FACULTY OF HEALTH

The relationship between the preferred rate of movement and the most optimal cadence in the skill of cycling

by

Anthony G. Whitty

Principal Supervisor: Associate Professor Mark Watsford

Co-Supervisor: Professor Aron Murphy
Professor Aaron Coutts

A thesis completed in fulfilment of the requirements of the degree of Doctor of Philosophy
30\textsuperscript{th} October 2017
# Table of Contents

List of Tables .................................................................................................................... iv  
List of Figures ................................................................................................................... v  
Acknowledgements .......................................................................................................... viii  
List of Publications ........................................................................................................... x  
Preface ............................................................................................................................. xii  
Abstract .......................................................................................................................... xiii  
List of Abbreviations ...................................................................................................... xvi  
Chapter 1 ......................................................................................................................... 17  
  1.1 Background ........................................................................................................... 18  
  1.2 Statement of the Problem ...................................................................................... 37  
  1.3 Aims and Hypothesis ............................................................................................ 39  
  1.4 Significance of the Project .................................................................................... 45  
  1.5 Limitations and Assumptions ................................................................................ 46  
  1.6 Delimitations ......................................................................................................... 46  
Chapter 2: Do the metabolic demands of a task determine the rate of performance?  
  A review of the preferred rate of movement in cycling and other locomotive skills..... 48  
Chapter 3: Factors associated with the selection of the freely chosen cadence in  
  non-cyclists ..................................................................................................................... 89  
Chapter 4: The relationship between the preferred rate of movement and  
  metabolic demands in non-cyclists ............................................................................... 110  
Chapter 5: The effect of low vs high cadence interval training on the freely chosen  
  cadence and performance in endurance-trained cyclists ............................................. 141  
Chapter 6 ....................................................................................................................... 173
6.1 Introduction ......................................................................................................... 174
6.2 Practical applications........................................................................................... 191
6.3 Directions for future research .............................................................................. 192
Reference List ............................................................................................................... 194
Appendices.................................................................................................................... 216
List of Tables

Table 1: Participant’s physiological, psychological and kinetic characteristics (n = 18; mean ± SD) at 40, 50, and 60 % of Wmax at cadences of 50, 65, 80, 95 and 110 rpm ................................................................................................................................ 100

Table 2: Mechanical variables of the crank cycle at 200 W ......................................... 101

Table 3: Mean Torque (N.m) at 0°, 45°, 90°, 135°, 180° measured during sub maximal cycling at different pedalling cadences ............................................................. 102

Table 4: Crank torque variables comparison between well-trained cyclists (WTC) and non-cyclists (NC) at different cadences. ................................................................. 122

Table 5: Heart rate and Ratings of perceived exertion at 60%Wmax at cadences of 50, 70, 90, 110 rpm and freely chosen cadence for non-cyclists (n = 16; mean ± SD). ........................................................................................................................................ 126

Table 6: Physiological, psychological and kinetic characteristics at 60% of Wmax at cadences of 50, 70, 90, 110 rpm and freely chosen cadence (n = 18; mean ± SD). ........................................................................................................................................ 156

Table 7: Crank torque variables for (LC) and (HC) groups pre-test and post-test at different cadences ........................................................................................................ 160
List of Figures

Figure 1: Means (with standard deviation bars) for metabolic variables and perceived exertion for preferred and non-preferred stroke rates. Adapted from Sparrow et al. (1999). PR= Preferred rate of movement, PR + ve = Above the preferred rate of movement, PR - ve = Below the preferred rate of movement. .......................... 20

Figure 2: The domains and their relevant variables that have been reported to influence the FCC and optimal pedalling frequency................................................................. 24

Figure 3: Conflicting results on delta efficiency values while pedalling at a constant power output at varying cadences. Adapted from (Chavarren & Calbet, 1999; Gaesser & Brooks, 1975; Sidossis et al., 1992).................................................................. 28

Figure 4: Group (mean ± SD) gross efficiency at low (open circles) and high (solid circles) submaximal power output as a function of pre-set pedal rate. Regression lines are extrapolated below 61 rpm. Pedal rates at maximum gross efficiency (open arrows) and at minimum RPE (arrows with horizontal lines) are pointed out as well as the mean freely chosen pedal rate (solid arrows) and the pedal rate at which maximum peak crank power occurred (broken arrow). Adapted from Hansen et al. (2002a). ................................................................. 35

