Individual and Event-Specific Considerations for Optimisation of Performance in Track Sprint Cycling

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Abstract

The track sprint cyclist is a unique athlete, and uncharacteristic of any other sprint athlete, they perform a portion of submaximal work prior to sprinting in most events. The nature and implications of this submaximal work are not well understood and there has been little investigation in elite athlete populations. An inertial load ergometer was constructed to investigate this prior work and also to track the responses and progression of training and fatigue. This ergometer was shown to be both reliable (CV elite participants: peak power = 0.7% (90% CI, 0.5-1.0), optimal cadence = 1.6% (90% CI 1.2-2.7) and valid (CV elite male participants, peak power = 4.6%, 90% CI 4.0-5.4%, r = 0.81). Smallest worthwhile changes in peak power (53 Watts) and optimal cadence (1.4RPM) were determined for this ergometer test. An opportunity to track and monitor a group of internationally successful track sprint cyclists through two pinnacle events allowed for a better understanding of the structure and consequence of their training. Application of a novel training stimulus using a counterweighted single legged modality at two contrasting cadences, in an attempt to confer a greater resistance to fatigue, also provided some interesting and unexpected results. It was found that the impact of the simulated prior work in the keirin on peak power was approximately 54% of that in the sprint (keirin -5.68%, ES = 0.23, sprint -10.52%, ES = 0.44) while optimal cadence only dropped 60% as much in the keirin (ES = 0.61) compared to the sprint (ES = 0.86). The duration and intensity of this prior work was determined to be responsible for the magnitude of degradation in peak power and optimal cadence. Importantly it can be interpreted that the change in optimal cadence reflects the net result of intrinsic muscle changes and optimisation to output the highest power capable. Single legged ergometer training at contrasting training cadences (70 and 130rpm) appeared to have positive impacts on T_0 (maximal torque) identified during inertial testing and on mean crank torque during longer duration testing (30s), but not resistance to fatigue. The effect likely related to changes in muscle coordination as a result of the training stimulus. The improvements in T_0 appear to be greater in elite male athletes following the higher training cadence. It is likely this improvement in crank torque through these race specific ranges will enhance the athlete’s ability to accelerate. In summary, inertial

ergometry is a reliable, valid and useful tool for assessing change over time in the track sprint cyclist. Understanding and management of acute and chronic fatigue and determining the appropriateness of the training stimulus are important in achieving the greatest impact on performance. Improving resistance to fatigue will potentially have a concomitant (negative) impact on optimal cadence which is contradictory to what has been hypothesised in the literature with respect to optimising performance. The nature of the relationship that optimal cadence has to performance is questioned as it would appear that optimal cadence is the net result of intrinsic optimisation of muscle properties to achieve a maximal power output (either peak or for a given duration).

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List of Abbreviations

ATP	Adenosine Triphosphate
AUTEC	Auckland University of Technology Ethics Committee
BYOS	Build Your Own Software
C_DA	Coefficient of Drag Area
CI	Confidence Interval
CSA	Cross Sectional Area
CV	Coefficient of Variation
EMG	Electromyography
ES	Effect Size
EXP	Exponent
f_{opt}	Optimal pedalling rate
FTS	Flying Team Sprint
GLUT-4	Glucose transporter protein
HIIT	High Intensity Interval Training
ICC	Intraclass Correlation Coefficient
IL	Inertial Load
ILT	Invercargill Licensing Trust
MMP	Mean Maximal Power
MRLC	Myosin Regulatory Light Chain
Nm	Newton metre
OC	Optimal Cadence
P_{rev}	Power averaged over a completed pedal revolution
PAP	Peak Aerobic Power Output
PCV	Power Control V (SRM power display unit)
PP	Peak Power
PTS	Peak Treadmill Speed
RPE	Rating of Perceived Exertion

RPM	Revolutions Per Minute
SD	Standard Deviation
SLE	Single Legged Ergometer (in reference to training modality)
SR	Sarcoplasmic Reticulum
SRM	Bicycle power meter (manufactured by Schoberer Rad Meßtechnik GmbH, Jülich, Germany)
SWC	Smallest Worthwhile Change
TE	Typical Error
TS	Team Sprint
T_0/T_{max}	Maximal Torque
T_{REV}	Torque averaged over complete pedal revolution
UCI	Union Cycliste International – cycling's international governing body
VO_{2max}	Maximal Oxygen Uptake
V_{rev}	Velocity (pedal cadence) averaged over a complete pedal revolution
V_0	Maximal Velocity
V_{200}	Velocity averaged for 200m time trial
W	Watt
WKO+	Power analysis software (produced by Peaksware LLC, Boulder Colorado, USA)

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Damian Wiseman

January 2015.

Acknowledgement

I knew when I began this thesis that it would and should be a journey I can look back on and be happy to have made it through. Now that I have reached the end I know it is a process I have grown from and one that sees me older, hopefully wiser, with even less hair and a great deal of it now grey. It has been very tiring and at times very challenging juggling study and family and I have come through the last four years with so many more questions than I have answers for it is exciting to think where we might be in another four. To make time now for the things I have been missing and tackling the outcomes of this work will be refreshing. There are a few more tools I need to collect and time to spend in the shed using them.

I would like to thank my supervisors, Professor Mike McGuigan and Dr Angus Ross. Having the best support, direction, guidance and patience through this process has helped to make it possible. I could not have gotten through this without it. It was always welcome to hear that what I was managing to get done was good and things were on track. Understanding all of the aspects of my situation with a growing family and how I work best was very much appreciated. From a conversation and a couple of great ideas in 2010 this grew into something very big, very quickly, and has never slowed down.

I cannot go any further without thanking my wonderful wife and children, who since the beginning of my enrolment have doubled in number (children, not wife) from two to four. How we ever got through this I do not know, there is a little bit of you all in here, much of it removed with the "delete" key after leaving my laptop open while I was away from it. Dad might be a little less tired and able to chase you all around now. Thanks George for all of your support in getting this completed, encouraging the journey from the beginning and being my sounding board for making sure I was on topic and on track. I should be able to function a little better in the mornings now and not keep you awake in the middle of the night. I knew I married the smartest person I've ever met for a reason.

I would like to acknowledge High Performance Sport New Zealand for the award of a Prime Ministers scholarship which made undertaking this research possible. I would also like to thank the athletes, coaches and all of the people I have worked with at BikeNZ. Being immersed in a high performance programme to carry out this research has been a valuable and necessary experience. I am confident this thesis has had a positive impact on all those who have been involved and I am grateful for the opportunity to undertake the research in such a supportive environment.

Ethical Approval

This thesis and the studies contained were approved by the AUT Ethics Committee – Approval: AUTEC 11/315 (see Appendix A).

Confidential Material

This thesis and all contained within are subject to embargo until January 2018. High Performance Sport New Zealand and Bike New Zealand believe the findings of this work represent a competitive advantage to the New Zealand track cycling team and the campaign to Rio Olympic Games 2016.

1. Introduction

Track sprint cyclists are unique sprint and power athletes, required to perform a period of submaximal work within all but one event before committing to a maximal "sprint" effort. Literature describing the elite track sprint cyclist is limited (Craig, Pyke, & Norton, 1989; Dorel et al., 2005; Flyger et al., 2013; Flyger, 2009; Gardner, Martin, Martin, Barras, & Jenkins, 2007; Gardner, Martin, Barras, Jenkins, & Hahn, 2005; Stone et al., 2004). As such, the requirements of this athlete in the sporting context extrapolated from sub elite cycling research may provide misleading conclusions when applied to elite athletes (Atkinson & Nevill, 2001). For this reason it is of benefit to work specifically with an elite subject population to better understand their physiological individuality and subsequent adaptation to training. Given the challenges that have been faced working with a high performance programme it is likely that elite research has been previously limited due to the availability of time for athletes to be engaged in projects outside of their core training focus. All of the athletes participating in this research were track sprint specialists competing at national and international level; competing regularly at World Cup, Continental Championships, World Championships, Commonwealth Games and Olympic Games.

With the time trial no longer contested at the Olympic Games, the only rider to ride with an absence of prior submaximal work is the first lap/lead rider in the team sprint. All other events require athletes to perform an amount of submaximal work prior to their maximal sprint effort. The track sprint cyclist needs to have an exceptional tolerance of the work completed prior to their maximal effort and an ability to generate and maintain the highest levels of power and speed possible for success in competition.

Research aims

The overarching intention of this doctoral research was to obtain a more detailed understanding of the elite track sprint cyclist and explore opportunities for performance improvement in this specific population.

Changes in performance were explored through several studies; investigating the potential impact of the prior submaximal work performed in certain events, longitudinal monitoring of training stimuli through two pinnacle events and a training intervention study exploring resistance to fatigue through single legged ergometer training. The tracking of optimal cadence was the key performance indicator used to evaluate the effect of these interventions on performance.

The research aim and the structure of the studies to investigate the effects on performance are shown in Figure 1.1.

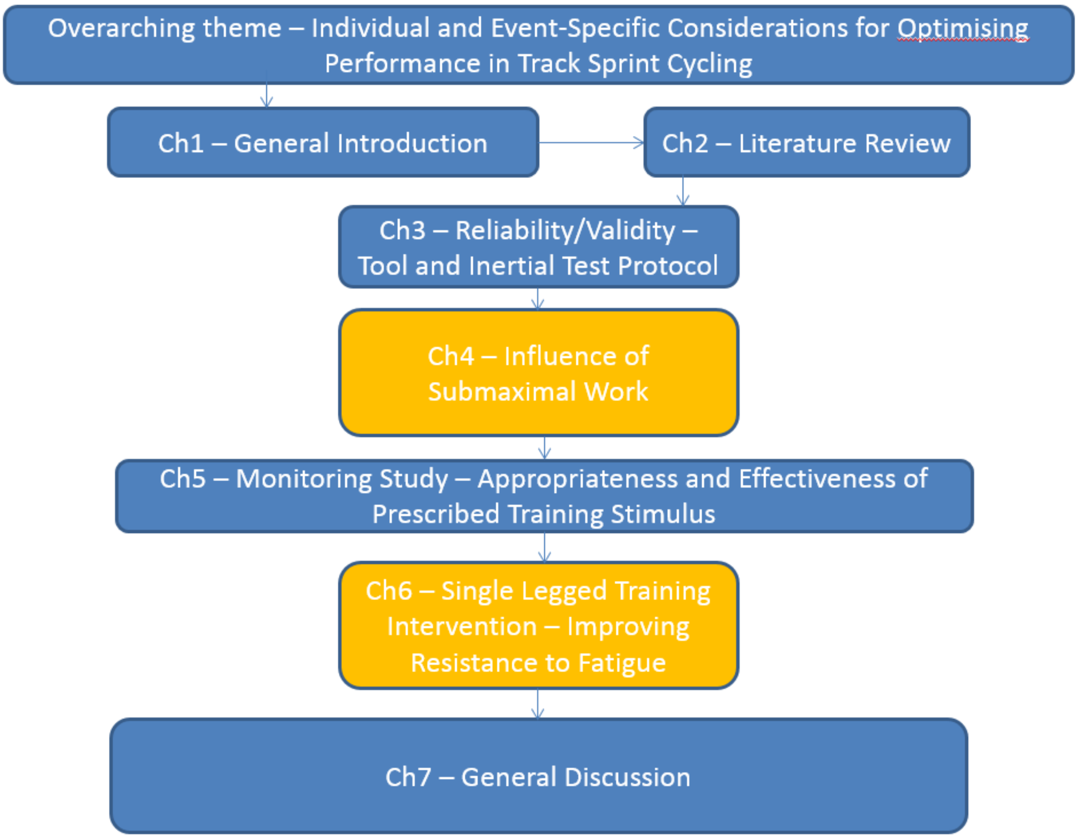


Figure 1.1. Doctoral thesis overview. Contrasting colours indicate the interventions undertaken by athletes during this thesis.

Rationale and conceptual framework

To monitor the changes in performance throughout the studies this research explored the relevance of optimal cadence (cadence at peak power) in monitoring and guiding performance improvement and training adaptation. This was carried out through the use of inertial ergometry for the elite track sprint cyclist. The thesis explored the changes of performance using a reliability and validity study followed by three experimental studies.

The concept of optimal cadence and its proposed relationship to performance leads to questions as to how it might contribute to enhanced understanding of the track sprint cyclist. Dorel et al., (2005) have indicated a higher optimal cadence value as being desirable in the context of performance and propose optimisation of performance in the 200m time trial (increased power production and reduced fatigue) by addressing potential undergearing. The strong correlation observed between optimal cadence and 200m time trial performance (r = 0.77) raises the question of whether further improvement in performance is possible by increasing race gearing (Dorel et al., 2005). Martin, Gardner, Barras and Martin, (2005) have also indicated the entire 200m time trial is performed on the descending limb of the power pedal rate relationship. A race cadence more closely aligned with the athletes optimal cadence may have the potential to further optimise performance as they will spend a greater amount of time at the cadence associated with peak power production. This also raises the question of efficacy of inertial ergometry in tracking and monitoring athlete responses (specifically peak power and optimal cadence) to training and helping to understand subsequent alterations in performance.

The isoinertial testing ergometer used in these studies was based on that of Martin, Wagner, and Coyle, (1997). The ergometer was constructed for regular and reliable assessment of fatigue-free lab-based peak power and cadence at peak power. This provided an opportunity to detect acute and chronic changes in these measures in an attempt to determine both training adaptation and athlete fatigue. A critical step in determining the usefulness of this ergometer was confirming the reliability of the ergometer and testing protocol and validating the power data obtained with concurrent field data.

The competitive requirements of a track sprint cyclist provide the athlete with a unique physiological situation where they are required to perform a period of work immediately before committing to a maximal anaerobic sprint effort. Quantification of the impact of the prior work completed, specifically in the sprint qualifying time trial and the motor paced portion of the keirin, provide a basis for focused strategies on performance enhancement. It is important to note that when discussed here, prior (submaximal) work is in relation to the work completed within the event prior to a maximal sprint effort and the subsequent short term work capacity of that maximal effort (MacIntosh, Svedahl, & Kim, 2004). This is in contrast with what is typically discussed in the literature with prior work or prior heavy exercise relating to work that could be contextualised as the preparatory "warm up" work (Jones, Wilkerson, Burnley, & Koppo, 2003; Burnley, Doust, & Jones, 2005). This 'within event' prior work represents an extreme situation whereby the prior work is performed at a given intensity right up to the execution of the performance task with no period of rest. It therefore must be considered differently and care has been taken to differentiate this prior work from that of a typical warm up. It is currently unknown just what impact this prior, predominantly aerobic, work has on the subsequent "race" effort outside of a general understanding of fatigue. To understand the influence of this prior aerobic work on the track sprint cyclist, it is necessary to understand the influence on the athletes physical capability. Therefore inertial ergometry was used to evaluate acute changes to peak power production and optimal cadence to determine the impact of this prior work.

Monitoring the track sprint cyclists through two pinnacle events creates further understanding of responses to training and allows for more information to contribute to the body of knowledge on this unique group of athletes. This information was also used to contextualise the performances at the Olympic Games in London 2012 and understand progression, or regression, of performance from the 2012 World Championships (Melbourne, Australia) and what may have contributed to the performance outcomes.

Given the fatiguing nature of training and competition for the track sprint cyclist and following performance deficits seen in competition, a novel training intervention to improve resistance to fatigue was investigated using a single legged ergometer training protocol. This novel training modality has not previously been investigated in sprint athletes with currently available research focused on endurance cycling performance (Abbiss et al., 2011; Turner, 2011). The significant stress this training modality places on muscle respiratory capacity (Abbiss et al., 2011) may present a potential benefit in preserving explosive muscle fibres by removing the need for longer duration aerobic training. A short duration high intensity interval training approach was also utilised to minimise the potential for undesirable muscle fibre type shifts.

Originality, significance and contributions of this research

Increasing the understanding of the elite track sprint cyclist and improving performance in this athlete are prioritised in the work that follows. Investigation into the usefulness and relevance of optimal cadence in this cohort of athletes and how this might be applied to enhance and understand performance is also explored in detail.

The thesis has resulted in contributions to the understanding of the track sprint cyclist. This includes the quantification of the impact of submaximal work completed prior to the maximal sprint event. In addition, the quantification of the impact on both peak power and optimal cadence was also examined. Information was also obtained on changes in peak power and optimal cadence longitudinally in a specific elite track sprint cycling group. The use of a single legged ergometer training stimulus in sprint cyclists was unique; in the literature to date this has only been employed in endurance cycling populations (when considering athlete groups). Knowledge of track sprint cycling in terms of progression in performance and power development as a result of the data captured during the build up to the London Olympics, is also a significant contribution.

Acceptance into an elite high performance programme to conduct this research is a valuable and rare occurrence and offers a very detailed understanding at the highest level of this sport. It is important to note that technical and tactical ability, while also heavily influential on race outcome, are not addressed in this thesis.

Thesis organisation

This thesis comprises seven chapters (Figure 1.1). The experimental Chapters 3-6 are written in a standard paper format (prelude, introduction, methods, results, discussion) and as such contain detailed information specific to each chapter. It is important to note that none of the chapters as they are read here are intended for submission for publication in their current format. Given this structure there will be some elements of repetition. Chapters 1 and 7 introduce and discuss the body of work as a whole and sit each side of the experimental chapters to create direction and bring the findings together to provide conclusions and application of the findings from the research.

The literature review in Chapter 2 provides an overview of the literature on cycling power, optimal cadence and the relationships of each to performance, muscle fibre composition and fatigue. Literature on athlete monitoring has also been reviewed as it relates to the longitudinal tracking of these athletes through two pinnacle events in 2012 (Chapter 5). Finally, a review of the literature on single legged cycling training outlines the current understanding of this novel training modality. A brief summary of high intensity interval training (HIIT) has also been included given this approach has been employed with the application of the single legged ergometer training stimulus (intermittent high intensity work).

It was necessary to begin this course of research with a technical investigation into the inertial ergometer that a great deal of this thesis has been based on (Chapter 3). Understanding the constraints of this testing tool and procedure are vitally important to ensure its usefulness in the remaining chapters of this thesis. The inertial ergometer and inertial testing results have played a very large part in understanding the alactic physiological qualities and what impact training and fatigue has on the outputs associated with this testing procedure. Reliability and validity as it relates to this ergometer and testing procedure are outlined in this chapter.

Chapter 4 applied the use of this ergometer to investigate the prior submaximal work performed within the keirin and during the laps leading into the maximal 200m time trial which precedes the match sprint competition to seed the competitors. The ergometer was manipulated to simulate the typical work carried out by each athlete in the competitive situation. Inertial testing before and after the simulated prior work provided an understanding of the impact on peak power and optimal cadence.

Chapter 5 followed, longitudinally, the participants of this research, who competed at the 2012 track cycling World Championships and the London 2012 Olympic Games, between November 2011 and July 2012. The training completed was with the intention of maximising performance at each event and has been described to more fully understand the performance outcome at each of these events. Training stimulus, subsequent adaptation and impact on performance as it relates to the power producing capabilities of the athlete was explored.

Chapter 6 explored a novel training approach utilising counterweighted single legged training. The intention of this training intervention was to develop improvement in resistance to fatigue without compromising the alactic qualities of the athlete and to also improve resistance to fatigue in a quest for greater consistency in performance.

The general discussion (Chapter 7) outlines the key findings and provides conclusions and application of the findings and results of the research, and discusses responsible mechanisms. An overview and developed understanding of the use and application of the physiological concept of optimal cadence is also discussed. For readability there is a single reference list of citations included at the end of this thesis.

2. Literature Review

Prelude

Optimisation of performance requires alignment of a multitude of factors. From the chronic training work leading into the event phase, and subsequent physical and physiological adaptation to improve gross levels of function, to the more acute training stress which takes advantage of a reduction in work along with its reduced levels of fatigue and suppression. It requires improvement and perfection of the technical skill to operate, in this instance, the bicycle under a variety of circumstances; it also requires the perfection and suitable execution of the tactical requirements when racing directly against other competitors (match sprint and keirin). While not discussed in this thesis changes in nutrition and mental preparedness for both competition and training will also impact on the performance ability of the athlete. The intention of this body of work was to improve the understanding of the physical outputs to enhance performance in an applied cycling context. In this context changes in power output have been intended to demonstrate changes in the physical capability of the athlete.

Introduction

Track sprint cycling occurs in an environment where riders operate on a fixed gear for known durations/distances with a goal to be able to reach and sustain maximum speeds. The unique situation of the track sprint cyclist is that there are very few events which do not require the rider to cycle for a period of time at a submaximal intensity before committing to a maximal sprint effort. Only the time trial (500m for women and 1000m for men) and the first lap rider for the team sprint (men and women) performs maximally from a stationary position. The majority of track sprint events include the aforementioned submaximal work prior to the maximal effort of sprinting. The time trial is no longer contested at the Olympic Games but it remains an event at World, Continental and National Championships and also at the World Cup level (as it is ridden to qualify for the events at the World Championships). In racing it is difficult to plan ahead to know the duration and intensity of this prior work, however in the flying 200m time trial for the sprint and the time spent behind the pacer in the keirin, the duration and intensity are the same from one event to the next. Optimising performance outcome in this group of athletes will therefore be related to maximising physiological adaptation to allow greatest power production, minimising aerodynamic drag and maximising a resistance to muscular fatigue (Dorel et al., 2005; Martin, Gardner, Barras, & Martin, 2006). Aerodynamic drag is not a focus of the output of this thesis but it is important in the context of overall performance in track cycling. It is mentioned, where relevant, at times throughout this thesis to provide additional information regarding its role in the performance outcome.

