature has dropped now 2:30 minutes before the start of the 2nd 2kTT – "In 2 minutes we will be doing a rolling start again into the second 2kTT. Please step onto the edges of the treadmill at that time. I will be turning up the treadmill for a 'rolling start' at a reasonable jogging pace. Once the timer hits the 200 metre mark, please jump onto the treadmill belt and the trial will begin. Remember, you can manipulate the speed as often as you like once the trial has started. This is a maximal test so push yourself as hard as you can."
0115 – 0125 (10mins)	2nd 2kTT	

Appendix J: Screening Questionnaire

ID_____

PROJECT TITLE: Assessing the accuracy of human perception during exercise

HUMAN RESEARCH ETHICS COMMITTEE APPROVAL NUMBER: 202265

PRINCIPAL INVESTIGATOR: James Wiltshire

PRINCIPAL SUPERVISOR: Professor Lorimer Moseley

CO-SUPERVISOR: Doctor Samuel Chalmers

Screening information will be kept strictly confidential

1. Are you fluent in the English language? ◯ Yes ◯ No

2. What is your current age? _____

3. Are you confident in your ability to run on a treadmill safely for 8 minutes? ◯ Yes ◯ No

4. Where did you grow up? _____

5. What is your current occupation? _____

6. What is your current level of fitness?

Poor Good

_____

7. Where have you been in the last hour (air conditioning, outside, etc)? _____

_____

8. How well do you believe you cope with heat when exercising?

Very Poorly Very Well

_____

9. Are you currently taking any medications (please record) _____

_____

10. Are you currently suffering from any of the following:

- Currently suffering an episode of acute pain or injury ◯ Yes ◯ No
- Poor circulation/peripheral vascular disease ◯ Yes ◯ No
- Psychiatric or neurological condition ◯ Yes ◯ No
- Cardiac condition e.g., Hypertension ◯ Yes ◯ No

If yes, please describe _____

_____

10. Are you able to commit to the time demands required by this trial? ◯ Yes ◯ No

Appendix K: Example Screenshot of Temperature Display