Figure 5: Flow diagram of the progression of studies one, two and three ...................... 44

Figure 6: The domains and their relevant variables that reportedly influence the FCC and optimal pedalling frequency. ................................................................. 61

Figure 7: Definitions of top dead center (DPtop), bottom dead center (DPbot). Ø c is the crank pedal angles. ................................................................. 65

Figure 8: Method used for determination of maximal and minimal torque................. 97
Figure 10: Gross efficiency data for HC and LC groups at 60%Wmax prior to and following training................................................................. 127
Figure 11: Definitions of top dead center (DPtop), bottom dead center (DPbot). Ø
c is the crank pedal angles........................................................................................................... 149
Figure 12: Method used for determination of maximal and minimal torque............ 150
Figure 13: Gross efficiency data for high cadence and low cadence groups at
60%Wmax pre and post training.................................................................................. 157
Certificate of Authorship and Originality of Thesis

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and in the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This research is supported by an Australian Government Research Training Program Scholarship.

_____________________________________________________
Anthony Gerard Whitty

30/10/2017
_______________________________
Date
Acknowledgements

I am going to start by thanking my supervisor Associate Professor Mark Watsford for everything that he has done for me over these past years. Without your expertise, assistance and guidance I would not have been able to do this. I really appreciate all the editing, reading and suggestions, but above all I am so thankful for your sense of humour and friendship that has allowed this journey to be completed. I honestly could not have got through this without all your assistance and hard work and it is something that I will be eternally grateful for. You are a ripping bloke who continually inspires others to achieve.

I also would like to thank Professor Aron Murphy for giving me this opportunity and for being so patient. You have always given me such amazing support both personally and with the project itself. I am really thankful for your hard work and guidance especially early on when framing the thesis and generating outside expertise in areas that was required.

I also thank Professor Aaron Coutts for all his work and time on this project. Aaron provided a huge amount of support in developing my writing and academic skills required to complete this thesis. I also thank Aaron for his support and honesty that was needed at times throughout the thesis. Aaron was always able to continually motivate me with his quick wit and sense of humour.

The completion of this thesis would not have been possible without the love and support of my family, especially during the challenging times. I would like to thank my children, Finn and Hollie for their constant support and unbridled positivity. I
would also like to thank my wonderful, beautiful and supportive wife Mandy. Her patience and support was what made the completion of this thesis truly possible. This is a journey that we definitely completed together and shared every hurdle. I would also like to thank my dog Ben for keeping me company between the early morning hours when most of the work for this thesis was completed.

I would also like to thank all the cyclists and fitness enthusiasts who participated in my studies. Again, without them this would not have been possible.

Finally, I would also like to thank Professor Justin Kemp for his support, expertise and time over the last 5 years. Justin was always willing to assist me and provided wonderful support and positivity.
List of Publications

Refereed journal publications arising from the work undertaken in this thesis:


Conference presentations arising from the work undertaken in this thesis:


2. Whitty, A. G., Murphy, A. J., Coutts, A. J. & Watsford, M. L (2014). The training effect on the freely chosen cadence, optimal pedaling frequency and
performance in trained cyclists. 6th Exercise & Sports Science Australia
Conference and Sports Dieticians Australia, Adelaide, April 10 – 12.
Preface

This thesis for the degree of Doctor of Philosophy is in the format of published or submitted manuscripts and abides by the ‘Procedures for Presentation and Submission of Theses for Higher Degrees – University of Technology, Sydney; Policies and Directions of the University’. All manuscripts included in this thesis are closely related in subject matter and form a cohesive research narrative.

Based on the research design, four manuscripts have been submitted for publication, with two having been accepted and published in peer-reviewed journals. These papers are initially brought together by an Introduction, which provides background information, an extension overview of the literature pertaining to all aspects of the thesis, and defines the research problem and the aims of the series of studies. The Literature Review, which is formed as a publication, provides a specific overview of previous knowledge regarding the relationship between the preferred rate of movement and the most optimal in locomotive skills. This review also provides a summary of the literature pertaining to the selection of the preferred pedalling rate in cycling.