Previous research has investigated the relationship between cycling cadence and power output (Debraux & Bertucci, 2011; Dorel et al., 2005; Emanuele & Denoth, 2011; Gardner et al., 2009; Laursen, 2009; MacIntosh, Neptune, & Horton, 2000; Umberger, Gerritsen, & Martin, 2006; Wiedemann, & Bosquet, 2010; Wright, Wood, & James, 2007) and torque (McCartney, Heigenhauser, & Jones, 1983). This relationship is important as it is indicative of the force-velocity relationship in cycling (MacIntosh et al., 2000). In the 'free state' the cadence at which a rider pedals is a function of the selected gear ratio and the speed at which they are travelling. The power output is similarly a function of the cadence (angular velocity) and torque required to travel at a given speed. A geared bicycle by design is therefore not intended to make the task of pedalling harder or easier but to allow the rider to operate at a cadence which is most suitable for developing power, or self-selected to be the most energetically optimal for that task depending on the individual characteristics of that rider. It is important to understand that cadence, power, speed and gear selection are inextricably linked in the performance of cycling. Pedalling rates when optimised for individual riders have implications for development of maximum power (Dorel et al., 2005; Martin, Gardner, Barras, & Martin, 2005; Gardner, Martin, Martin, Barras, & Jenkins, 2007). It would therefore seem critical that the most appropriate gear is selected at any given time. This is especially important in track cycling as the athlete does not have an option to change gear while riding and operates with a single, fixed, gear. The gearing selected must reflect an understanding of the speed demands of that task and to allow an appropriate cadence range to be operated within; going faster relates directly to increasing that cadence. In track cycling the interaction of the inertia of the rider and bicycle system, the components of drag and rolling resistance in the system and the power able to be created by the rider ultimately determine the system speed. The faster the system, and therefore the performing athlete are able to travel, the greater the improvement in performance that is possible.

Cycling power

As indicated by Martin, Davidson, & Pardyjak, (2007) maximal cycling power is dependent on pedalling rate, muscle fibre type distribution, muscle size, cycling position and fatigue. Stone et al., (2004) have also shown a strong correlation between isometric strength and rate of force development in sprint cycling and the advantage this confers to the ability to produce power. A compromise in cycling power output is almost certain to have a detrimental impact on cycling performance (Martin et al., 2006); the ability to produce the highest level of performance is inextricably linked to an ability to generate and maintain the greatest levels of power output (O'Bryan, Brown, Billaut, & Rouffet, 2014). The relationship established by Paton and Hopkins, (2001) and Flyger, (2009) of percent change in average power during a time trial event is approximately three times that of the change in time e.g. a three percent decrease in power causes one percent increase in time. For equivalent environmental conditions it would seem reasonable that a relative reduction or compromise in power production would deliver a slower event time by 1/3 of a percent of that change in average power.

Peak cycling power output has been shown to be related to both muscle size and fibre type composition (Dorel et al., 2005; Hautier, Linossier, Belli, Lacour, & Arsac, 1996; Martin et al., 1997; McCartney et al., 1983). Greater volumes of lean mass and greater proportions of type II muscle fibres have correlated strongly with higher peak power outputs. Cycling position has been shown to influence power development; Reiser, Maines, Eisenmann, and Wilkinson, (2002) showing much higher power when standing to perform a 30s Wingate test in twelve trained cyclists (peak power 8.2% higher in the standing protocol). Reiser, Maines, Eisenmann, and Wilkinson, (2002) have also noted that this may require cyclists to perform maximal power testing in the standing position to give a more accurate determination of their absolute maximal power generation. Martin et al., (2007) also confirmed a significantly higher peak power when standing, but given power development across the joints relevant to cycling is unchanged in standing versus seated power production, they cite the use of the upper body musculature in this difference.

Stone et al., (2004) investigated the relationships between isometric strength, rate of force development and performance in the track sprint cyclist. Divided into two phases; in the first phase athletes performed an isometric mid-thigh pull to assess maximal isometric strength, completed a vertical jump test to assess rate of force development and carried out a Wingate test on an ergometer in the laboratory. In the second phase of trials a track-based time trial over one lap of a 333m outdoor velodrome was performed. Athletes performed two separate 333m time trials on the second day of testing in phase two, each time trial was performed on a small gear (84 inch) in the morning and a large gear (90 inch) in the afternoon. In the context of track sprint cycling a gear of 84” is typically ridden for warm up, and would be considered small (a large gear is typically much larger than the 90” gear ridden in the study of Stone et al., (2004)). Dorel et al., (2005) report gear ratios that would equate to a range of 96-100” self-selected by participants for their events. Potentially gearing selection for this trial was not optimised, however, there appeared to be a tendency for stronger correlations with the power related variables with the time trial performance on the smaller gear. Stone et al., (2004) showed that there were strong relationships between the relative performance of athletes in strength and rate of force development testing and performance ability on the track. This leads to the conclusion that the better performers tended to be larger and stronger. Power was not assessed in the time trial testing carried out on the velodrome. The positive relationship between strength and power production has also been demonstrated by Cormie, McGuigan, and Newton, (2010) where performance of a ballistic training programme increased performance in both weak and strong participants. Magnitude of improvements were similar for both groups but there was a tendency for the stronger group to display greater improvements in jump performance following ballistic training. High levels of physical strength were advantageous to the ability to assimilate ballistic power training and thus overall benefits of power training.

Cycling power is a result of the interaction of muscle shortening velocity and excitation state (Martin, Brown, Anderson, & Spirduso, 2000). Martin and Spirduso, (2001) highlight this relationship with a detailed investigation into the relationship of pedal rate and pedal speed to the development of maximal cycling power. They looked at power, optimal pedal rate and optimal pedal speed as a result of completing maximal power testing on an inertial ergometer over a range of crank lengths (120-220mm). Controlling for changes in the inertial loading as a consequence of altering crank length was achieved through changing the gearing on the ergometer and each crank length condition was at an approximately equivalent overall inertial loading. They found only a 4% difference in peak power across all crank length conditions (crank length variation of 83%) also finding that the crank length to leg length ratio accounted for 20.5% in the variation seen in peak power. They introduce the concept of cyclic velocity (Hz x $m.s^{-1}$) as the product of pedalling rate and pedalling speed which sees a convergence of the range of crank lengths about a similar point. The relationships for pedalling rate and pedalling speed were inversely related with optimal pedalling rate (indicative of muscle excitation state) decreasing with increasing crank length while optimal pedalling speed (indicative of muscle shortening velocity) increased with increases in crank length. What this serves to highlight, as discussed by Martin, (2007) is the interaction between pedal speed and pedal frequency in the development of maximal cycling power. This would appear to have implications for both gear selection in the acute sense and optimisation of crank length to the physical and physiological characteristics of the individual athlete. In contrast, Barratt, Korff, Elmer, and Martin, (2011) found no difference in maximal cycling power over a range of different crank lengths (150, 165, 170, 175, 190mm) when pedal rate was optimised, citing an absence of change in joint specific powers as responsible. This has implications for gear selection in track cycling as the selected gear constrains the muscle shortening velocity, directly relating it to the pedal rate (Yoshihuku & Herzog, 1990).

Cycling power, muscle activation and fatigue

Fatigue to the athlete represents an effective ceiling to performance. An ability to resist fatigue is a desirable quality in an athlete and the understanding of the mechanism by which it is developed is also necessary. Current literature would appear to consistently demonstrate that fatigue in track sprint cycling is highly related to the number of contraction cycles and is greater at higher contraction frequencies (Tomas, Ross, & Martin, 2009). An ability to adopt strategies which will minimise or reduce the number of contractions required is therefore likely to benefit overall performance. This will also have implications for where in the power pedalling rate relationship the athlete is operating; likely benefiting performance through maintenance of higher power outputs by riding at or closer to the cadence associated with maximal power production.

Warm up structure (duration and intensity) is also something which will impact in this situation and the literature has shown conflict (Tomaras & Macintosh, 2011); traditional track sprint warm up structure resulting in a greater level of fatigue and compromised performance than a shorter and lower intensity experimental warm up protocol. Wittekind et al., (2012) also confirmed the negative impact on performance of a 30s ergometer test after severe warm up when comparing three different warm up intensities (moderate = 6mins working at 40% peak aerobic power output (PAP), heavy = 5min working at 40% PAP followed by 1minute at 80% PAP and severe = 5min working at 40% PAP followed by 1minute at 110% PAP). In the context of severe intensity cycling performance Burnley et al., (2005) determined that moderate and heavy work in the warm up contributed to performance improvement in a seven minute performance task. A significant improvement in mean power output (~2.7%) was observed following both the heavy and moderate prior work protocols. While the duration of the performance task places this into a more endurance oriented context it is an interesting contrast to the literature concerning sprint cycling warm up and short term maximal performance tasks.

Applying the work of Sargeant and Dolan, (1987) loosely to a real world situation (with an estimation of power at VO_{2max} in an elite group occurring at approximately 450W) would give work being carried out in the intended aerobic prior work trials proposed as 52% in the Keirin (2min duration) and 82% (average) in the lead in for the flying 200m (building progressively through each lead in lap from 50, 69 and 127% of VO_{2max}). This would suggest that the work while being paced in the Keirin could potentially offer benefit to the race portion of the event and subsequent ability to produce power. The laps prior to the 200m time trial for sprint qualification may result in power production being adversely affected. It would be likely that elite track sprint riders would differ physiologically from the participants in this study and no specific description of the training status of the participants was given. The relevance of an ecologically valid and specific warm up in a real world situation may also alter the responses seen here.

Changes to recorded electromyography (EMG) signal have also been shown to confirm a difference in muscle activation with an increase in EMG activity when skeletal muscle is under the influence of fatigue (Hautier et al., 2000). This increase in EMG activity is reflective of the increase in neural drive to maintain power output. Kirsch and Rymer, (1987) observed a neural compensation for muscular force when investigating elbow joint torque and fatigue. While they observed changes in EMG related power alterations returning to baseline in 5-10 minutes they did not see muscle weakness changes return to normal for approximately 7 hours post intervention. MacIntosh, Neptune, and Horton, (2000) found that as power output increased the most efficient (lowest level of muscle activation seen with EMG) cadence to achieve this power output increased also. Hautier et al., (2000) demonstrated that in maximal sprint efforts on a cycle ergometer EMG/torque ratio increases to compensate for contractile loss as a result of repeated bouts of sprinting. Their participants performed 15, five second maximal sprints with 25s of recovery between on a friction braked ergometer. They compared the results of the first and thirteenth sprint efforts and showed a decrease in power output of the agonist muscles. Therefore subjects cannot offset contractile failure by overactivating power producing muscles and thus producing less force and power when in a fatigued state. Morris et al., (2010) investigated contractile characteristics related to high intensity exercise performance in seventeen healthy, recreationally active participants. They compared performance and fatigue characteristics from a 30s maximal Wingate test with a 180s electrically stimulated fatigue trial where participants were stimulated at 40Hz for 250ms every second. The study looked at twitch characteristics before and after the 180s fatigue effort (fatigue index, rate of torque development and relaxation rate) relative to changes in power throughout the 30s Wingate test. They observed a strong correlation between fatigue in the maximal Wingate test and the stimulated fatigue trial (r=0.73) and commented that this compared well with fatigue in the

Wingate test and muscle fibre composition determined histochemically (r=0.73) as determined by Bar-Or et al., (1980). Muscular fatigue displays an inverse relationship to the ability to generate muscular force and power (Amann, 2011). Fatigue may be peripheral (Allen, Lamb, & Westerblad, 2008), as a result of the metabolic consequences of strenuous exercise within the muscle, or central (Gandevia, 2001), as a result of the reduction of the central motor drive (Amann, 2011) or, a combination of both. Mendez-Villanueva, Hamer, and Bishop, (2008) demonstrated a decline in EMG amplitude during a repeated sprint trial where they investigated the effects of ten, 6s maximal sprints with 30s of active recovery in eight healthy, recreationally active males. EMG activity in the vastus lateralis muscle was seen to decline over the sprint repetitions and a positive relationship was observed with both the magnitude of decline of EMG activity and the power decrements over subsequent repetitions and the power decrements and anaerobic reserve of the participants.

O'Bryan et al., (2014) investigated the changes in muscle coordination via EMG associated with the decrease in power during a 30s isokinetic cycling test. In ten active male participants they measured the EMG activity in eight muscles involved with pedalling: gluteus maximus, vastus lateralis and medialis (medius obliquus), medial and lateral gastrocnemius, biceps femoris and semitendinosis (hamstrings). As with the changes in EMG amplitude and onset/offset of activation they determined the co-contraction relationships with four muscle pairs: gluteus maximum and gastrocnemius, vastus lateralis and gastrocnemius, vastus lateralis and hamstrings and gluteus maximus and rectus femoris. The 30s work time was divided into 6s blocks and mean power decrement from the first block (where peak was achieved) to the mean power in the final 6s reducing by ~60%. Changes in EMG activity were most pronounced in rectus femoris and gastrocnemius with large reductions in EMG amplitude. The hamstring muscles demonstrated the least amount of disturbance and co-contraction activity of gluteus maximus and gastrocnemius and vastus lateralis and gastrocnemius was markedly reduced. Onset of muscle activity in gastrocnemius, hamstrings and gluteus maximus occurred later during the 30s effort and offset occurred earlier in all muscles (except gastrocnemius). The findings of O'Bryan et al., (2014) largely support those of Dorel, Guilhem, Couturier, and Hug, (2012) who assessed changes in muscle coordination in a maximal sprint cycling task compared with a submaximal intensity (150W). Following maximal and submaximal (150W) trials in fifteen elite sprint cyclists (five female and 10 male) they discovered that maximal activation of the muscles involved in pedalling did not occur and there was a disproportionate change in the activity of the pedalling musculature. Cycling trials were carried out to determine optimal cadence and then submaximal work completed at 150W for all participants for 3min. This submaximal work was then followed by three minutes at an estimated second ventilatory threshold power (310W for male and 220W for female participants) and completed at a cadence corresponding to 80% of optimal cadence. Following this participants completed five, 6s, isokinetic sprints at predetermined optimal cadence values (60%, 80%, 100%, 120% and 140%) presented in randomised order. The only comparison in this study was made between the sprints completed at 80% of optimal cadence for determination of differences between the submaximal conditions. Their findings indicate a large increase (multiplied seven to nine times) in hip flexor muscle activity during the 'all out' sprint activity compared to the 150W condition, and moderate increases (multiplied five to seven times) in activity of the knee flexors and hip extensors. There was a smaller (multiplied two to three times) increase in plantar flexors and knee extensors. The smaller level of increase in the knee extensors and plantar flexors relate the level of activation in these muscles during submaximal exercise as they are the most activated at this intensity. Interestingly Dorel, Guilhem, Couturier, and Hug, (2012) also noted from a performance perspective that the relative strength of the plantar flexors, in their role of transferring the force produced by the hip and knee extensors to the pedal, will have implications for recruitment of these large force producing muscles. Therefore the strength ability and potentially fatigue resistance of these muscles may provide limitations to performance.

Optimal cadence

The concept of optimal cadence forms a significant portion of this thesis and the research contained. Given the nature of this testing and the information available in the literature it does appear to be an attractive metric for monitoring a track sprint cycling population. Optimal cadence is defined as the cadence at which peak power is achieved (MacIntosh et al., 2004). Throughout the scientific literature this physiological concept is referred to by a variety of terms: optimal cadence (Dorel et al., 2005; Emanuele & Denoth, 2011; MacIntosh et al., 2004; Williams, Hammond, & Doust, 2003) cadence at peak power (Martin et al., 2005), optimal velocity (Sargeant, Dolan, & Young, 1984) and optimal velocity maximum (Sargeant & Dolan, 1987).

Given the importance of contraction velocity in the development of cycling power optimal cadence is intended to provide a basis for selecting an appropriate pedalling rate when testing maximum cycling power in the laboratory (Sargeant, Hoinville, & Young, 1981). It has also been suggested that cadence at peak power can provide information on muscle fibre type (Hautier et al., 1996; Pearson, Cobbold, Orrell, & Harridge, 2006; Sargeant et al., 1984). Laboratory determination has been achieved with a number of ergometers and methodologies: inertial-load method/ergometer (Gardner et al., 2007; Martin, Wagner, & Coyle, 1997) repeated velocity tests on an isokinetic ergometer (McCartney, Heigenhauser, & Jones, 1983; Sargeant et al., 1984; Williams et al., 2003), purpose built cycling ergometers (SRM) (MacIntosh et al., 2004) and friction braked cycling ergometry (Dorel et al., 2005; Dorel et al., 2010; Hautier et al., 1996). This power-cadence relationship has also been modelled for application to endurance athletes (Emanuele & Denoth, 2011) taking the approach of optimising cycling cadence based on the highest mechanical power output that the cyclist is able to sustain for a given task. Optimal cadence selection has been defined in endurance cycling tasks poorly with muscular stress, energetic cost and the perception of effort all implicated in optimising cadence for performance (Ansley and Cangley, 2009). Emanuele and Denoth (2011) investigated this modelled relationship with a group of eight cyclists who performed an incremental test, working through 70, 80, 90, 100 and 110rpm at a fixed blood lactate concentration. Their methods are not clear in just how they applied this cycling test as it would appear the cyclist performed at a single predetermined pedal rate during each testing session (five in total). While controlling for pedal rate they claim the testing was performed on a standard racing bicycle using and SRM mobile ergometer. Cadence at peak power has also been reported from field data collected on elite track sprint athletes during competition (Gardner et al., 2005).

Optimal cadence and muscle fibre type

It has been acknowledged that the power-cadence relationship in maximal effort cycling provides information on muscle fibre type (Hautier et al., 1996; Sargeant et al., 1984; Vandewalle et al., 1987). Sargeant et al., (1984) indicated a different optimal cadence for subjects with greater or less than 50% of cross-sectional area composing type II muscle fibres. They indicated participants with predominantly slow twitch (<50% fast twitch cross sectional area) had an optimal cadence of 104rpm and those predominantly fast twitch an optimal cadence of 119rpm. Sargeant et al., (1984) did not give an indication of the methods for fibre type determination or any indication of the range for optimal cadence in these two groups, only that division based on these criteria yield a significant difference. It would be expected that a higher proportion of type II fibres would have the highest optimal cadence but this information was not discussed. Hautier et al., (1996) observed a strong correlation between fast twitch muscle fibre cross-sectional area and optimal cadence (r=0.88) and concluded that optimal cadence directly relates to the characteristics of the mixed muscle (contribution of both type I and II fibres). Hautier et al., (1996) also noted positive correlations with optimal cadence and squat jump performance (r=0.87). The optimal cadence of mixed muscle (equal proportions of type I and II muscle fibres) being ~120rpm and type I muscle fibres 60rpm (Sargeant, 1994). There is no report of optimal cadence specifically for type II fibres. McCartney et al., (1983) reported the optimal cadences in two subjects with histochemically determined muscle fibre type from the vastus lateralis. Their results showed the subject with the greatest proportion of type II fibres (72%) had a higher optimal cadence (162rpm) while the subject with a lesser proportion of type II fibres (53%) had a much lower optimal cadence (119rpm). The peak power data for these subjects was particularly impressive with the respective peak power values 2539W and 1709W for the two subjects. Martin, et al., (1997) also reported a high correlation (r=0.86) between lean thigh volume and peak power.

Sargeant, (1994) has indicated the minimum contribution of type II fibres at different proportions of peak power by exploring the relationship between velocity (cadence) and the minimum proportion of type II fibres required at different fractions of maximum power. Given this, it would appear possible to spare the higher power, more explosive, type II fibres at lower intensities. For an elite international sprint cyclist with a maximum power output of 1800W, working at an average power output of 233W (84rpm) in the motor paced laps of the keirin, this represents almost 13% of maximum power. Based on the argument from Sargent (1994) this could be achieved with very limited use of the type II fibres; approximately five percent of power coming from type II fibres. In the laps prior to maximal acceleration in the flying 200m contribution of type II fibres to power requirements might be as little as 15%, however with greater fluctuation and a progressive increase in power and speed during these laps this would likely underestimate type II contribution. While their data would indicate that this work is at an intensity sufficient to preserve type II function for the most important phase of the event they do acknowledge that their data likely underestimate the lack of contribution of the type II fibres. They also assume that the type I fibres are contributing maximally at any given time.

Optimal cadence and fatigue

Following periods of exertion, or sufficiently fatiguing exercise, cadence at peak power has been observed to change (MacIntosh et al., 2004). MacIntosh et al., (2004) have shown cadence at peak power was reduced following 30s of maximal exercise (fatigued optimal cadence). Given this, it is reasonable to assume that acute changes to cadence at peak power are not due to fibre type alteration but some other change in any or all of: muscle activation, neural drive or metabolic factors relating to energy supply/waste product accumulation. Based on the data reported by Sargeant, (1994) it is also reasonable to accept that while there is no acute fibre type shift there is likely an acute fibre type specific fatigue and/or difference in ability to recover from this exercise. Sargeant, (1994) suggested that acute changes in optimal cadence related to the body's drive to regulate an optimum ability to produce maximal power in the fatigued state.

It should be noted that there is a distinction here between the submaximal prior work completed within the event before the maximal sprint effort has begun, and the work performed as a part of the warm up process. Distinction will be made at all times between the two so the reader should not assume a reference to "prior work" is concerned only with the riders warm up given the discussion of prior work in the literature largely refers to the process of warm up. For this reason the literature concerned with the prior work component of warming up has not been specifically reviewed. There is reference, where relevant, to the impact of warm up on the subsequent ability to perform.

The effects of a warm up prior to maximal anaerobic performances may provide some indication of the influence of prior aerobic work, although there is typically a significant lag between the completion of the warm up and the initiation of the maximal anaerobic work. Sargeant and Dolan, (1987) investigated the effect of prior work/warm up on short-term power output in a 20s maximal isokinetic effort at 112rpm (optimal cadence for peak power determination in this study). In three separate experiments they investigated the effect of duration of prior work (30s, 1min, 3min and 6min at 98% VO_{2max} in two subjects), intensity of prior work (35%, 50%, 75% and 100% of power output at VO_{2max} for 6mins in five subjects) and duration of recovery (0s, 15s, 60s, 180s and 360s following 6min at 87% of $VO2_{max}$ in four subjects) on short term maximal power output. Sargeant and Dolan, (1987) found that following 6min of work at 39% and 56% peak power in the maximal test had increased by 15 and 11% respectively. They also found that any duration of prior work at 98% of VO_{2max} caused a decrement in peak power in the following 20s maximal trial. All other prior work intensities saw a decrease in maximal power (20-40% reduction in peak power following work at intensities greater than 60% of VO_{2max}). Recovery duration (following 6min at 87% of VO_{2max}) also had a substantial effect on maximal peak power attained; with no rest a reduction in maximal peak power was observed, a return to control values was observed within two minutes of recovery and beyond this at three and six minutes maximal peak power values were observed to exceed control values. Sargeant and Dolan (1987) assessed power at a pedalling velocity determined to elicit maximal power in six subjects with the optimal cadence being 112rpm. The literature would suggest that cadence at peak power for elite sprint athletes is in the range of 126 – 133rpm (Dorel et al., 2005; Gardner et al., 2005; Hintzy, Belli, Grappe, & Rouillon, 1999). Sargeant and Dolan (1987) provided no indication of the training status or background of these athletes, however the data would indicate that these subjects are either not sprint trained or were slow twitch dominant athletes given an optimal cadence of 112rpm and the low peak power values reported. Application of these findings in a competitive situation is difficult as an athlete at a competitive event will have already undertaken an appropriate warm up and this warm up may indeed blunt some of the responses seen by Sargeant and Dolan, (1987).

MacIntosh et al., (2004) investigated differences in optimal cadence following a 30s bout of maximal work on an isokinetic ergometer. They observed a downward and left shift of the power/cadence (torque/velocity) curve in the trial immediately following the 30s effort relative to the fatigue free initial trial; essentially a decrease in peak power and a corresponding decrease in the cadence at peak power. Subjects completed a 10min warm up protocol including three short sprint efforts. Determination of non-fatigued optimal cadence was via a seven second maximal acceleration following one minute of pedalling at 50rpm (no indication of work load is given other than commenting that this is "to low effect"). Fatigued acceleration testing (fatigued optimal cadence) following the 30s maximal test was performed following five seconds of pedalling at 50rpm immediately after the 30s maximal test.

Given type II muscle fibres are more susceptible to fatigue (Morris et al., 2010), it would be reasonable to expect that athletes with a greater proportion of type II muscle will demonstrate a high susceptibility to fatigue. In this context, given high optimal cadence is highly correlated with a greater proportion of type II muscle, track sprint cyclists displaying high optimal cadence values will therefore also have a greater predisposition to fatigue. Tomas et al., (2009) found that the accumulation of work (cumulative pedal revolutions) was responsible for fatigue in power output over a 30s maximal isokinetic cycling effort performed at optimal cadence. Based on this information and that of MacIntosh et al., (2004), athletes with a higher optimal cadence would expect a downward and left shift in the power-cadence curve when placing high demands on those muscle fibres. This could suggest gearing selection in these athletes would be optimised by selecting higher gears in competition to resist influence of fatigue as a consequence of pedalling rate. Tomas et al., (2009), Martin and Spirduso, (2001) and Barratt, Korff, Elmer, and Martin, (2011) have investigated the effects of different length cranks on the resultant maximal power production to differentiate the effects of pedal speed and pedal rate on fatigue and joint power production. Barratt et al., (2011) investigated a smaller range in crank length (150, 165, 170, 175 and 190mm) than Martin and Spirduso, (2001) who looked at crank lengths from 120mm to 220mm. Tomas et al., (2009) ran their investigation over two crank lengths, 120mm and 220mm, both optimised for production of maximum power to account for pedalling velocity (optimal cadence for 120mm, 135rpm and for 220mm, 109rpm). Optimisation of pedal rate for each condition was based on the work of Martin and Spirduso, (2001) as previously discussed, to negate the effect of pedal speed. Tomas et al., (2009) did indicate that there was negligible benefit to selecting crank length based on a lower pedalling rate. This would then result in a greater pedal speed (Martin & Spirduso, 2001) leaving the results difficult to interpret. Selecting a larger gear ratio to lower pedalling rate with the same mechanical advantage (crank length) is likely to influence fatigue by reducing the accumulated contraction cycles (Tomas et al., 2009). Tomas et al., (2009) have indicated joint related differences in the power production with the different crank lengths may be responsible for some of differences seen in this study. There was no discussion of muscle fibre type involvement. Martin, (2007) has detailed the time courses of activation and relaxation kinetics as they relate to cycling. In sprint cycling at high pedalling rates (155 rpm) individual flexion/extension phases will occur within 194ms and with muscle half relaxation time up to 76ms. The time available to complete muscle contraction to peak force development and supply sufficient or maximal force is somewhat limited. This will also explain the limitations to muscular power at higher cadences (Samozino, Horvais, & Hintzy, 2007).

Dorel, Bourdin, Van Praagh, Lacour, and Hautier, (2003) investigated two pedal rate conditions on physiological and mechanical responses to all out sprint cycling. They compared maximal work over two sets of 12, five second repetitions riding at V_{opt} (optimal cadence, in this study 116.6rpm ±4.7rpm) and 0.5 V_{opt} (60.6rpm ±4.9rpm) and found a significantly greater amount of work was completed at V_{opt}. They comment that efficiency is higher at V_{opt} given the greater amount of power produced in the higher cadence trials. They did not explore pedal rates above V_{opt} and have commented that this is an investigation that needs to be carried out in the future. This work, combined with that of Tomas et al., (2010) continues to support the role of pedal frequency and contraction number in the development of fatigue in cycling. Following work which modelled the track cycling standing start performance Flyger et al., (2013) have indicated findings which implicate the number of completed pedal revolutions is responsible for up to 90% of fatigue during maximal cycling efforts. Flyger et al., (2013) also comment the accumulated is work responsible for less than 20% of the change in power. Data presented by O'Bryan et al., (2014) showed a drop of approximately 26% of the peak power value over 57 pedal cycles; with power plotted against pedal cycle representing an approximate drop of 1.3% in power per pedal revolution. Given the relationship established between fatigue and pedal rate (Tomas et al., 2010) the strategic manipulation of this situation to mitigate fatigue will be critically important to performance. In track cycling contraction rate is directly linked to pedal frequency (cadence) and is a product of gear ratio and the current velocity. This relationship with fatigue will form the basis for gear selection with consideration for cadence and the increased potential for reducing fatigue with higher gear ratios. Weyand, Lin, and Bundle, (2006) reported findings which support that the relationship between sprint duration and performance is determined by the time of external force application. After testing the maximal power output achieved in a 3s bout of exercise, and the greatest power able to be supported aerobically in seven trained cyclists (four male and three female), this data was applied to the anaerobic reserve model (a model previously determined by Bundle, Hoyt, & Weyand, (2003) for running). Bundle et al.,(2003) also present the argument that sprint performance is driven by the demand imposed on skeletal muscle rather than being metabolically limited in exercise lasting 60s or less. Performance in this time frame was discussed as being determined by muscular force application and the duration dependent relationship with intrinsic muscle fatigue. The time of external force application for a given bout of exercise is the product of the time trial duration and the duty cycle (time of external force application) which would again appear to be in agreement with the prior discussion; fatigue in sprint cycling is a consequence of accumulated contraction cycles (Tomas et al., 2010).

Based on available literature alterations to optimal cadence in the acute phase would appear to be due to the influence of fatigue (MacIntosh et al., 2004). The concept of the regulation of the intrinsic muscle properties to optimise power production in the presence of fatigue would seem reasonable if the prioritised outcome is maintaining an ability to provide power (Sargeant, 1994). In contrast to the fatigue-free state it could be thought that this situation allows the change in optimal cadence to reflect alterations within the muscle to still produce a maximal power output. It could be argued the change in muscle excitation, drive to spare ATP and cycling of Ca_{2+} and neural alterations (changes in EMG activity), would contribute a change in the cadence at which peak power is achieved.

It would appear the maintenance of muscular outputs in the presence of increasing fatigue is assisted by increases in activation as detected by EMG. Studies have also shown differences in the activation, sequencing and coordination of pedalling in the presence of fatigue. This would appear to further support the construct that determination of optimal cadence in the fatigued state represents the net underlying changes to developing muscular power. Changes in individual muscle activation and coordination will have broad reaching implications for individual joint power development and contribution to overall multi-segment power production.

Athlete Monitoring

Much of the literature directed towards monitoring of elite athletes has been done from the perspective of managing or preventing overtraining or to assess short-term effects of a training intervention (Mackinnon, 2000). Ongoing detailed monitoring of elite athletes in this thesis has been targeted towards optimisation and prioritisation of performance through an attempt to understand the impact of the training dose and response as it relates to these athletes. Currently there is a lack of research on long term monitoring of track sprint cyclists.

Studies reporting the monitoring and progression of athletes leading into pinnacle competition or throughout a season can fail to show improvements in performance (Tran, Rice, Main, & Gastin, 2014). Tran, et al., (2014) followed twenty one elite male rowers from the Australian Institute of Sport over a six month period through their specific preparation and domestic competition phases. These phases were completed in the ‘lead in’ to the 2012 London Olympic Games. They found a similar distribution of rowing specificity during each of the phases with ~32% of training time performing nonspecific modes of training. Interestingly they saw no significant differences between physiological characteristics or rowing time trial performance between any of the testing time points. The athletes monitored by Tran et al., (2014) completed training predominantly at low intensities (80% of work) with ~15-20% of training completed at high intensities with a small amount of threshold work.

Nimmerichter, Eston, Bachl, and Williams, (2011) monitored power output and heart rate in eleven cyclists (one female and ten male) over eleven months (from the first week of December to the end of October the following year. All were endurance cyclists competing nationally and internationally in mountain biking, road and track cycling. Training data files were analysed using Training Peaks WKO+ power analysis software (Peaksware LLC, Boulder Colorado, USA). They found that total training time was related to the performance measures (~16 hr/week in the national level athletes and ~25 hr/week in the international level athletes) and observed differences between heart rate and power output in the high intensity training (typically interval) training sessions. This difference did not persist in the context of the entire season or in the lower intensity training data. They found better performances by athletes in this study were related to higher volumes of training, higher intensities during training and lower variability in cycling power output. Similarly Anderson, Hopkins, Roberts, and Pyne, (2006) tracked the variation in fitness test responses of 40 swimmers within and between seasons over a period of five years. Much of the within season improvement (~2.2% for females and ~1.5% for males) was lost due to detraining during the offseason. An average net annual improvement of ~1.0% for females and 0.6% for males was reported.

Coutts, Reaburn, Piva, and Rowsell, (2007) investigated a method for monitoring overreaching in team sport athletes to differentiate biological markers of training adaptation from non-functional overreaching/overtraining. A battery of physical testing and biochemical markers were used to differentiate these states. They concluded that the only definitive marker of non-functional overreaching/overtraining in team sport athletes were performance measures as assessed in the multistage fitness test. Gabriel, Urhausen, Valet, Heidelbach, and Kindermann, (1998) investigated the impact of overtraining on the immune system of a group of triathletes (n=3) and cyclists (n=12) over a period of 19 months. They did cite a change in performance as a component of the diagnosis of overtraining syndrome but did not discuss the detection of this syndrome in relation to a time frame for return to competition. It would be expected that an early return to full training and competition would be a positive outcome of this ongoing monitoring. Lucía, Hoyos, Pérez, and Chicharro, (2000) studied the stability of heart rate and other markers of performance (lactate threshold, ventilatory thresholds one and two) over the season of a group of professional road cyclists (13 men). The cyclists were evaluated in the laboratory during rest, precompetition and competition periods. Interestingly, despite improvements in power output at lactate threshold and ventilatory thresholds, target heart rate levels (heart rate at lactate threshold and at ventilatory thresholds one and two) remained stable through the season (from rest to precompetition to competition time points). Bouchard, Rankinen, and Timmons, (2011) have also discussed the complexity of the role of genetic variation and the gene-exercise interactions present in resulting adaptation to exercise. The genetic variation in the individual physiology in tandem with the variation in the underlying genetically determined response to the training stimulus increases the complexity of understanding the relationship between the training stimulus and subsequent adaptation.

Foster et al., (2001) investigated the use of session rating of perceived exertion (RPE) in the determination of the overall stress of multiple types of exercise. They had participants undertake both steady state and non-steady state exercise training; comparing both the use of session RPE and heart rate summation to quantify the training impact. This study was undertaken in two parts where initially a group of recreational level cyclists were investigated performing eight bouts of both steady-state and non steady-state training. Interval bouts were of 30min duration and included steady state work (±10%, ±25% and ±50% of mean power output), and a 1:1 interval approach following warm up of either 30s, 60s or 120s with intensity ±25% of mean power output. In the second phase of this investigation the same steady state versus on steady state approach was applied to the members of a men's collegiate basketball team. During the basketball phase the steady state activity was treadmill running while the non-steady state activity involved monitoring the participants during their usual basketball trainings. The session RPE method of determining exercise stress was consistently greater than the heart rate responses. The use of session training loading, the product of the session RPE and session duration, allows for comparison of multiple modes of training despite the obvious differences in the impact of each mode. Session RPE has since shown to be a reliable method of quantifying resistance training and other modes of training (Day, McGuigan, Brice, & Foster, 2004).

While training monitoring has been routinely carried out with elite athlete populations it is typically undertaken for investigated monitoring of overtraining and overtraining syndromes. Tracking and monitoring of performance and physiological metrics is very limited with little data published in sprint cycling or sprinting in general.

Single legged cycle training

Single legged cycle training use with sprint cyclists has not been discussed in the literature to date, being used solely with endurance cyclists with the intent of improving endurance cycling performance (Abbiss et al., 2011; Turner, 2011), rehabilitation (Burns, Pollock, Lascola, & McDaniel, 2014) and in people with reduced tolerance to exercise (Wezenberg, de Haan, van der Woude, & Houdijk, 2012). Single legged cycling utilising a counterweight applied to the contralateral pedal has been shown to preserve biomechanical properties of the pedalling with two legs (Abbiss et al., 2011; Bundle, Ernst, Bellizzi, Wright, & Weyand, 2006; Elmer, Amann, McDaniel, Martin, & Martin, 2013; Turner, 2011). The consequences of employing a system where only half of the metabolically active tissue is working creates a situation where oxygen supply is not a limiting factor (Thomas & Martin, 2009). Abbiss et al., (2011) have demonstrated enhancements in aerobic processes and muscle respiratory capacity over and above those seen with comparable two legged cycling. The stress able to be placed on the cyclist when using only one leg is far greater per leg than can be placed when using two legs together and removes the limitation of metabolic substrate supply (Abbiss et al., 2011).

Abbiss et al., (2011) investigated the effects of three repetitions of 4min of work, with 6min of rest, in nine trained cyclists with more than two years of cycling experience. The experimental training block was undertaken over a period of 21 days and six training sessions were completed during this time. During the single legged training all repetitions were completed on one leg before moving to the next leg. Turner, (2011) alternated working legs every 5min in fourteen (12 male, two female) trained cyclists with greater than four years cycling experience. The participants completed three training sessions of one hour duration per week for four weeks with twelve single legged training sessions in total, double that undertaken by Abbiss et al., (2011). Turner, (2011) had participants perform their single legged training at 50% of the double leg training intensity (double leg intensity was 70% of W_{max}). Abbiss et al., (2011) reported that single leg training intensity was performed at 58% of the double leg intensity. However this intensity was self-selected to provide the greatest average power output they could sustain for the 4min work period. Turner, (2011) found no difference in time trial performance between either the single leg or double leg training groups. Abbiss et al., (2011) saw significantly greater increases in cytochrome c oxidase subunits II and IV and GLUT-4 protein concentration but no significant difference in double leg time trial performance when comparing the double and single legged training groups. The increases in GLUT-4 protein concentration are likely to enhance glycolytic metabolic pathways, however no differences were seen in the time trial performance of the single leg training group compared to the double leg training group (305 ± 30W single leg vs 295 ± 35W, double leg) or measures of aerobic power, cycling efficiency or economy. Gorselink et al., (2002) have shown an increase in skeletal muscle fatigability in GLUT-4 deficient mice. It is possible a shorter more lactic/glycolytic performance task may highlight the performance enhancement through this metabolic improvement. Bundle, Ernst, Bellizzi, Wright, and Weyand, (2006) used counterweighted single legged cycling with six male participants. Five of the participants in this study were engaged in endurance training (two cyclists, two former competitive runners, one cross country skier) and one did not exercise regularly. Bundle et al., (2006) investigated the influence of anaerobic metabolism on force production during sprint cycling, comparing counterweighted single legged cycling and double legged cycling using 'all out' efforts over a time range from 15 to 400s. They found evidence of a metabolic basis for impaired muscle force production and subsequent neuromuscular compensation during sprinting; observing a greater maintenance of pedal force via aerobic means in one legged compared to two legged cycling. Six moderate to highly fit males performed 15-

19 all out trials for each condition (either single or double-leg cycling) using pedal forces intended to elicit failure between 15 and 400s. Tests continued in each pedal force condition until participants could no longer maintain a cadence of 100rpm. In another novel investigation Elmer, Amann, McDaniel, Martin, and Martin, (2013) used single legged cycling to determine the presence of inhibition in voluntary neuromuscular function in the rested contralateral limb following high-intensity endurance exercise. They did not find any evidence of the performance of a maximal single leg cycling effort impairing the function of the (contralateral) rested leg, after performing a ten minute fatiguing cycling time trial, when compared to fatigue induced in the ipsilateral leg. Maximal torque-pedalling rate and power-pedalling rate relationships indicated a reduction in maximal power (22 ± 3% at 30s) and maximal isometric torque (20 ± 2% at 30s) in the ipsilateral leg with no change in the contralateral leg following the fatiguing time trial. There also appears to be a reduction in optimal cadence in the presence of fatigue in the ipsilateral leg.

The alteration of training cadence is a consideration in the single legged training intervention undertaken in this thesis. The manipulation of training cadence has been carried out to address the concerns of the coaching staff relating to movement velocity. The effects of different training cadences has been investigated by Paton, Hopkins, and Cook, (2009) who had 18 male endurance cyclists perform training at either a low (60-70rpm) or a high (110-120rpm) pedal frequency over a four week period. Participants substituted part of their usual training for eight 30 minute sessions over the four week period where they performed explosive single legged jumping (20 jumps performed in a two minute period) and high intensity sprints (five x 30s with 30s of active recovery) at the assigned training cadence (high or low). Performance in both groups improved over the four week period but a greater magnitude of improvement was seen in the low cadence training group. Average power in a 60s time trial was improved 5.6% (±5.3) (mean (±SD)) in the low cadence group and 3.0 (±6.4) in the high cadence group, power at 4mmol lactate was improved 10.6% (±8.0) in the low cadence group and 3.3% (±6.2) in the high cadence group. Maximum oxygen uptake was also improved in both groups (4.5% ±3.9 low and 1.1% ±5.6 high). Paton, Hopkins, and Cook, (2009) also monitored changes in testosterone during these training sessions and saw a larger change in testosterone concentration in the low cadence group (97% ± 39%) compared to the high cadence group (62% ± 23%). They postulated that it is likely the combination of the higher pedal forces involved in the lower cadence training stimulus and the anabolic consequences of the greater elevation in testosterone had implications for the more pronounced adaptations seen in the lower cadence training group.

Overall the benefits obtained with single legged training have been shown to relate to improved endurance cycling performance via increases in muscle respiratory capacity. To date there has been no discussion of the use or benefit of single legged cycling training as a training modality for sprint cyclists. There would appear to be a reasonable argument for the use of this training approach to a track sprint cyclist with the ability to make gains previously sought by long duration work on the road. The impact of this mode of training on power and optimal cadence needs to be understood for application in this context. The potential transience of the (biochemical) changes remains unknown as do any structural changes. The volume of single legged work required for adaptation and a dose response relationship for physiological and performance adaptations and training cadence, will be necessary to achieve clarity of the inclusion of this work into the training programme.

High intensity interval training

High intensity interval training has been shown to provide concurrent improvements in both aerobic and anaerobic indices (Gibala et al., 2006) and induce similar overall training adaptations to classic long duration low intensity training (Gibala et al., 2006; Kohn, Essén-Gustavsson, & Myburgh, 2011; Tabata, Irisawa, & Kouzaki, 1997). Tabata et al., (1997) investigated the effects of two different interval based approaches commonly used by Japanese speed skaters in training (this study was completed on a bicycle ergometer). They compared bouts of 20s working at approximately 170% of VO_{2max} with 10s of rest (typically six to seven repetitions) (IE1) with 30s at an intensity approximately 200% VO_{2max} followed by two minutes of rest (typically four to five repetitions) (IE2). They found the accumulated oxygen deficit and the peak oxygen uptake of IE1 was not significantly different to the participants maximal accumulated oxygen deficit and VO_{2max} determined through maximal testing at the commencement of the study. This is in contrast with the significantly lower accumulated oxygen deficit and peak oxygen uptake seen in the IE2 protocol. Their conclusion was that the IE1 protocol was able to maximally stimulate both aerobic and anaerobic energy systems. The protocol described here by Tabata et al., (1997) (6-7 x 20s:10s) has been popularised in recent times with much of the general exercising public exposed to this approach (Olson, 2014).

Gibala et al., (2006) had 16 active men assigned to either a low volume sprint interval group or a high volume endurance training group (eight in each) and undertook six training sessions over 14 days. The sprint interval group performed between four and six repeats of 30s of 'all out' cycling with four minutes of recovery while the endurance group performed 90-120min of continuous cycling at approximately 65% of VO_{2max}. Training volume was therefore substantially different for each group with the sprint interval group completing only 10% of the volume of work completed by the endurance group. Despite these volume differences improvements in muscle buffering and oxidative capacities and overall performance were similar for the two training groups. Participants completed two performance time trials in the laboratory, one of 50kJ (approximately equal to two kilometres) and one of 750kJ (approximately equal to 30km). Both groups showed a reduction in 750kJ time trial time (10.1% for sprint and 7.5% for endurance) and 50kJ time trial time (4.1% for sprint and 3.5% for endurance). A key finding in this study was the shorter duration sprint interval training approach achieved effectively the same adaptation and performance outcomes as the endurance training group. The total exercise time for each group over the two week intervention was 630min for the endurance group and 15min for the sprint group (working intervals only – this increases to 135min with the recovery time included).