The body of the research is presented in manuscript form (Chapter 3 to Chapter 5), in a logical sequence following the development of research ideas in this investigation. Each manuscript separately outlines and discusses the individual methodology and the findings of each study. The Discussion chapter provides an interpretation of the collective findings and practical applications from the series of investigations conducted as part of the thesis. This chapter also suggests directions for future research.
Abstract

Research examining the relationship between the preferred rate of movement and the most optimal in locomotive sports has demonstrated that both novice and well-trained participants select a preferred rate of movement that minimises the metabolic demands of the task. Referred to as the metabolic demand hypothesis, it has been suggested that novices will initially produce a movement pattern that is unstable, inaccurate and high in metabolic demand when compared to a well-trained participant. However, after a period of practice, novice participants will adopt a refined movement pattern with increased metabolic efficiency and reduced internal mechanical work required to coordinate and control the limbs.

In cycling, the preferred rate of movement is commonly referred to as the freely chosen cadence (FCC). Previous cycling research has demonstrated that elite and novice cyclists select a FCC that is significantly higher than the most optimal metabolic cadence. Instead, the FCC may be attributed to mechanisms other than the need to minimise the metabolic demands of the task, such as mechanical, psychological or physiological factors. However, other cycling studies have shown that the optimal metabolic cadence in well-trained cyclists increased as power output was elevated at higher exercise intensities and more closely resembled the FCC than previously shown. Therefore, to date, there remains conflicting findings as to whether the skill of cycling adheres to the metabolic demand hypothesis and exactly what variables directly influence cadence selection.

The aims of this thesis were to firstly determine whether the skill of cycling adhered to the metabolic demand hypothesis. Secondly, if this was not the case, the research
sought to investigate variables or mechanisms responsible for influencing cadence selection. Finally, the research aimed to determine the impact of a specific cadence-based interval training protocol on the FCC and performance. These aims were investigated using separate studies.

In study 1, a group of non-cyclists completed a series of tests at varying workloads, measured in relative terms of each participant’s fitness level, to determine their FCC and optimal pedalling frequency. The findings revealed that non-cyclists preferred to cycle well above the most optimal metabolic cadence, possibly in order to decrease muscle strain and mechanical load rather than the need to minimise aerobic demand.

In studies 2 and 3, non-cyclists and well-trained cyclists completed a 6-week cadence-based interval training program to determine whether the FCC could be altered with specific training. These studies were also conducted to determine if the selection of the FCC in both cohorts was related to minimising the metabolic demands of the task, and to assess the impact of the interval training program on performance. Collectively, the findings from these studies demonstrated that both well-trained and non-cyclists selected a FCC that was significantly higher than the most metabolically optimal cadence suggesting that the skill of cycling did not adhere to the metabolic demand hypothesis. Unlike other cycling research, the findings from these studies did not support the notion that cadence selection was solely based on minimising muscular effort or reducing the perceived exertion of the task. However, the findings were able to provide evidence to suggest that cycling cadence selection is different to other locomotor activities and may be under the control of central pattern generators (CPG). This was evidenced by the fact the FCC was highly
individualised, recorded strong between-day reliability in all participants, and was shown to be impacted by internal and external factors such as increases in power output and mechanical loading. The findings from studies 2 and 3 also revealed that regardless of the training stimulus, both well-trained and non-cyclists preferred to pedal at higher cadences and that low cadence interval training has the potential to have a greater impact on performance outcomes than high cadence training.
List of Abbreviations

beats·min\(^{-1}\): beats per minute

DP\(_{\text{bot}}\): bottom dead point of the crank cycle

DP\(_{\text{top}}\): top dead centre of the crank cycle

FCC: freely chosen cadence

GE: gross efficiency

NE: Net efficiency

WE: Work efficiency

DE: Delta efficiency

iEMG: integrated electromyography

m: metres

min: minutes

n: number

VO\(_{2\text{max}}\): maximal oxygen uptake

RE: running economy km·h\(^{-1}\) – kilometres per hour

RPE: rating of perceived exertion

RPM: revolutions per minute

T\(_{0\deg}\): torque at 0°

T\(_{135\deg}\): torque at 135°

T\(_{180\deg}\): torque at 180°

T\(_{45\deg}\): torque at 45°

T\(_{90\deg}\): torque at 90°

T\(_{\text{mean}}\): mean torque

T\(_{\text{peak}}\): peak torque

W\(_{\text{max}}\): maximal work capacity