Kohn et al., (2011) exposed 18 well trained endurance athletes to a six week HIIT training intervention. Participants trained at individualised intensities and durations based on data obtained in the maximal exercise testing completed at the commencement of the study. Training intensity was defined as 94% of peak treadmill speed (obtained from the maximal exercise test) which athletes ran at for 60% of the time it had taken to reach exhaustion at that running velocity (a separate test at training velocity was conducted to find the time to exhaustion), the average interval time was 2.7 ± 0.5min. Participants completed six intervals with a recovery time of half their interval length time. They observed increases in peak treadmill speed and reductions in plasma lactate levels following the HIIT training intervention. They observed no changes in muscle oxidative capacity but saw increases in lactate dehydrogenase activity.

Conclusion

Performance in track sprint cycling is the result of both the acute factors of the physical and physiological state on the day of competition relating to fatigue, freshness, the impact of the final preparation on the power producing capabilities and fatigue resistant qualities of the athlete. An understanding of these factors is necessary to have the athlete arrive at competition in the most optimal condition (Fitz-Clarke, Morton, & Banister, 1991), and similarly an understanding of these factors will also allow an optimal structure and manipulation of the training stimulus. In the chronic sense the performance and improvement in performance, from one competition to the next, is inextricably linked with the physiological improvement as a result of the training stimulus and subsequent adaptation in producing larger quantities of power for longer. The positional optimisations and equipment considerations in the minimisation of aerodynamic drag and the technical and tactical ability of the athlete are all related to the overall performance outcome. Pursuit of maximisation of all of these qualities is the goal of the coach and athlete.

3. Inertial Ergometer Reliability and Validity

Prelude

Based on the work of Martin et al., (1997) an isoinertial ergometer was contructed through modification of a commercially available “spin bike” to use as a monitoring testing tool throughout this thesis. The determination of power with this system relies on a commercially available mobile bicycle ergometer (SRM - Schoberer Rad Meßtechnik GmbH, Jülich, Germany) rather than changes in flywheel kinematics. Confirming the reliability of the power measurement system and determining the reliability and validity of the isoinertial ergometer was also critical to provide confidence in the interpretation of the power and optimal cadence data. An important consideration of this process is understanding the smallest worthwhile change (SWC) in power and optimal cadence and whether this ergometer and test procedure were sensitive enough to detect meaningful changes in performance.

Introduction

Accurate and correct measurement is key to understanding change in any variable associated with the performance of athletes. In the case of cyclists, and cycle based testing, changes in the output of the athlete provides information on the responses to an acute intervention, adaptation to training, and provides an ability to set training targets. Cycle based testing in the laboratory is achieved using a number of common ergometers seen in exercise physiology laboratories such as Kingcycle (Kingcycle Ltd, High Wycombe, Bucks, UK), Velotron (Racermate Inc, Seattle, Washington, USA) and Monark (Monark Exercise, Vansbro, Sweden). For power assessment, these ergometers have varying degrees of measurement error. Balmer, Davison, Coleman, and Bird (2000) reported the Kingcycle ergometer to be unreliable in tests of time trial performance with another study by Balmer, Davison, and Bird, (2000) also reporting it to be unreliable in determinations of peak power when compared with SRM. Paton and Hopkins, (2006) found a greater source of ergometer error present in the Kingcycle when compared with SRM and PowerTap. Abbiss, Quod, Levin, Martin, and Laursen, (2009) investigated the accuracy of the Velotron ergometer compared to a dynamic calibration rig and found its level of accuracy to be dependent on the type of testing being performed. The Velotron performed with an average relative error of 0.80% in the constant power trials at 250W and -0.34% at 414W (Abbiss et al., 2009). During the 35s high intensity interval trials, the Velotron over reported power output (3.0% greater) during the work intervals, also missing the spike in peak power at the commencement of the interval (underreporting peak power by 55.8%). The Monark friction braked ergometer provides resistance by either hanging a weighted basket (and as such a known static weight) to the friction strap or via tensioning the friction strap around the flywheel and observing the displacement of a weighted pendulum when the flywheel rotates. The pendulum loaded model has a greater degree of error than the basked loaded model with errors in both attributable to inconsistencies in the friction derived resistive forces with the pendulum model typically underestimating by ~5% at workloads of approximately 300W in calibration studies (Paton and Hopkins, 2001).

In the field the use of mobile ergometers has become more popular with an increasing number of manufacturers offering devices. Devices such as SRM, PowerTap (CycleOps, Madison, USA), Quarq (SRAM, Chicago, Illinois, USA), Pioneer (Pioneer Corporation, Kanagawa, Japan), Stages (Stages Cycling, Boulder, Colorado, USA), and Rotor Power (Rotor Componentes Tecnologicos, S.L, Madrid, Spain) all providing power measurement from the athletes own bicycle. The SRM, Quarq and Rotor units determine torque applied through the crank arm with the placement of strain gauges mounted in the crank spider while the Stages and Pioneer systems detect strain in the crank arms themselves. Pioneer operate strain gauges in both crank arms while Stages power meters utilise only a non-drive side instrumented arm which users fit to their own crankset. The PowerTap system employs a similar mechanical strain determination of torque with this located at the rear hub. There are also pedal based power measurement systems available which offer force measurements at the pedal to determine the power output of the rider. These mobile ergometers have become increasingly popular for both elite and sub-elite cyclists and provides sports scientists and coaches with tools to set and monitor training loads and undertake field based fitness and performance testing.

Each mobile ergometry system has its own inherent errors associated with its method of power measurement with few being reported in the literature. Considered the gold standard of mobile cycle ergometry, the SRM ergometer has been well described in the literature with determinations of error, reliability and confirmation of the manufacturers claims of accuracy reported (Abbiss et al., 2009; Balmer et al., 2000; Gardner et al., 2004; Jones and Passfield, 1998; Paton and Hopkins, 2001; Paton and Hopkins, 2006;). Gardner et al., (2004) noted that there is often misunderstanding in the literature surrounding the calibration of the device with many researchers mistakenly performing a zero offset of the system and referencing this as a calibration procedure. There is also concern for those researchers relying on factory calibration and underestimating the potential for these units to drift from their factory settings (Gardner et al., 2004). Variation seen in the accuracy (2.3 ± 4.9%) of the SRM power meter typically relate to improper factory calibration values, and once accurately calibrated, provide stable measurement throughout a season (-0.8 ± 1.7%) (Gardner et al., 2004). It would seem reasonable, given the documented accuracy of the SRM power meter, to utilise a direct measurement of crank torque for determining peak power and optimal cadence rather than replicating the methods of Martin et al., (1997) using flywheel kinematic data. This direct measurement of torque will also provide instantaneous torque data capture and reflect rider input to the crank arm prior to movement of the flywheel.

Dynamic calibration of power meters has been cited as the preferred and most accurate method for calibration (Gardner et al., 2004; Wooles et al., 2005; Paton and Hopkins, 2006). Maier et al., (2014) have indicated problems with the accuracy of a direct drive dynamic calibration system through the crank axle/bottom bracket with systems measuring from instrumentation in the crank arm or pedal. Maier et al., (2014) have demonstrated a high degree of reliability for a calibration procedure involving cycling on a treadmill at a known speed and gradient. It is also important to note that SRM slope has been shown to drift with changes in temperature. Gardner et al., (2004) demonstrated an average 5.2% change in readings when moving from prolonged exposure to 6° C or 21° C to standard lab conditions. Environmental temperature is considered in relation to measurement accuracy in the research presented here and regular calibration will address calibration drift as a result of travel to a different climate.

This thesis is based on monitoring of elite athletes. It was intended that an inertial ergometer and an inertial testing protocol was the most optimal approach to this. It was also used to test several hypotheses in later chapters. Establishing reliability of the measurement and understanding the relevance of the test data as it relates to the state of the athlete from a field performance perspective is important (Hopkins, Hawley, & Burke, 1999). Establishing correlations between ergometer derived peak power values and field derived peak power values supports the use of the inertial ergometer as a tool for assessing the physiological status of the athlete and readiness to perform. The determination of reliability will confirm the ability of this ergometer and testing protocol to detect differences in athlete output which will indicate real change by comparing TE with SWC based on the methods of Hopkins (2004).

The purpose of this study was to determine the reliability and validity of the inertial testing ergometer which was used for subsequent investigations to determine fatigue free peak power and cadence at peak power. In the field and for more practical applications this data was used to track and monitor athletes in training and determine its appropriateness for understanding adaptations to the training load. The inertial testing protocol and methodology were used to provide a physiological snapshot of the state of the riders throughout the research project and to provide feedback to coaches and sports science staff who worked with the athletes participating in the research. It was also used to assess subsequent hypotheses relating to changes in peak power and cadence at peak power resulting from prior submaximal work and specific training.

The intention of establishing the validity of the data was to determine the efficacy of the test protocol and understand the relevance of the peak power information supplied from the inertial test. It was important to understand whether achieving a high power was a valid indicator of the athlete's potential to produce high power in subsequent field performance.

Methods

Experimental Approach to the Problem

Two separate instances of data capture were used to establish the reliability and validity of the hardware to track, monitor and describe the track sprint cyclist. Reliability was established at the beginning of the research through a series of controlled repeated trials. The validity of the power data provided by the ergometer and testing protocol was confirmed through the comparison and correlation of inertial ergometer peak power data to field peak power data. This was collected from specific work on the track with elite participants during their preparation for the London Olympic Games.

Inertial Ergometer

The inertial ergometer is shown in Figure 3.1.

Figure 3.1. First generation inertial ergometer constructed from a stationary bicycle trainer with the stated physical properties utilised in this research.

The inertial ergometer was constructed from a modified stationary bicycle with a flywheel weight of 31.2kg (diameter 450mm) and a gear ratio of 4.769 (utilising a 62t chain ring and a 13t sprocket) giving an estimated inertial load of 11.698kgm^2. Torque data was collected from commercially available instrumented SRM bicycle cranks (SRM - Schoberer Rad Meßtechnik GmbH, Jülich, Germany) via a data logger which recorded and stored, for download, crank torque at a frequency of 256Hz. A higher resolution pedal cadence was calculated based on flywheel speed and gear ratio. Cadence data was available every 3.77° of each pedal revolution. Data was downloaded and analysed with an in-house software package to determine peak power and cadence at peak power, through the fit of a 3rd order polynomial intersecting the origin, to the data points collected from the first 6.5 pedal strokes (13 data points for each trial). SRM instrumented cranks were regularly calibrated via a static calibration protocol using a known mass and first principles to calculate the instruments slope (Hz/Nm) and ensure accurate data collection.

Inertial Characteristics

Flywheel inertia and inertial load, while not necessary given the direct measurement of applied torques via instrumented SRM cranks was estimated according to the following parameters to allow comparison with the ergometer properties as described by Martin et al., (1997).

Flywheel Inertia

Given the extensive decomposition of the flywheel described by Martin et al., (1997) and measurement of the inertia of nine component parts of the flywheel used here a wheel with equivalent distribution of mass was sought. It was not possible to locate a wheel of equivalent dimensions with additional mass. A heavier, 19kg, smaller diameter, 450mm, wheel (compared to 8.9kg and 520mm wheel used originally) was sourced and the overall inertial properties approximately scaled for this reduced diameter. The mass distribution of the new wheel was matched as closely as practically possible to the original wheel. The addition of extra mass through the addition of four steel discs to the outer surfaces of the wheel to increase the inertia of the wheel, was intended to mirror the same weight distribution allowing for practical constraints..

Inertial characteristics of this ergometer were calculated based on the detailed and accurate analysis performed by Martin et al., (1997) and a constant (*k*) was introduced (Equation 3.2) based on the inertial equation below (Equation 3.1):

$I = mr^2$ (Equation 3.1)

To give:

$I = kmr^2$ (Equation 3.2)

Detailed calculations are shown in Appendix B.

The inertial load of the ergometer was calculated according to Equation 3.3 where *I* is the moment of inertia of the flywheel and *G* is the gear ratio of the system (Gardner et al., 2007).

$IL = \frac{1}{2}\ I\ G^2$ (Equation 3.3)

The original ergometer described by Martin et al., (1997) and initial construction attempts for this ergometer incorporated an intermediate drive system. This was constructed as such due to the light weight nature of the cast alloy flywheel in the system (~9kg), the system was redesigned with a single drive system with a greater mass flywheel (personal communication J.C. Martin, 2011) as the intermediate drive had resulted in mechanical problems. A gear ratio of 4.769 (utilising a 62 tooth chainring driving a 13 tooth sprocket) was used to achieve an inertial loading within the range described by Martin et al., (1997) as giving equivalent results and as close to their actual inertial load (10.93kgm^2) as possible. Given the direct high frequency measurement of pedal torque exact knowledge of system inertia was not crucial for the determination of power.

Power Meter Calibration

Based on first principles; application of a known torque to elicit a change in the output frequency of the power meter a calibration factor (slope, Hz/Nm) was determined for use in the SRM power measurement system. Wooles, Robinson and Keen (2005) described a static calibration procedure utilising a large mass hung over a chainring bolted to the power meter (small lever, known diameter) with the power meter secured to a bench. First principles method of determining calibration in the current study used a smaller mass (~5kg) applied with a long lever (at 1.0m and 2.0m) providing a calibration procedure where the power meter was able to remain fixed to the athletes bike. Application of the mass until the system was completely still and the frequency output from the power meter was constant gave an output frequency in response to a known torque. This method establishes a corresponding slope/calibration factor (in Hz/Nm) used by both the SRM power measurement system and the in house software system to determine torque and subsequently power when combined with angular velocity (determined from cadence). This method was repeated regularly to check calibration of all power meters used in the research both on athlete bicycles and testing ergometers.

Reliability Trials

Participants

Ten trained, nationally and internationally competitive track sprint cyclists, eight male (mean ± SD; 82.2 ± 11.1kg, 178.0 ± 3.9cm) and two female, (mean ± SD; 75.2 ± 13.2kg, 176.5 ± 2.1cm) participated in reliability trials. Included in this was a subgroup of four male (mean ± SD; 87.1 ± 6.8kg, 180.8 ± 1.1cm) international track sprint cyclists who were competing regularly at World Cup, World Championship and Commonwealth Games level. All other riders were specifically training as sprint cyclists and competing at an elite national level. All participants were provided study information and gave their consent to participate in the research. The study was approved by the Auckland University of Technology Ethics Committee (AUTEC, approval 11/315).

Experimental Protocol

Data was captured from sessions both in the testing laboratory and in the field, where the inertial ergometer was located at the velodrome, over a three week period. Participants underwent an inertial testing protocol as outlined below and previously described by Martin et al., (1997) completing four trials separated by three minutes rest at each testing session. Participants presented to the initial testing session where they had their height, weight and age recorded. Participants either had their seat height measurement from their own bicycle or bought their bicycle to the session and a seat position measurement was taken. Inertial ergometer seat position for each rider was then adjusted to the closest actual position of each rider’s own seat. The participants completed two testing sessions separated by a week and matched to occur on a day which had been preceded by comparable training. While this was not deemed to be necessary for the purposes of determining reliability it was requested by the coaching staff this activity needed to fit in with the overall training schedule.

Testing Warm Up - Participants underwent a five minute warm up at approximately 100rpm and 100W. Warm up procedure for the reliability trials was completed by participants on their own bike on a portable cycle trainer comprising of three rollers on which they balanced and simulated riding on solid ground. Warm up intensity was not specifically controlled or recorded, however, the weight of the bike and rider system with high pressure training tires using this device provides a low intensity demand on the rider in the order of approximately 100W at cadence 100rpm.

Participants then completed four maximal sprint efforts from a seated, motionless start, beginning with the right foot at a crank angle of approximately 50° and lasting approximately four seconds separated by three minutes of rest. Participants remained seated for the entire duration of the test. The right crank arm was aligned with the slope of the down tube of the ergometer prior to the beginning of each trial with each trial begun using the right leg. Each rider was given a three second countdown and then strenuous verbal encouragement was given throughout the duration of the test. The experimenter gave the instruction to the rider for them to cease accelerating and inform them their test was over, a brake was then applied and the flywheel slowed. When ready the athlete dismounted the ergometer. An offset was performed during each trial in accordance with the manufacturer's instructions (SRM) and data downloaded and analysed via an in-house software package for the analysis of power meter data compiled using MATLAB (MathWorks, Natick, Massachusetts, U.S.A.).

Statistical Analysis

Reliability was determined according to the methods of Hopkins (1997). Raw typical error was calculated as SD (standard deviation)/√2, coefficient of variation (CV) of the log transformed data using the same formula for typical error (TE) and backwards transformation of the data (100*(EXP(y/100)-100) where y = log transformed TE. The TE of the log transformed data was reported as a CV expressed as a percentage of the mean along with the raw TE; both expressed at 90% confidence intervals (90% CI). A CV of less than 5% was used to confirm reliability (Buchhiet, Lefebvre, Laursen and Ahmaidi, 2011). Intraclass correlation coefficients (ICC) were reported of the log transformed data with 90% CI and used to determine test retest reliability. Cut off values for ICC are typically determined as questionable below 0.8, moderate between 0.80 and 0.89 and highly reliable above 0.90 (Vincent, 1999). The SWC for peak power and optimal cadence for the inertial ergometer test was calculated according to the methods of Hopkins (2004) by applying one fifth of the between subject standard deviation or Cohen effect size (ES) of 0.20. The sensitivity of the test procedure was determined to be acceptable if the TE was less than SWC (Roe et al., 2016).

Results

The results of the reliability analysis are shown in Table 3.1. Based on data from 16 unique trials (ten athletes), comparing four repeated maximal four second sprints on the inertial ergometer, TE (as a percentage of CV of log transformed data) of the cadence at peak power values was shown to be 1.7% (1.4-2.3) (raw TE 2.42rpm). Comparing only elite male athletes (probable Olympic athletes, seven trials) in the group the number for cadence at peak power improved to 1.6% (1.2-2.7) (raw TE 2.20rpm). ICC values indicated questionable reliability for optimal cadence (-0.09). Reliability of repeated peak power for all athletes resulted in TE of 0.9% (0.8-1.2) (Raw value 13W). When only the elite male athletes were considered this number was 0.7% (0.5-1.0) (Raw value 11W). The SWC calculated for peak power for all participants was 53W and for the elite group, 18W, both values larger than the respective raw TE (13.04 and 11.00W) and would indicate acceptable sensitivity of the test. While SWC in optimal cadence for all participants was calculated at 1.4rpm and for the elite group of 0.4rpm (in both instances these values were smaller than the raw TE, 2.42rpm and 2.20rpm respectively), suggesting that the sensitivity was poor.

Table 3.1. Reliability of inertial ergometer.

		All (n=10)	Range (90% CI)	Elite (n=4)	Range (90% CI)
% Typical Error (CV)	**OC**	1.7%	(1.4-2.3)	1.6%	(1.2-2.7)
	Power	0.9%	(0.8-1.2)	0.7%	(0.5-1.0)
Intraclass Correlations (ICC)	**OC**	0.90	(0.80-0.96)	-0.09	(-0.43-0.47)
	Power	1.00	(1.00-1.00)	0.99	(0.97-1.00)
Smallest Worthwhile Change (SWC)	**OC**	1.4rpm		0.4rpm	
	Power	53W		18W	

Confidence Intervals (90%) are reported in parentheses. Log transformed ICC values are reported with 90% confidence intervals (CI) in parentheses. OC = optimal cadence.

Intraclass correlation coefficients reported in Table 3.1 for the elite only group (-0.09, range -0.43 to 0.47) highlight an important limitation with this small sample size as it has a larger variation than that seen in the entire group.

Figures 3.2 and 3.3 show the optimal cadence reliability data to provide a visual representation of the spread of the data.

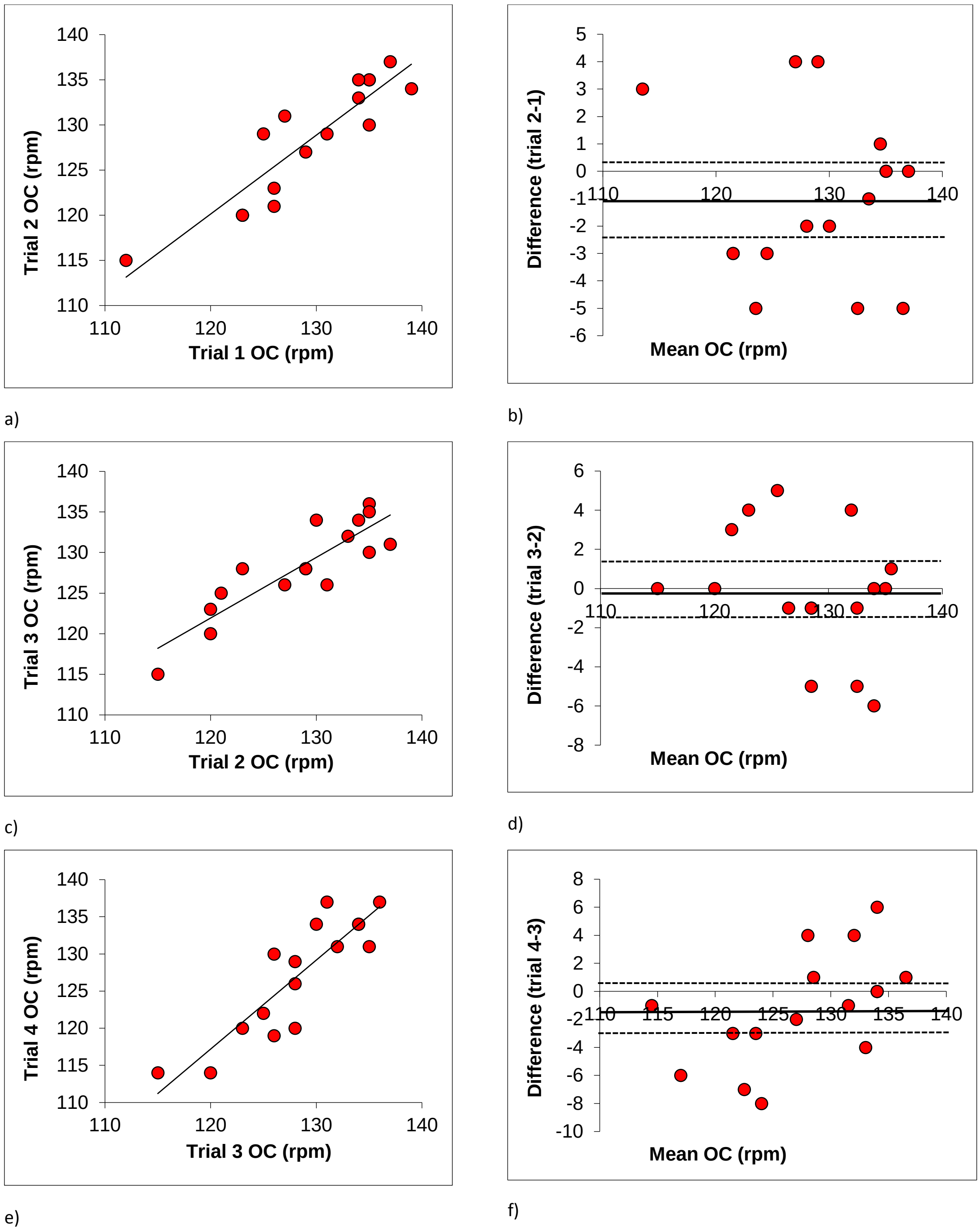


Figure 3.2. Plots of optimal cadence (OC) for all participants displaying comparisons between subsequent pairs of trials (plots a, c and e) to highlight relationships between repeated trials and Bland-Altman plots from each subsequent pair of trials (b, d and f). Solid line represents mean while dashed line indicates 90% CI.

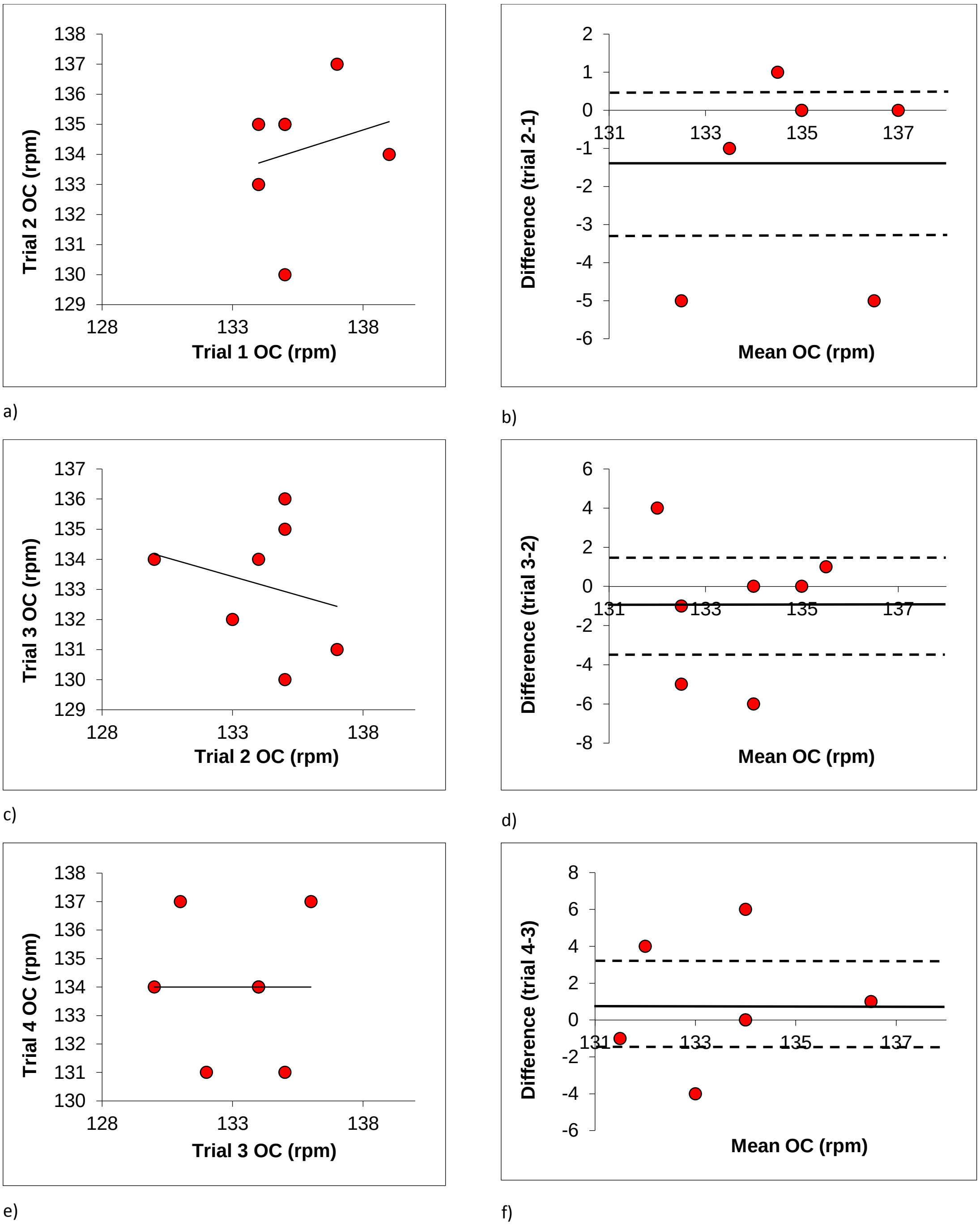


Figure 3.3. Plots of optimal cadence (OC) for elite participants only displaying comparisons between subsequent pairs of trials (plots a, c and e) to highlight relationships between repeated trials and Bland-Altman plots from each subsequent pair of trials (b, d and f). Solid line represents mean while dashed line indicates 90% CI.

Validity Trials

Participants

Five trained male (mean ± SD, weight 89.7 ± 8.1kg, height 181.6 ± 1.9cm) track sprint cyclists preparing for the London 2012 Olympic Games (three selected riders plus two reserve riders) participated in the collection of information to validate the data gathered from the inertial ergometer against concurrent field data. Data was collected during training in Valencia, Spain at the Palacio Velodromo Luis Puig from June to July 2012.

Experimental Protocol

Participants completed a single inertial test as a component of their usual warm up at each track session. Depending on the training scheduled for that day the warm up comprised of either 15 minutes riding on the velodrome at progressively greater intensities, or 15 minutes riding on a stationary trainer where participants balanced upright on three rollers on their track bicycles. The roller warm up procedure was also completed at a progressive intensity finishing with a single sprint effort lasting between six and ten seconds. On days where two track sessions were performed inertial testing was only performed during the warm up of the first track session. Following the warm up participants walked from the track centre to the changing rooms where the inertial ergometer was located and performed a single inertial sprint, as previously described, before resuming their training session. In this instance the inertial sprint essentially comprised a portion of the warm up for the participants. Participants were excluded from an inertial sprint on a small number of occasions due to injury or illness.

Calibration of the SRM instrumented cranks (SRM - Schoberer Rad Meßtechnik GmbH, Jülich, Germany) installed on both the inertial ergometer and the athletes training bicycles was completed regularly using the first principle approach described previously. Any change in the slope of the crank output was updated in the analysis software. All power meters were offset according to software and data analysis requirements which followed the same principle specified by the manufacturer for accurate data collection.

Participants were provided with the same level of external encouragement during each trial and it was assumed that participants were giving 100% effort each time.

Statistical Analysis

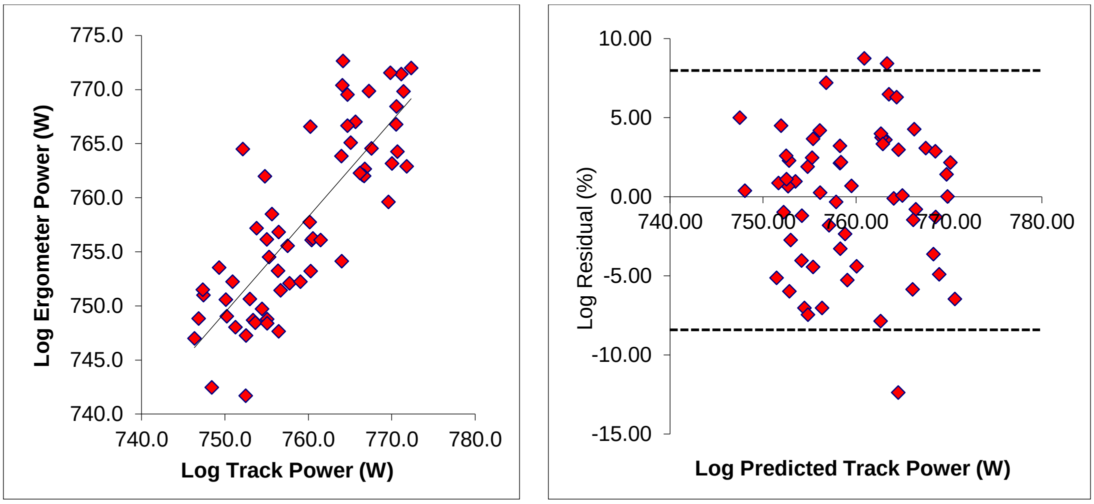
Each pair of data (for each training session and each athlete) was analysed for validity by means of linear regression as described by Hopkins (1997). Log-transformed data has been used as the raw data was not normally distributed. Data is reported with confidence levels of 90%.

Results

The results of the validity analysis are shown in Table 3.2. Correlating 61 pairs of data from inertial trials and high peak power activities on the track: standing starts and acceleration efforts either with or without another rider or motorbike to chase yielded a Pearson correlation coefficient of r=0.81 (confidence limit 0.73-0.88) and a CV of 4.6% (confidence limit 4.0-5.4%).

Table 3.2. Validity data comparing ergometer peak power with field peak power data from n=5 athletes preparing for Olympic Games.

	Male Olympic Athletes (n=5)	Confidence Limits (90%)
Pearson Correlation	0.81	0.73 – 0.88
CV (%)	4.6	4.0 - 5.4



a) b)

Figure 3.4. Plots of log transformed data to give visual indication of data spread. Comparison of ergometer peak power with track based peak power (a) and residual versus predicted track power based on regression of log transformed ergometer and track data (b) (dashed line represents 90% CI).

Discussion

The key finding of this investigation was the reliability and validity of the inertial ergometer testing and protocol for reporting power values. Repeated testing of elite track sprint cyclists showed the protocol (including the measurement tools used) to be reliable (CV for power 0.7%) giving confidence that measured changes beyond these levels represents an actual performance difference for an athlete. Similarly the peak power generated in the inertial load test correlated strongly (r= 0.81, 0.73-0.88) with high power work in the field (track based work). Optimal cadence was shown to be reliable in the larger group (ICC = 0.90, range 0.80-0.96). Power was highly reliable in all cases (all participants ICC = 1.00, range 1.00-1.00 and elite only ICC = 0.99, range 0.97-1.00). Variability in the optimal cadence data and the poor sensitivity of the ergometer test protocol does limit application of this metric. However, observed changes in optimal cadence are not typically this small. Marked change in ICC when moving from the larger participant group to elite only was the result of the small sample size and relatively larger degree of variation in data (Figures 3.2 and 3.3).

This is consistent with previous studies (Gardner et al., 2007) which have shown good linear agreement between laboratory and field based testing data for torque and power pedalling rate relationships (0.99±0.01 and 0.983±0.02). However, Gardner et al., (2007) used a laboratory inertial load approximately three times greater (37.16±0.37kg.m^2) than this testing ergometer and the ergometer of Martin et al., (1997) and almost half as great as the calculated inertial load in their field testing scenario (69.70±3.80kg.m^2). The inertial loading of Gardner et al., (2007) is therefore more closely comparable to those experienced during a standing start on the track. In the case of Gardner et al., (2007) a direct comparison between field and laboratory based determination of maximal torque and power pedal rate relationships was investigated, whereas in the current research validation of the level of power expression during a high power training effort on the track was compared with the ergometer data preceding that training session.

From the results of the present study it is clear that in situations where athletes are performing maximal power activities on the track the ergometer is a valid indicator of field peak power, i.e. if ergometer test results yield high power values then it can be reasonably expected the track session will also yield high power values. Ergometer data from days where lower peak power activities were performed, such as efforts where riders already began at a high velocity, technique or tactical work have not been included as the athletes in this situation are not able to develop the greatest power they are capable of. The inability to develop maximal power in these situations results from the starting velocity being higher when maximal effort occurs as such the resultant torque is applied for less time and is not as great (Samozino, Horvais, & Hintzy, 2007). It is likely that this is related to suboptimal muscle coordination and a potential influence of fatigue after high pedal frequencies (Samozino et al., 2007). A context specific power would indicate their status in this situation; however, it is comparable with efforts of a similar nature but not with the inertial ergometer efforts. Training where riders were either working from a standing start, or from a low speed and accelerating maximally displayed a similar demand to the inertial ergometer sprint and was therefore directly compared. A potential limitation in the comparison of the track based efforts with the ergometer testing also related to the length of time taken to achieve peak power. The ergometer testing resulted in peak power values being obtained between 1.8s and 2.2s from commencing the test. When on the track, peak power occurred between six and ten seconds following the commencement of the maximal effort. This additional time required to overcome the higher inertia in the field will likely have implications for fatigue and this may explain the lower than expected correlation value achieved here (R= 0.81).

The data demonstrated the inertial method of determining peak power and cadence at peak power was both reliable and valid. These findings are also in agreement with what has been previously reported in the literature (Martin et al., 1997). Martin et al., (1997) also demonstrated high reliability: 3.3% ± 0.6% for P_{rev} at Max, 2.7 ± 0.9% for V_{rev} at Max in thirteen active males. The data from the present study (CV 0.9% for power and 1.7% for optimal cadence) would indicate the ergometer has a high degree of reliability despite the differences in the hardware and data capture used on this equipment. Reported here is an equivalent P_{rev} value as power reported is the average over one pedal stroke.

The testing protocol was also shown to be sensitive enough to detect meaningful change in peak power, in both the larger athlete group, and the elite group. As would be expected with the greater level of homogeneity in the elite participant group the number is smaller (larger group, 53W compared to elite only group, 18W). The raw TE of 13W and 11W for peak power of the entire group and elite group respectively, highlight the low noise and sensitivity in the testing procedure and equipment.

Use of the testing procedure may miss small but worthwhile changes and give indications of relevant changes in optimal cadence only when the signal is large enough to overcome the noise present in the measurement (therefore when optimal cadence changes are greater than 2.42 and 2.20rpm for the entire group and elite group respectively). Despite this the results show comparable reliability with Martin (1997) in determining the cadence pedal rate relationship and cadence at peak power values. It is possible the direct measurement of crank torque is responsible for the much smaller CV seen with power when compared to Martin (1997) where flywheel kinematics derived the power and torque data.

Conclusions

The testing protocols and hardware as described here were demonstrated to be both reliable and valid in the determination of peak power. This gave confidence in the data collected for both the tracking and monitoring of the athletes using this equipment and the research outcomes and conclusions to be drawn from the use of the hardware and inertial testing protocol. The ergometer and test protocol have also been found to be sensitive enough to detect meaningful change in peak power but not in optimal cadence. In this instance it is possible that some small changes may not be detected. The sensitivity to detect changes in peak power gave confidence for reliably detecting changes in power given the importance of this metric.

4. Influence of Submaximal Work in Event Prior to Maximal Sprint Effort on Optimal Cadence and Peak Sprint Power

Prelude

In track cycling the differentiation of sprint and endurance disciplines is typically based on the distance and speed of the event. Therefore it would be expected in a cycling sprint discipline that an athlete is performing maximally from the beginning to the end of their event, as is typical of sprint events in other sports. However, contrary to most other sports this is not the case with track sprint cycling. In track sprint cycling (more specifically during Olympic discipline track sprint events) only one rider in one event is subject to this situation: the lead rider of the first lap in the team sprint. All other riders perform, to varying degrees, a component of submaximal work prior to their maximal "sprint" effort. The time trial (1000m for men and 500m for women) is the only other event in which riders begin maximally from a motionless start; however this is no longer an event at Olympic Games. It is therefore important to understand the impact of performing work at a submaximal intensity (prior to the maximal exertion which defines the nature of the event) on the subsequent peak power and optimal cadence achieved by the athlete.

Introduction

MacIntosh et al., (2004) have shown that cadence at peak power reduces following 30s of maximal exercise (fatigued optimal cadence). Given that, it is reasonable to assume that acute changes to cadence at peak power are not due to fibre type alteration. Changes to expression of optimal cadence in this situation are likely to be the result of fatigue owing to a combination of changes in: muscle activation, neural drive (MacIntosh et al., 2000) or metabolic factors relating to muscular fatigue such as a decrease of ATP stores or a perturbation to the movement of calcium ions for muscle contraction (Allen, Lamb, & Westerblad, 2008; MacIntosh et al., 2004). Sargeant, (1994) noted that acute changes in optimal cadence related to the body's drive to regulate an optimum ability to produce maximal power in the fatigued state. Sargeant, (1994) also indicated the minimum contribution of type II fibres at different proportions of peak power by exploring the relationship between velocity (cadence) and the minimum proportion of type II fibres required at different fractions of maximum power. From this it would appear possible to spare the higher power, more explosive, type II fibres at lower intensities. So for a sprint cyclist with a maximum power output of 1800W working at an average power output of 233W (and 84rpm) in the motor paced laps of the keirin this represents almost 13% of maximum power. Based on the argument from Sargeant, (1994) this power output could be achieved with very limited use of the type II fibres (sparing them for maximum effort at a later time). The data suggested approximately 5% of power in the motor paced laps of the keirin would be coming from type II fibres (Sargeant, 1994). In the laps prior to maximal acceleration in the flying 200m contribution of type II fibres to power requirements might be as little as 15%. While their data would indicate that this work is at an intensity sufficient to preserve type II function for the most important phase of the event, they do acknowledge that their data likely underestimates the lack of contribution of the type II fibres. Sargeant, (1994) also assumed that type I fibres are contributing maximally at any given time. The current research intends to show the impact of this prior work on the optimal cadence and power producing potential of the athlete. Ultimately this will provide a relative measure of the impact of this prior work on the type II muscle for each athlete and the subsequent expression of power.

MacIntosh et al., (2004) investigated the differences in optimal cadence following a 30s bout of maximal work on an isokinetic ergometer. They observed a downward and left shift of the power/cadence (torque/velocity) curve in the trial immediately following the 30s effort relative to the initial fatigue free trial. This was essentially a decrease in peak power and a corresponding decrease in the cadence at peak power. Subjects completed a ten minute warm up protocol including three short sprint efforts. Determination of non-fatigued optimal cadence was via a seven second maximal acceleration following one minute of pedalling at 50rpm (no indication of this work load is given other than commenting that this is “to low effect”). Fatigued acceleration testing (fatigued optimal cadence testing) following the 30s maximal test was performed following five seconds of pedalling at 50rpm immediately after the 30s maximal test.

Given type II muscle fibres are more susceptible to fatigue (Morris et al., 2010), it would be reasonable to expect that athletes possessing a greater proportion of type II muscle to also be more sensitive to fatigue (Morris et al., 2010; Sargeant, 1994) or exhibit a greater potential for fatigue. Tomas et al., (2010) found that the accumulation of work (cumulative pedal revolutions) was responsible for fatigue in power output over a 30s maximal isokinetic cycling effort performed at optimal cadence. Based on this information, athletes with a higher optimal cadence would expect a greater downward and left shift in the power-cadence curve when placing high demands on those muscle fibres. Therefore, the purpose of this study was to investigate the influence of the work performed prior to the maximal sprint effort on peak power and cadence at peak power during two distinct lengths of time and intensities, specific to the qualifying 200m time trial for the sprint competition and the time spent behind the pacer in the keirin. It was hypothesised that there will be a greater degradation in peak power and optimal cadence in the simulated sprint prior work than the keirin. Based on the information above it was expected that the higher intensity over this shorter duration will be responsible for the difference.

Methods

Experimental Approach to the Problem

In order to investigate the effect of prior work this study simulated the prior work in both the keirin and sprint qualifying ride (200m time trial) and followed each with an immediate inertial test to determine the impact of this work on the peak power and optimal cadence of the athlete. The simulated work was carried out on a modified inertial ergometer as previously described (Chapter 3) through a system of manually braking/altering the resistance on the ergometer according to each athletes required power output for each event simulation. The modified inertial ergometer was used as it was not possible to source an ergometer with the ability to manipulate loading and perform the inertial testing procedure with minimal delay.

Participants

Nine participants, five male (mean ± SD, weight 88.5 ± 8.7kg, height 181.6 ± 1.9cm) and four female (mean ± SD, 66.1 ± 7.1kg, 167.5 ± 5.4cm) all internationally competitive track sprint cyclists were recruited to participate in this study. Participants had a mean (±SD) of 4.9 (± 2.4) years of international racing experience (range: two to eight years). The years of international racing experience of participants (average age 22.4 ± 3.3 years, range 18 to 28 years) included time spent racing internationally as junior representative athletes (until the year in which they turn 19). All participants were provided study information and gave their consent to participate in the research. This study was approved by the Auckland University of Technology Ethics Committee (AUTEC approval 11/315).

Given the schedules of the athletes participating in this study data collection took place during a number of training camps both in Invercargill at the ILT Velodrome (Surrey Street, Invercargill, New Zealand) and the Sports Performance Research Institute New Zealand laboratories (Mairangi Bay, Auckland, New Zealand).

Prior Work Intensities

Work intensities, defined by the power and cadence requirements (for each simulated prior work duration) were determined specific to each individual athlete participating in the study to ensure a valid representation of the impact of the prior work on their subsequent neuromuscular ability through analysis of each athletes own historical race power files.

Prior work for the Flying 200m time trial which ranks riders for the match sprint competition has been broken into three, 21 second blocks (total time 63s, time range was 60-66 seconds) as this is closely related to the number of whole laps ridden during the lead in to their 200m time trial and a power and cadence target was determined through analysis of each riders historical racing and training power files. A minimum of three and a maximum of five (where available) power files from rides in competition were used to determine the breakdown of the ride. Figure 4.1 shows a typical flying

200m power trace. Riders were instructed to maintain a target cadence while the resistance was altered by adjustments to the braking mechanism to achieve the target power output during each of the three blocks; providing oscillations in resistance to mimic the kinematics of the ride. As can be seen in Figure 4.1 travelling around the top of the velodrome produces oscillations in speed and power as it is not a constant flat surface. Riders were requested to lift their intensity higher and higher as they approached the end of the third block of time to replicate as closely as possible the build in intensity towards maximum acceleration. The rider was then instructed to stop, the brake applied to the flywheel with the cranks bought to a stop at the correct start position within two seconds and the inertial test commenced with minimal delay. The inertial test data was collected and analysed in accordance with methods described previously (Chapter 3). Prior work power and cadence data was captured via a commercially available SRM track power measurement system (SRM - Schoberer Rad Meßtechnik GmbH, Jülich, Germany) and analysed using Training Peaks WKO+ (Peaksware LLC, Boulder Colorado, USA) to confirm targets were met.

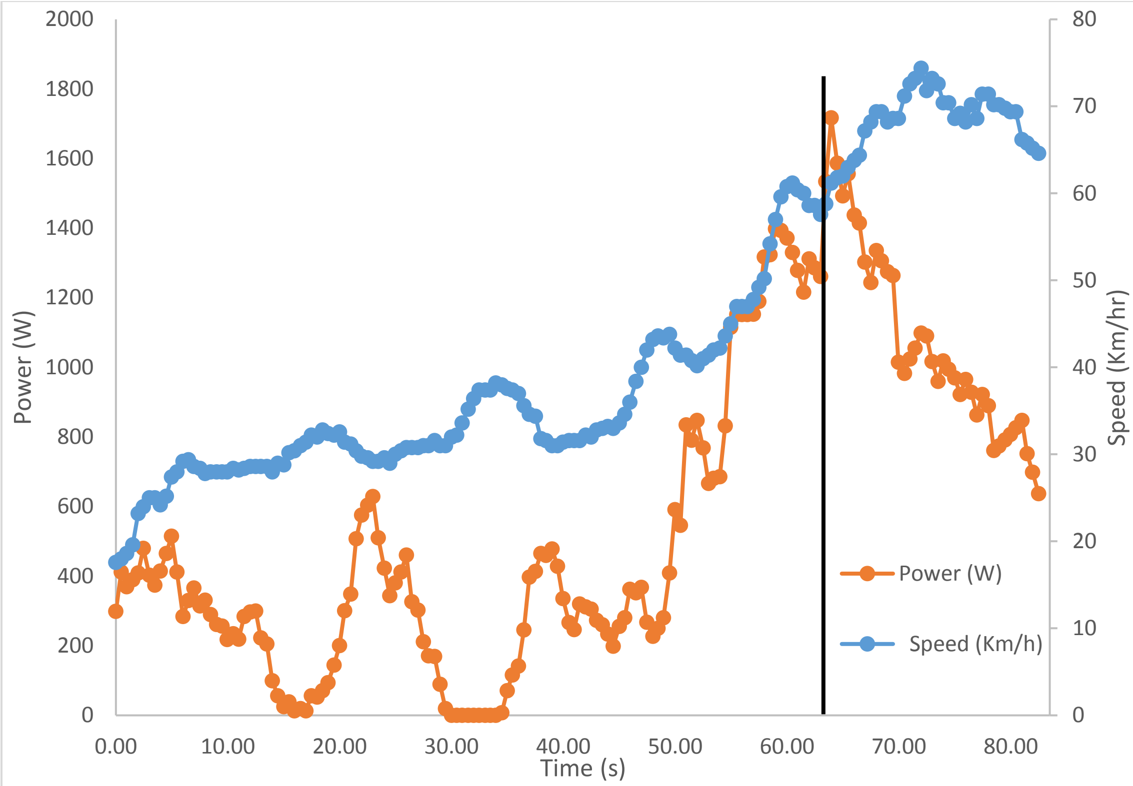


Figure 4.1 Typical F200 time trial profile showing power and speed from the beginning of the time trial. The vertical line indicates one minute and three seconds duration to the point of maximal acceleration.

Prior work for the keirin was determined in the same manner as for the 200m time trial. Given the event is motor paced for five and a half lap's riders power files were analysed to quantify and then replicate the work done in the 1375m prior to the race proper commencing when the pacer leaves the track. A minimum of three and a maximum of five (where available) power files from rides in competition were used to determine the breakdown of the ride. Figure 4.2 outlines the typical progression seen in the power files analysed for this event. Deflection at approximately 90s can be seen in both power and speed/cadence. As riders are not allowed to pass the pacer, the race begins and can possibly last anywhere up to 2.5 laps (approx. 640m). Given the potential variability in this event, it was only the influence of this motor paced prior work that was investigated for this event. All riders had power files from competition analysed to find the power and cadence range they would usually work at during this portion of the event. Pacing for the event gradually builds speed from 30km/hr to 50km/hr for men and 25km/hr to 45km/hr for women. Given this increase in speed, power files were analysed to ensure intensity was also progressed accordingly. Analysis of files yielded very little change in power requirement to maintain the required speed in the first 1000m so power output and cadence requirements were broken into two intervals of 90s and 30s to reflect the change in intensity owing to the higher speeds before the pacer leaves the track. As with the flying 200m simulation a degree of oscillation in the applied resistance intended to mimic the gradual increase in intensity as the race progresses. The low power outputs, even though the speed is increasing in the early laps, were likely related to the riders existing in a single file pace line and receiving either shelter from the rider(s) in front of them, or the pacer (motorcycle or derny) if they are the lead rider. Power is generated in a stochastic nature given the rider is following in a pace line. A typical keirin power file is shown in Figure 4.2 with the point of deflection in power output indicated; the red lines are indicative of the deflection in power output indicating the relative change in intensity.

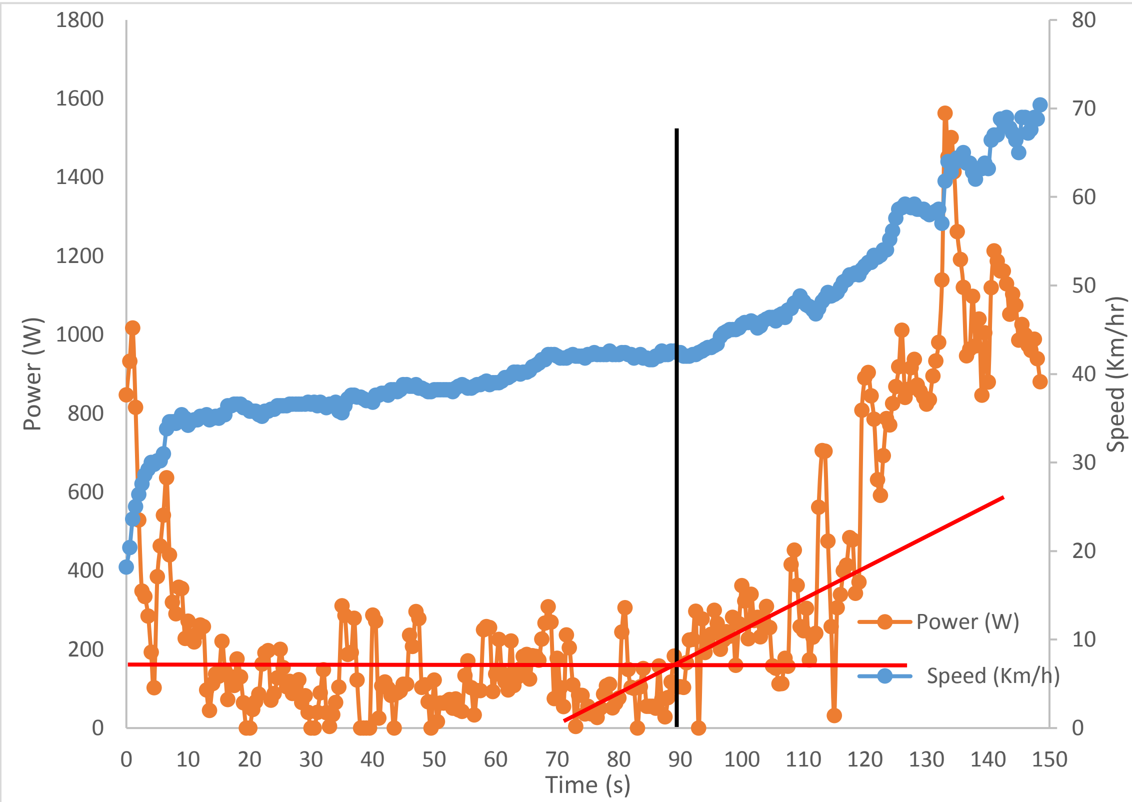


Figure 4.2. Typical keirin race file showing power and speed throughout the event. The vertical line is at 90s and indicates the point at which the intensity increases. Red lines are indicative of this change only.

Testing

As participants presented to the lab, baseline measurements were taken (height, weight) and the participants completed the first prior work trial. Given the training and competitive schedules of the athletes they were only required to complete four repeats of each work condition (two per lab visit). They therefore presented for testing on four occasions as two work trials were completed at each testing session separated by a rest/recovery period of 20min. The order of the prior aerobic work condition was assigned randomly at each occasion until the final testing session where the last remaining prior work condition was completed.

Participants performed a warm up as previously described (Chapter 3) which consisted of approximately 100W @ 100rpm for five minutes. Once completed participants undertook two inertial trials (four second maximal acceleration efforts from a standing start) with three minutes recovery between each test. The average peak power and cadence at peak power from these two tests were recorded as the baseline peak power and cadence at peak power reference for this test session (data was captured and analysed as previously described in Chapter 3). The baseline inertial testing served to control for the state of the athlete on the day of testing and control for the influence of their current training schedule allowing for valid comparison with the inertial data collected following the prior work simulation. No adjustments were made to the collected data based on baseline testing. However, relative comparisons made following the prior work simulations reflected the impact of the prior work on that day. Following a passive rest period of six minutes participants then performed the predetermined period of simulated within event prior work at an intensity (specific cadence and power output) determined by analysis of the athletes own race power files. This rest period (six minutes) was used as it was double the rest duration used previously for repeated inertial testing and considered sufficient to allow participants to be sufficiently recovered before performing the prior work trial. This six minute rest period represents a more than adequate time for phosphocreatine replenishment (Dawson., et al 1997). It was increased to eight minutes for one participant on one occasion who refused to begin following the six minute recovery period. Prior work conditions were randomly assigned. Once the prior work was completed the ergometer flywheel was immediately bought to rest and participants repeated the four second maximal sprint. Changes in peak power and cadence at peak power were investigated in the repeated four second sprint effort and compared to the baseline for that testing session. Participants then rested for 20mins and repeated the prior work test protocol; the baseline inertial testing completed at the beginning of the testing session was applied to the second trial; another baseline measure was not performed prior to the second prior work trial. A duration of 20min of passive recovery was utilised for this rest period as it was typically at least 30% longer than would usually be available to the athlete in training when completing this type of work (longest rest periods in training were typically 15min) and aligned with the shortest time between sprint rounds in competition. Also taken into consideration was the performance of the inertial test, analogous to the maximal acceleration that would be performed in a field based training situation at the completion of a typical track warm up. Given these considerations, this provided an ecologically valid situation for the athlete to perform maximally. An average of the data collected in both trials was used for analysis.

The prior aerobic work was completed on a modified inertial ergometer fitted with a braking mechanism and additional SRM (SRM - Schoberer Rad Meßtechnik GmbH, Jülich, Germany) power controller (PCV) to give the experimenter an indication of their work output and the rider a target for the prescribed cadence. Participants completed the work bout at or as close to the prescribed target power outputs as possible with the resistance controlled by the experimenter as no available ergometer could provide the variation in output required for this investigation. Following the designated work time they immediately stopped, returned their foot to the starting position and repeated the maximal inertial test. The data from the aerobic work period was analysed to ensure work done was consistent with the targets set for each athlete. Comparison between intended and actual work outputs are presented. The procedure was repeated again after a 20min rest period.

Participants were requested to ensure that the day preceding testing was a rest day or contained only exercise of light intensity and short duration. While testing was not conducted during a heavy phase of training, athletes were required by the coach to be training throughout this investigation. Performing the baseline inertial testing prior to the commencement of the prior work condition gave the ability to control for the fatigue state of the athlete on any given day and reflect true changes in their ability to produce power and the cadence at which this power was achieved.

Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for each measure collected. Relative changes (%) were also calculated to show changes in dependent variables. ES was calculated and evaluated using the scale defined by Hopkins (2000) with values of 0.0-0.2 interpreted as showing a trivial effect, 0.2-0.6 showing a small effect, 0.6-1.2 a moderate effect, 1.2-2.0 a large effect and 2.0-4.0 a very large effect. The differences between actual power and cadence outputs of the event simulations were compared with the intended power and cadence outputs using a paired samples t-test and accepted when $P<0.05$. Power output data, where indicated, was scaled allometrically using scaling coefficients of 0.88 for males (Stickley, Hetzler, Wages, Freemyer, & Kimura, 2013) and 0.93 for females (Hetzler, Stickley, & Kimura, 2013).

Results

Prior work completed in the sprint qualifying lead in had a significant impact on the optimal cadence of the athletes ($p=0.0001$, ES = 0.86) (Table 4.1). There was a small effect on the athletes ability to achieve their highest power ($p=0.051$, ES=0.44) (Table 4.1). The prior work completed in the keirin simulation had a moderate effect on optimal cadence but was not statistically significant ($p=0.22$, ES=0.61) (Table 4.1). The magnitude of effects for the group as a whole were almost two fold for power versus optimal cadence and tended to be larger in the sprint compared to the keirin.

Table 4.1. Mean peak power and optimal cadence values (±SD) before and after simulated sprint and keirin prior work condition (all data).

	Sprint (n=35 trials)				Keirin (n=28 trials)			
	Pre	Post	%Diff	ES	Pre	Post	%Diff	ES
Power	1567 (±378)	1398 (±332)	-10.52	0.44	1652 (±425)	1556 (±398)	-5.68	0.23
Optimal Cadence	127.8 (±8.2)	119.0 (±9.6)	-6.82	0.86	128.0 (±8.3)	122.7 (±8.6)	-4.16	0.61

Of note is the upper range of relative peak powers (W/kg) for the female athletes, these were found to be slightly higher than the lowest in the range for the male athletes (Table 4.2). This was confirmed in the allometrically scaled data where the influence of body mass has been removed.

Table 4.2. Mean relative peak power (±SD) with ranges for each group and normalised relative power calculated from baseline inertial peak power for male and female athletes.

	Relative Power (W/kg)	Normalised
Male	21.1 (±1.8)	0.41 (±0.06)
Range	19.0-23.7	0.36-0.51
Female	17.9 (±1.5)	0.38 (±0.02)
Range	16.5-19.7	0.34-0.40

Male athletes (Table 4.3) showed very similar relationships to the female athletes (Table 4.4) for relative changes in optimal cadence and peak power for sprint trials and peak power for keirin trials. There was a much smaller relative change (approximately half) for optimal cadence in the keirin trials between male and female athletes with males approximately twice that of the female athletes (males = -5.04%, females = -2.58%).

Table 4.3. Mean peak power and optimal cadence values (±SD) before and after simulated sprint and keirin prior work condition (male athletes).

	Sprint (n=20 trials)				Keirin (n=18 trials)			
	Pre	Post	%Diff	ES	Pre	Post	%Diff	ES
Power	1860 (±143)	1666 (±102)	-10.24	1.27	1943 (±154)	1828 (±154)	-5.93	0.73
Optimal Cadence	131.9 (±7.7)	123.8 (±8.8)	-6.05	0.88	132.7 (±6.5)	126.1 (±9.0)	-5.04	0.78

Table 4.4. Mean peak power and optimal cadence values (±SD) before and after simulated sprint and keirin prior work condition mean (female athletes).

	Sprint (n=15 trials)				Keirin (n=10 trials)			
	Pre	Post	%Diff	ES	Pre	Post	%Diff	ES
Power	1177 (±185)	1041 (±102)	-10.91	0.89	1128 (±162)	1068 (±145)	-5.22	0.40
Optimal Cadence	122.4 (±5.1)	112.7 (±6.5)	-7.84	1.91	119.7 (±2.9)	116.6 (±2.7)	-2.58	0.98

As shown in Figure 4.3 there was a consistent decrease in the peak power produced following the simulated sprint prior work in the male athletes.

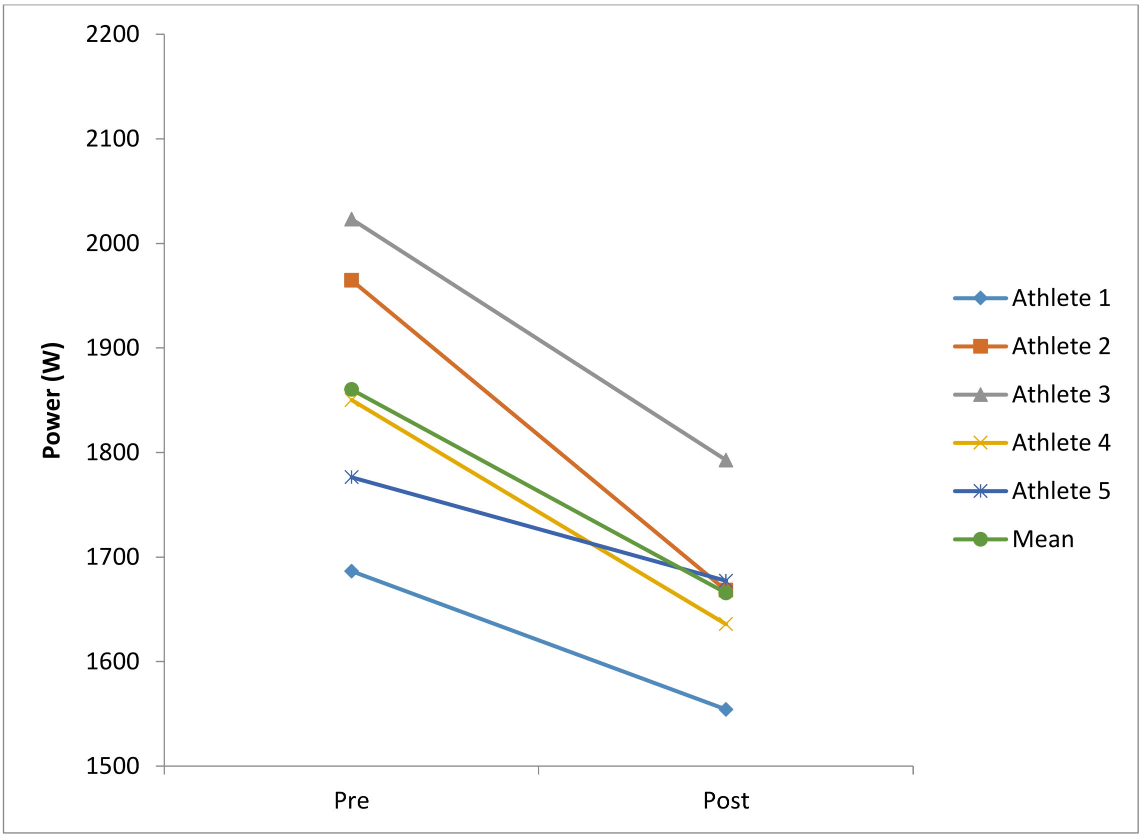


Figure 4.3. Mean peak power changes following simulated sprint prior work (male athletes).

As can be seen in Figure 4.4 there was a consistent decrease in the peak power produced following the simulated keirin prior work in the male athletes.

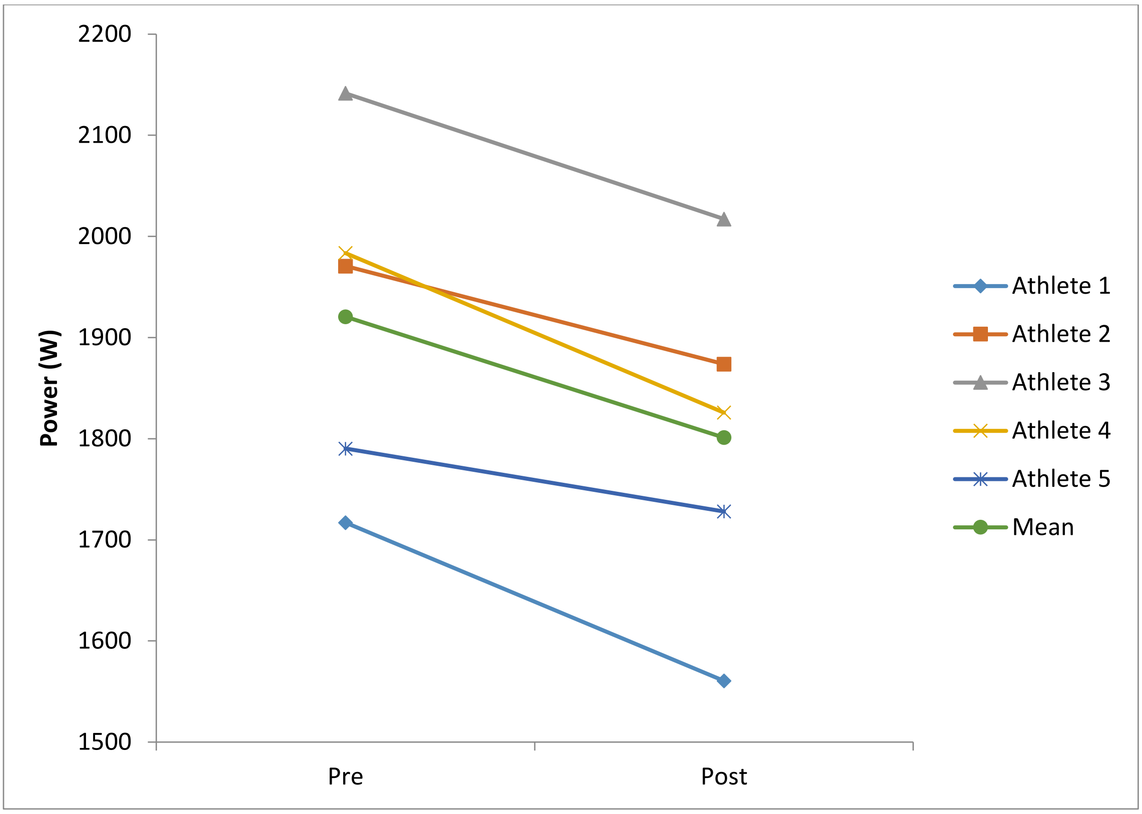


Figure 4.4. Mean peak power changes following simulated keirin prior work (male athletes).

As shown in Figure 4.5 there was a consistent decrease in optimal cadence following the simulated keirin prior work in the male athletes.

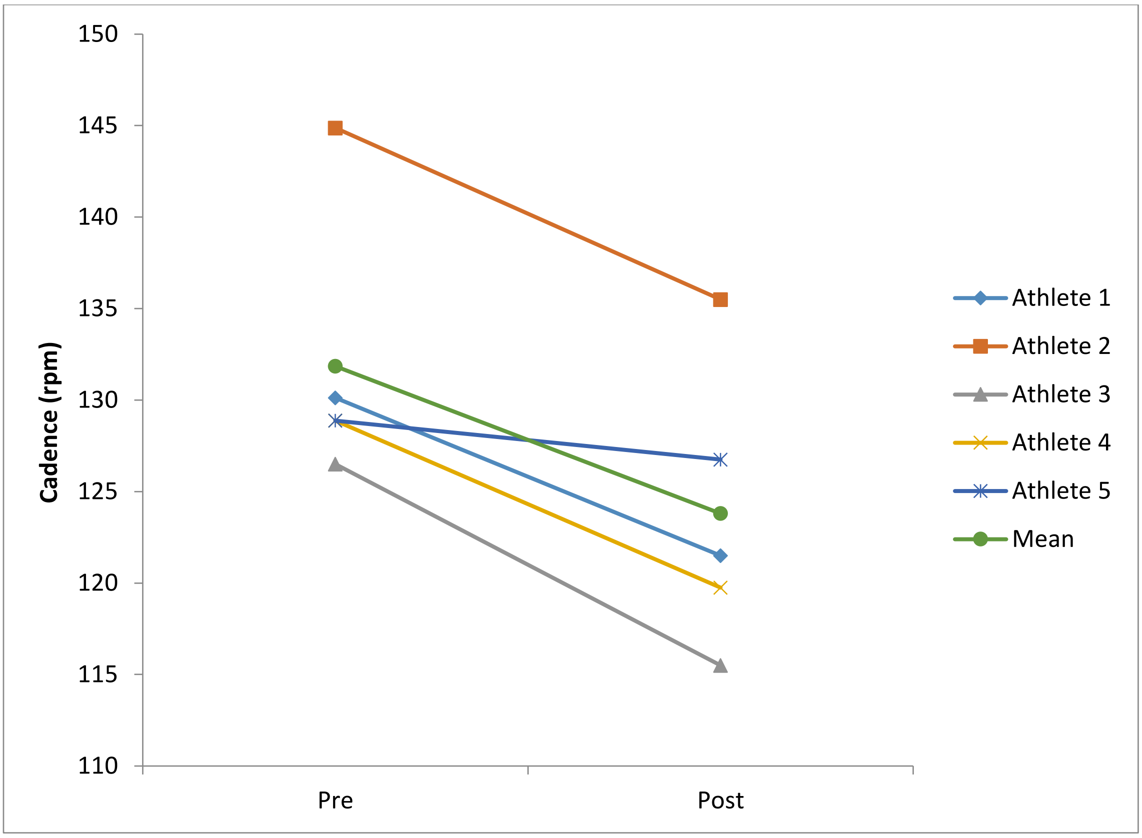


Figure 4.5. Mean optimal cadence changes following simulated sprint prior work (male athletes).

There was a consistent decrease in optimal cadence following the simulated sprint prior work in the male athletes (Figure 4.6).

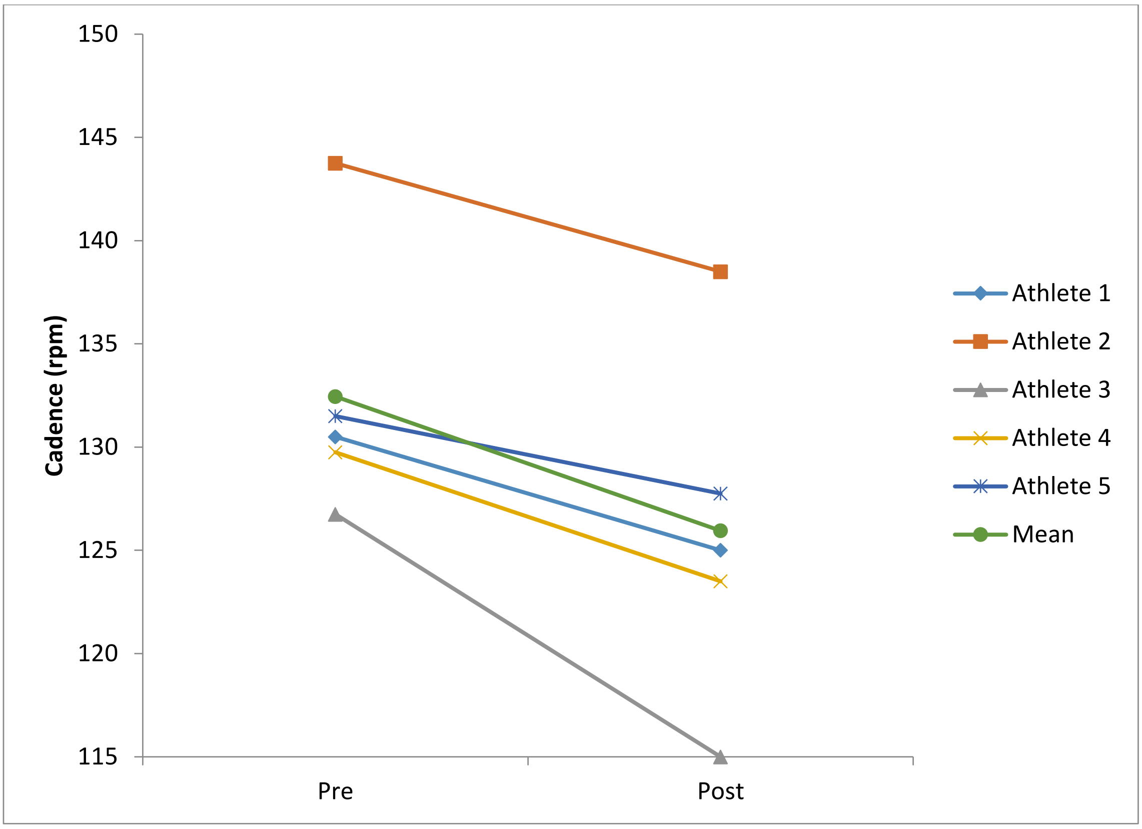


Figure 4.6. Mean optimal cadence changes following simulated keirin prior work (male athletes).

The magnitude of change in peak power and optimal cadence for the female athletes investigated was very similar to the male participants. Of note was the much smaller change in optimal cadence (-2.58%) following the keirin prior work simulation (Table 4.4). While the relative drop in peak power following the simulated keirin prior work was of the same magnitude of difference to the men the ES would indicate the difference is only small.

As can be seen in Figure 4.7 there was a consistent decrease in peak power production following the simulated sprint prior work in the female athletes. However there was a large amount of individual variation and one participant in particular was much less powerful than her peers.

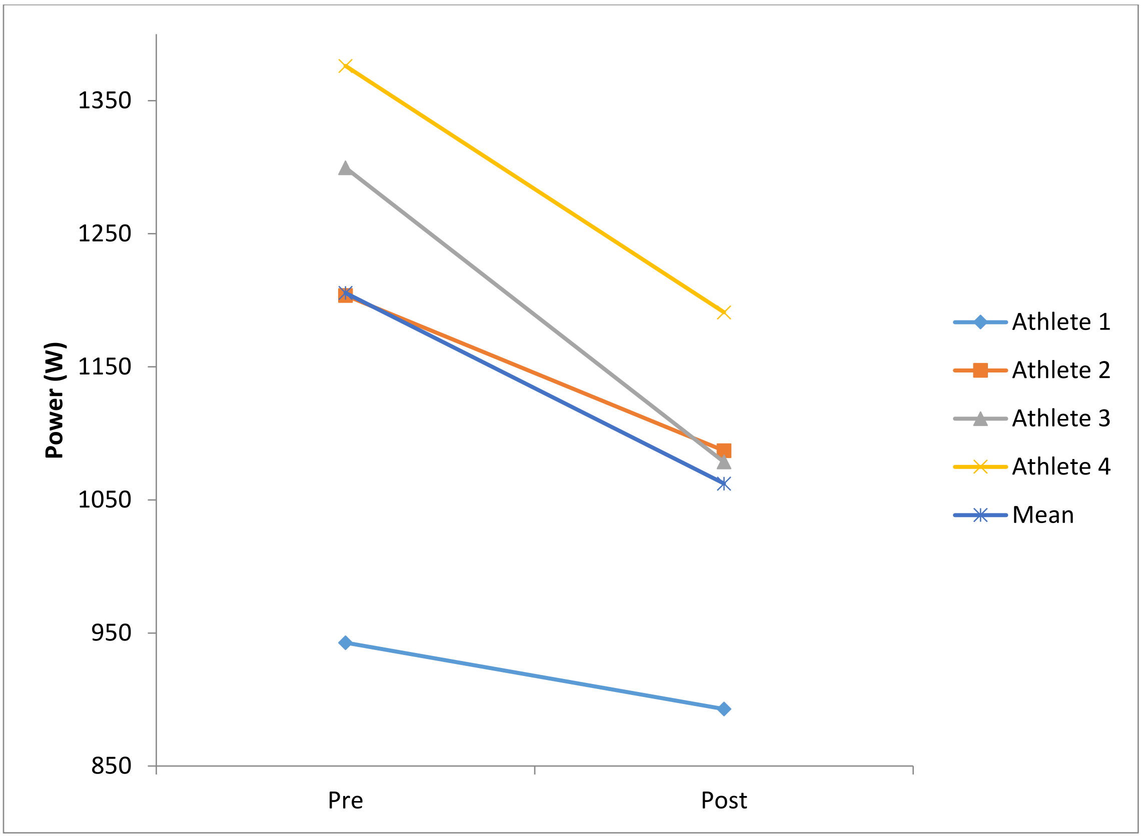


Figure 4.7. Mean peak power changes following simulated sprint prior work (female athletes).

As can be seen in Figure 4.8 there was a consistent decrease in peak power production following the simulated keirin prior work in the female athletes, however there was a large amount of individual variation and one less athlete available for analysis in the data due to unavailability. Again the magnitude of change was less than the sprint condition.

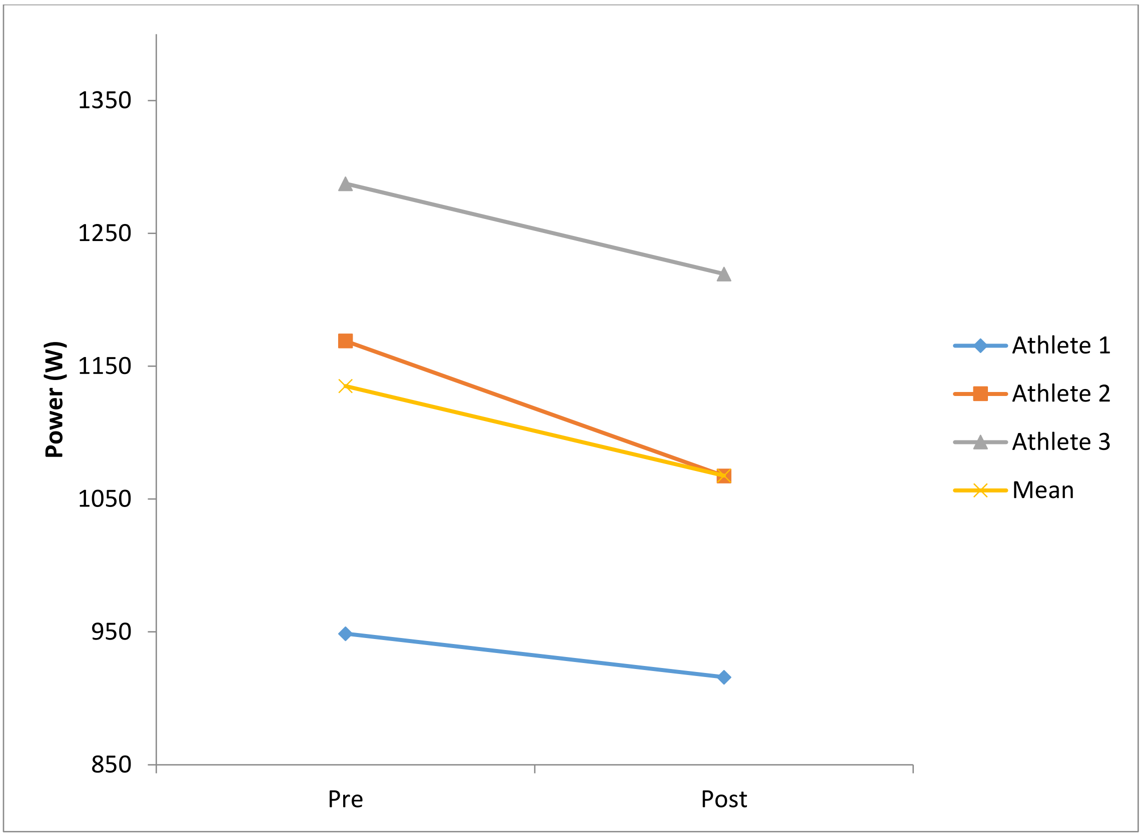


Figure 4.8. Mean peak power changes following simulated keirin prior work (female athletes).

Figure 4.9 provides individual information highlighting changes in mean optimal cadence following the sprint prior work condition. Of note in this plot is the contrasting magnitude of response to this condition from athlete 1.

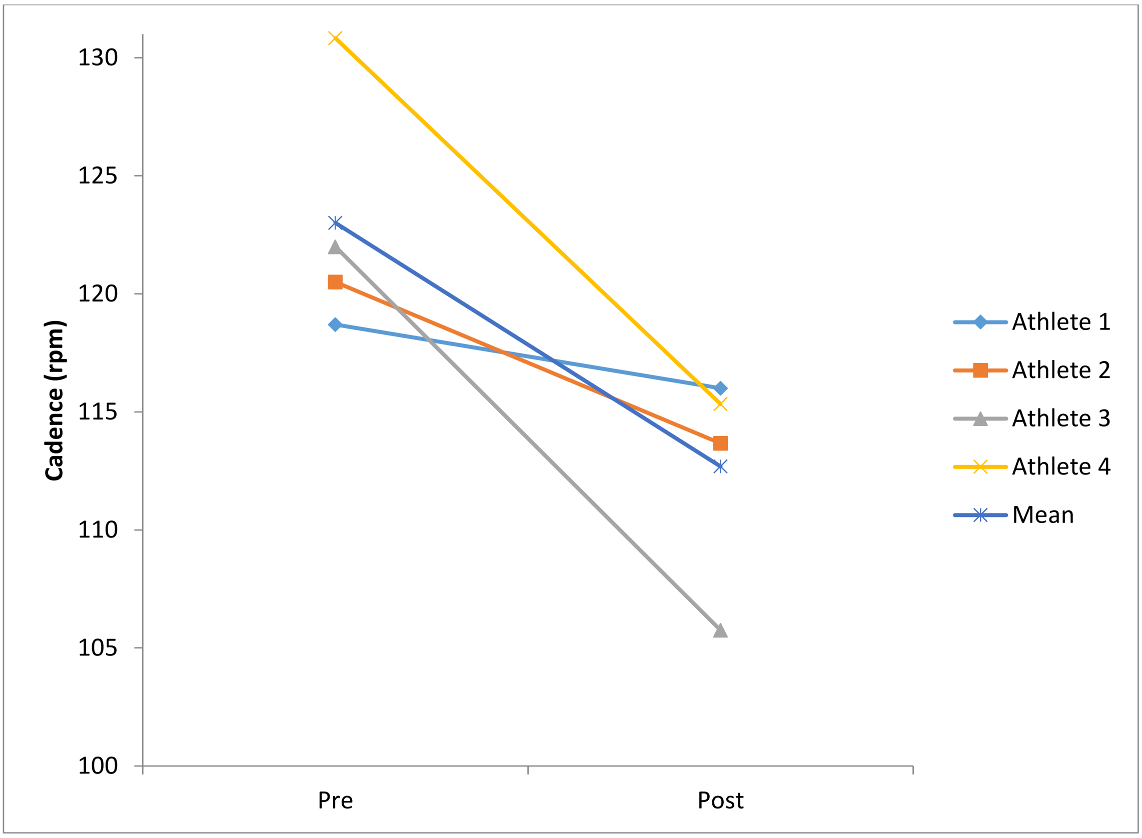


Figure 4.9. Mean optimal cadence changes following simulated sprint prior work (female athletes).

Figure 4.10 indicates a similar relationship in the magnitude of change between fatigue free optimal cadence and fatigued optimal cadence following the keirin prior work condition.

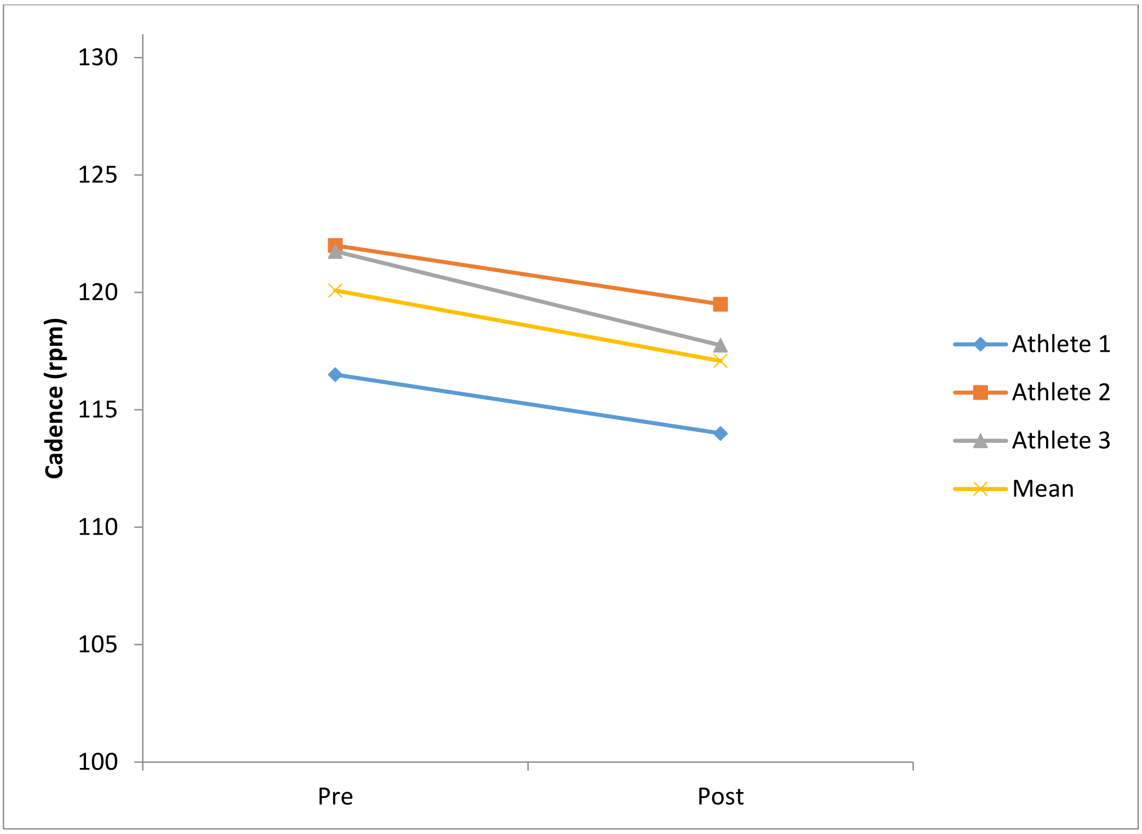


Figure 4.10. Mean optimal cadence changes following simulated keirin prior work (female athletes).

Table 4.5 indicates a lack of significance (p=0.81 sprint and p=0.64 keirin) and trivial effect size (ES=-0.03 sprint and ES=0.1 keirin) observed in the intended and actual prior work data.

Table 4.5. Comparison of intended and actual prior work achieved during both sprint and keirin prior work trials (male and female data). ES = Effect Size; W = Watts.

		Power
Sprint Lead in (n=35 trials)	**Goal (W)**	271.0 (±79.8)
	Actual (W)	273.5 (±76.7)
	% Diff	2.15
	ES	-0.03
	P-value	0.81
Keirin Lead in (n=28 trials)	**Goal (W±SD)**	229.2 (±67.5)
	Actual (W)	221.1 (±58.1)
	% Diff	-3.7
	ES	0.1
	P-value	0.64

Results - Individual Case Studies

Athlete 3 – Multiple event specialist

Table 4.6 indicates the peak power and optimal cadence changes relative to each simulated prior work condition. Of note is the relative drop in optimal cadence for this athlete (-9.29%) as the change is approximately twice as high as the average change in the group (-4.16%). There were large relative differences in peak power and optimal cadence following the prior work for the sprint condition of 11.44% and 8.74% respectively. These changes in power are reflected at a similar magnitude in the normalised data.

Table 4.6. Mean absolute, relative and normalised relative peak power (± SD) and optimal cadence values before and after simulated sprint and keirin prior work condition for athlete 3 only. ES = Effect Size.

	Sprint (n=4 trials)				Keirin (n=4 trials)			
	Pre	Post	%Diff	ES	Pre	Post	%Diff	ES
Power (W)	2023.00 (±48)	1792.00 (±104.00)	-11.44	1.60	2141.00 (±49.00)	2017.00 (±36.00)	-5.78	1.60
Relative Power (W/Kg)	20.48 (±0.48)	18.15 (±1.06)	-11.38	1.60	21.68 (±0.50)	20.42 (±0.37)	-5.80	1.60
Normalised Relative Power	0.36 (±0.01)	0.32 (±0.02)	-11.11	1.33	0.38 (±0.01)	0.36 (±0.01)	-5.26	2.00
Optimal Cadence (rpm)	126.50 (±5.90)	115.50 (±7.90)	-8.69	1.26	126.80 (±2.00)	115.00 (±7.40)	-9.31	1.46

Athlete 3 displayed weak relationships between optimal cadence, both peak and average power and standardised time when race data was investigated (Table 4.7).

Table 4.7. Correlation of optimal cadence and peak power with time from race data for athlete 3 only.

	Time
Optimal Cadence	0.21
Peak Power	-0.27
Average Power	-0.37

Athlete 4 – Team sprint specialist

There was a consistent large drop in peak power and optimal cadence observed in the simulated sprint qualifying ride (11.43% and 7.08% decrease with peak power and optimal cadence respectively) with a smaller decrease for the prior work completed for the keirin; all displaying a large effect size (Table 4.8). These changes in power are reflected at a similar magnitude in the normalised data.

Table 4.8. Mean absolute, relative and normalised relative peak power (± SD) and optimal cadence values before and after simulated sprint and keirin prior work condition for athlete 4 only. ES = Effect Size.

	Sprint (n=4 trials)				Keirin (n=4 trials)			
	Pre	Post	%Diff	ES	Pre	Post	%Diff	ES
Power (W)	1850.00 (±141.00)	1635.00 (±81.00)	-11.43	1.37	1983.00 (±29.00)	1825.00 (±86.00)	-7.97	1.53
Relative Power (W/Kg)	23.66 (±1.80)	20.91 (±1.04)	-11.58	1.37	25.36 (±0.38)	23.35 (±1.10)	-7.95	1.52
Normalised Relative Power	0.51 (±0.04)	0.45 (±0.02)	-11.76	1.50	0.45 (±0.01)	0.41 (±0.02)	-8.98	2.00
Optimal Cadence (rpm)	128.90 (±2.14)	119.80 (±2.22)	-7.06	1.73	129.80 (±1.44)	123.50 (±3.87)	-4.85	1.45

Athlete 4 indicated a weak relationship between optimal cadence and standardised race time, with a moderate negative relationship with average power during the 200m event (Table 4.9).

Table 4.9. Correlation of optimal cadence and peak power against time from race data for athlete 4 only.

	Time
Optimal Cadence	-0.25
Peak Power	-0.36
Average Power	-0.75

Discussion

The key finding from this study was the pronounced downward and leftward shift in the power/cadence curve following both the simulated sprint and keirin prior work conditions with a greater magnitude of change in the sprint condition. Findings observed support the hypothesis for this study; that there would be a greater degradation in peak power and optimal cadence in the simulated sprint prior work than the keirin. The magnitude of change for differences in peak power were almost double in the sprint prior work condition compared to the keirin prior work condition (10.52% for sprint compared with 5.93% for keirin when data from all athletes is considered, ES = 0.44 for sprint compared to 0.23 for keirin). Differences between the male and female athletes participating in the research were of a similar magnitude for peak power changes for both sprint and keirin. The trend is consistent with the findings of MacIntosh et al., (2004). However, the magnitude of difference in both optimal cadence and peak power between non-fatigued and fatigued conditions was much larger (33% lower OC and 45% lower power) following their maximal 30s fatiguing protocol. In contrast to their study, the prior work seen here was not maximal and this lends support to the magnitude of change in both variables being dependent on duration and intensity of the preceding work. This was further evidenced by a smaller change in the keirin prior work condition where the intensity of prior work is lower. It is important to note how closely matched the simulated lead in data for the prior work trials was to the goal power outputs (Table 4.5). This lack of significance gives confidence the manipulation of the work output during the simulation was not responsible for the differences seen in the data.

The previous literature indicates a strong relationship between 200m time trial time performance and optimal cadence with Dorel et al., (2005) observing a significant relationship between velocity during the 200m time trial (V_{200}) and optimal pedalling rate ($ƒ_{opt}$) (r=0.77). This supports the hypothesis explored by Dorel et al., (2005) that an athlete entering race day with a higher optimal cadence is more likely to achieve a better qualifying time than if their optimal cadence is low or compromised in any way. In contrast unpublished data from the male athletes participating in this research showed a poor correlation between optimal cadence and standardised time (r=-0.14), although, there is a large degree of variation (range in individual data: -r = 0.57 to 0.83) which serves to highlight the heterogeneity of physiologies present in these study participants. Consistent with Dorel et al., (2005) was the lack of relationship between peak power and F200m/race time (Dorel et al., 2005). Dorel et al., (2005) did not state the correlation between these variables however in the current study there was a weak negative relationship r = -0.45. It is possible that some of the differences were the result of differences in gear selections for the 200m time trial. In the participants of this study there is a greater range of gearing selections (and typically larger) made than those discussed by Dorel et al., (2005) where participants self-selected much smaller gears uniformly.

Evidence suggests optimal cadence has a strong relationship with muscle fibre type (Hautier et al., 1996; Pearson, Cobbold, Orrell, & Harridge, 2006; Sargeant et al., 1984). However it must be reasonably assumed that acute changes in optimal cadence are not related to changes in muscle morphology. It is also possible to interpret an acute decrease in optimal cadence post a fatiguing intervention as an athlete exhibiting less fast twitch muscle characteristics and as such at a disadvantage with respect to athletic performance. While the downward and leftward shift in the power-cadence curve seen here is consistent with the literature (MacIntosh et al., 2004), Sargeant (1994) has indicated that acute changes in optimal cadence relate to the body's drive to regulate the ability to produce maximal power in the fatigued state. This would suggest that power production is the most important component to be maintained, it is prioritised by the body and optimised through changes able to be detected by alterations to optimal cadence. As evidenced in this work the extent of the perturbation in optimal cadence appeared to be dependent on the intensity of the fatiguing work carried out; the decrease in peak power greater for the sprint trials than for the keirin trials.

It is therefore important to build an understanding of this shift in the power-cadence curve and the potential mechanisms responsible for optimising output in this situation. A key perturbation driving alterations to muscle contraction in situations of muscular fatigue relates to the modification of calcium release, and reuptake, and its role in sparing of ATP (Boyas & Guével, 2011). Calcium release from the sarcoplasmic reticulum (SR) has been shown to dictate ATP use during muscle contraction (MacIntosh, Holash, & Renaud, 2012). Sparing of ATP through alterations to SR calcium release and an increase in calcium sensitivity in myosin regulatory light chain (MRLC) promotes the ability to maintain contraction forcefulness (MacIntosh et al., 2012). Harmer et al., (2014) have also shown that ATPase activity is reduced during intense exercise, likely related to a drive to spare ATP. A reduction in the release of sarcoplasmic calcium and subsequent ATPase activity for resequestration of calcium promotes sparing of ATP in this context. The increased calcium sensitivity from MRLC phosphorylation therefore allows for increased force production for a comparatively lower level of calcium availability. Based on this information a drive to maintain maximal power output is critical and as previously addressed by Sargeant, (1994) will be prioritised. Intrinsic modifications to contractile elements and force production are therefore demonstrated by acute changes in optimal cadence and the optimal cadence change is dependent on the body's course of action to optimise power production despite its apparent relationship to overall muscle fibre composition.

Ca^{2+}-ATPase activity has also been shown to differ between male and female participants, with it being lower in women (Harmer et al., 2014). It is thought to be linked with muscle fibre type differences as women typically have a greater proportion of type I muscle (Roepstorff et al., 2006). In this study the results demonstrated baseline optimal cadence differences between males and females of approximately 11-12rpm (Table 4.3, male and Table 4.4 female data). Given the relationship between optimal cadence and muscle fibre type this would then indicate that the female participants have less fast twitch muscle present. It could also be expected the gender difference in Ca^{2+}-ATPase activity may potentially contribute to a reduced capacity to spare ATP during activity. When considered together, these points provide a reasonable argument for acute alterations to optimal cadence in fatigue when preservation of muscle contractile force is maximised through changes in calcium cycling and sensitivity.

Changes in the ability to coordinate muscle activity is also a likely contributor to the changes seen in fatigued optimal cadence. The changes observed by O'Bryan et al., (2014) in EMG of the major muscles associated with pedalling show reductions in the activity of the gastrocnemius and rectus femoris. Dorel et al., (2003) have also shown changes in the relative contributions of pedalling musculature with the development of fatigue and show gluteus maximus and biceps femoris increasing in activity in the presence of fatigue. In a subsequent investigation Dorel, Guilhem, Couturier, and Hug, (2012) have also shown a disproportionate increase of activity in the major pedalling muscles contrasting submaximal with maximal sprint cycling. While they do not investigate fatigue their work supports the modification of muscle involvement and activity in maximal sprint cycling. It is likely that subtle alterations will be intended to maximise power production (Sargeant, 1994) and relative contributions of pedalling muscles to overall joint power will be modified to achieve this optimisation.

The net results of both the treatment of calcium ions and changes in muscle activity will contribute the changes seen in optimal cadence values following the simulated prior work conditions investigated. Reduction in the ability to express fast twitch characteristics of muscle would agree with both the greater magnitude of change in optimal cadence and peak power production in the more intense lead in work completed in the sprint trials compared to the keirin. It seems realistic to assume calcium ions have an important impact mechanistically in maintaining muscle contraction in the presence of fatigue. It is possible that this mechanism is responsible for maintenance of the ability to still produce power, and a higher power in the keirin trials compared to the sprint trials (related to the prior work intensity) following the prior work periods of both of the events investigated here.

Relationship to performance

Available literature indicates a strong relationship between 200m time trial performance time and optimal cadence. Dorel et al., (2005) showed a significant relationship between V_{200} and f_{opt} (r=0.77). It seems reasonable to conclude that if an athlete can enter the event/day with the highest optimal cadence value possible and all other things being equal in their ride (correct execution of technical elements) this will likely improve their chances of producing their best time in an event. From the data presented here it is also reasonable to expect that optimisation of the pacing strategy during the lead in laps for the sprint to minimise the work completed would result in a smaller magnitude of degradation in power production. While the data here agree with Dorel et al., (2005), in that there is no relationship between peak power and 200m performance time, it could be expected that preservation of ATP via sparing calcium for muscle contraction during all aspects of this ride will have a relationship to overall performance (Allen et al., 2008). Despite this involvement of metabolic energy supply being disputed by Bundle and Weyand (2012) where they have argued sprint performance is demand driven and based on external force output. Alterations to race strategy with the intention of preserving ATP or optimising the energy distribution throughout this prior submaximal period would likely contribute to a greater average power (also a greater ability to apply eternal force) over the duration of the race. Again, strategies to reduce aerodynamic drag will also influence this power/time relationship.

Individual athletes

Two athletes, athlete 3 and athlete 4, have been selected for further discussion given their physiological attributes and event requirements.

Athlete 3 was the most powerful of all of the athletes investigated in this study when absolute power production is considered. Athlete 4 had the greatest relative power production (expressed in W/Kg, Tables 4.6 and 4.8) and the highest normalised relative power output (0.51). Athlete 3 exhibited a similar disturbance in optimal cadence following both the keirin and sprint prior work simulations (sprint -8.74%, keirin -9.29%), reflecting a 50% greater drop in optimal cadence for the sprint and an almost two fold difference in the keirin than the mean of all males in the study (mean percent change in optimal cadence was -6.05% and -5.04% for sprint and keirin respectively). It is possible that the race files obtained for this athlete were confounded and inflated by the strategy which had enabled a successful result in those events, creating a greater work requirement in the simulated work than the other athletes involved in this research. It is also possible that this athlete needs to ensure good position and race strategy to minimise excessive energy cost prior to the pacer leaving the track. As expected, in the race situation this will be challenging. Mentioned in this chapter already, the performance/race outcomes of the keirin, in a field of peers of equal physiological ability, is largely due to tactical ability and race execution. An energy saving strategy in an event like the keirin might not be a realistic option in a race setting. It is therefore reasonable that this athlete would benefit from strategies to improve resistance to fatigue and training to stress the SR and spare ATP through adaptation of release and resequestration of calcium ions and improvement in calcium sensitivity. It could be expected that as a result of this training strategy a chronic decrease in optimal cadence would be achieved.

Athlete 3 has (sometime after the conclusion of this study) begun riding the 200m time trial without standing and utilising a much larger gear ratio. The definition of large and small in relation to gear selection is relative to the perceptions of the individual describing the gear. Both Dorel et al., (2005) and Stone et al., (2004) discuss gear selection with Stone et al., (2004) defining small (84”) and large (90”) gearing selections in their study. Dorel et al., (2005) mention the self selected gearing selections of their riders being 7.32, 7.47 or 7.63m/rev. To compare equally the 84” and 90” gearing of Stone et al., (2004) equates to 6.52 and 6.93m/rev. The gear ratios reported by Dorel et al., (2005) would equate approximately to gear inches of 96”, 98” and 100”. In the context of fatigue and ATP sparing and given the findings of Tomas et al., (2010), where fatigue is shown to be related to the number of accumulated contraction cycles, that a lower cadence will then provide sparing of ATP to support the maintenance of a higher torque and therefore power output during the (later) timed portion of the event. Repeating this simulation with more recent “seated” lead in data may offer different insight with respect to work intensity and accumulated fatigue with this athlete as a result of the larger gear and corresponding lower cadence. Data here is only from ’standing’ results. With respect to the alterations to this athletes race strategy it is possible to produce larger powers (approximately 8% larger (Reiser, Maines, Eisenmann, & Wilkinson, 2002) when standing owing to the involvement of the upper body musculature (Martin et al., 2007). Athlete 3 was the largest athlete in this study, and as such being larger creates a greater frontal surface area (Dorel, et al., 2005). Martin et al., (2006) reported field and wind tunnel derived values of C_DA (drag) and claimed 0.245m^2 seated and 0.304m^2 standing, clearly indicating a reduction in drag for a seated rider. The athletic characteristics of their largest subject, a match sprint specialist at 1.83m tall and 96kg is very close to athlete 3 in the present study. For the athlete in the study by Martin et al., (2006), the standing and seated drag area values were 0.414m^2 and 0.332m^2 respectively. Remaining seated reduces the resistive forces the athlete is subjected to as aerodynamics are improved, however, the trade off with this approach is a compromised ability to produce peak powers as large as when standing (Davidson, Wagner, & Martin, 2004).

From historical data of the athletes involved in this research it was shown (in our male participants) that peak power exhibits only a moderate correlation with overall performance in the 200m time trial (r = -0.45). Dorel et al., (2005) did find a significant relationship with peak power relative to frontal surface area (P_{max}/A_p). The differences in drag at high velocities, and therefore differences in relative intensities at a given speed may also explain a portion of the variation seen in the small sample of athletes in the present study. Historical data from this group also showed average power during the 200m time trial is a weak descriptor of the variation that is seen when compared with standardised (standardised for environmental conditions of: temperature 23.0°, pressure 1013 hPa, relative humidity 50%) race time (r=-0.35). There has not been an estimation of frontal surface area or drag to differentiate relative powers in relation to these characteristics.

Athlete 4 showed a consistent large drop in peak power and optimal cadence in the simulated sprint qualifying ride (11.43 and 7.08% drop with peak power and optimal cadence respectively) with a smaller decrease for the prior work completed for the keirin; both displaying a large ES (ES peak power sprint 1.37, keirin 1.53 and optimal cadence sprint 1.73 and keirin 1.45). Athlete 4 did not show a very strong relationship between optimal cadence and event performance (Table 4.9) but did exhibit a stronger relationship with average power and time in the overall flying 200m (r=-0.75).

Typically athlete 4 completed a greater proportion of low speed acceleration work with less emphasis on the high speed flying components of training. It could be argued athlete 4 did not gain enough metabolic stress in their training to tolerate the duration of prior work completed in each of the two events. Interestingly athlete 4 did deviate greatly from the male average for differences in peak power and optimal cadence following the simulated racing work (male mean sprint PP = -10.24%, OC = -6.05%, keirin PP = -5.93%, OC = -5.04%, athlete 2 PP = -11.43%, OC = -7.08%, keirin PP = -7.96%, OC = -4.82%), however power degradation tended to be higher.

Observational analysis of athlete 4 would also indicate a compromised aerodynamic drag due to suboptimal body position. Again this was likely to be the result of performing the bulk of training to improve the ability to accelerate from low speed with much of this work out of the saddle at high torque and low cadence (relative to this flying work). It could be accepted then that adaptation to the ability to apply torque in the standing position was related to contraction velocity as torque applied at higher contraction velocities is much lower (Samozino et al., 2007). It is possible that the strength of the relationship between average power and performance time was the result of a high degree of drag at speed. With the likely compromises to an ability to produce acceleration power when standing and the strength of the relationship between average power and event time for the 200m time trial athlete 4 was compromised both physically and aerodynamically in their generation of speed; their event time was more reflective of the work they were doing during the race.

Given the role of calcium in mediating sparing of ATP and our ability to detect and track this with changes in optimal cadence it will have specific implications for the trainability of the SR and calcium cycling. This understanding is developed further in Chapter 6 where improvements in resistance to fatigue were specifically targeted. It is likely that the hypothesis presented by Dorel et al., (2005) that race cadences more closely aligned with optimal cadence will create a situation of enhanced performance ability is a component of a more complicated multifactorial relationship; linking fatigue from the prior work requirements and the body's drive to maintain power production. It has been shown here duration and intensity of the preceding work has the greatest contribution to excursion in peak power from fatigue free values and a downward and/or leftward shift in the power/cadence curve.

It should be noted that indicators of performance in the keirin can be considered physiologically similar to that of the 200m time trial. An ability to generate a maximal acceleration and maintain the achieved maximum speed is common in all track sprint cycling events. However, success as determined by racing results in this event is much more reliant on the tactical racing ability of the athlete. It is reasonable to expect that once an athlete is physiologically competent to be competitive with his or her peers in this event then the racing outcome is much more dependent on racing strategy and tactics. This was beyond the scope of this thesis. It is possible to make inferences about physiological state once the pacer has left the track and the race begins proper. In particular the differences of the prior work on peak power and optimal cadence at this point and relating this back to an overt physiological performance such as the flying start 200m time trial for the beginning of the sprint competition.

Differentiation of lab and field data

It is important to note that the field collected data has only been used to show the relationship between power values (peak and average for the 200m distance) and standardised race times during 200m time trials ridden in competition. In this instance the performance of the prior work and subsequent maximal acceleration will differ slightly to the laboratory setting. Laboratory simulation of the influence of the prior work involves the cessation of pedalling on the ergometer to bring the flywheel and pedals to a complete stop for the performance of the inertial test. This gives relevant comparison between fatigue free values and the influence of the prior work performed in the simulation. The data here have been analysed in the same manner as Dorel et al., (2005) with lab determined optimal cadence values compared with field data.

Conclusions

From the information presented in this chapter it may be concluded that the initial 1375m completed behind the motor bike in the keirin can be factored into the race preparation of the athlete and is not sufficient to negatively impact on their ability to perform in the race proper. By exploring gearing and alternative pacing strategies for the 200m time trial it may be possible to optimise the ability to maintain higher peak power; particularly in those athletes that demonstrate a relationship between peak power and more successful/optimal performance. Similarly performance is likely to be enhanced through ensuring gear selection and pacing strategies will minimise fatigue present at the point of maximum acceleration in the work prior to the commencement of the timed portion of the event. Optimisation of position and equipment to minimise drag and exploit the relationship shown between peak power and aerodynamic drag will also likely contribute to a better overall performance. Outside of race day performance the construction of appropriate training periodisation entering racing situations with the highest possible optimal cadence is likely to have a significant impact on the physiological performance ability of the track sprint cyclist in both the keirin and the match sprint competition.

5. Monitoring of Elite Track Sprint Cyclists Preparation for the London Olympic Games

Prelude

Critically important to any athlete and coach is the prescription and execution of a training programme constructed to achieve a training stimulus which will elicit a specific training adaptation. Even more important than this training adaptation is the creation of a positive outcome on future competition performances. In track sprint cycling the need to develop aerobic and anaerobic power and capacity, strength, power, speed and technical/tactical components introduces a challenge for the coach writing the training programme (Craig & Norton, 2001). Improvements in performance are the coach and athletes ultimate goal. The ability to have the athlete in their peak physical condition on the day of competition is a challenge which is very difficult to achieve and is demonstrated by how few Olympic athletes (~30%) perform personal bests at the quadrennial competition (C. D. Palmer, personal communication, June 26, 2014 citing analysis of athlete performance data comparing Olympic performance with personal best performance). The results presented here were intended to contribute to the knowledge base of progression and adaptation in power output and associated physical qualities across two significant pinnacle events and to the understanding of the track sprint cyclist in general.

Introduction

Cycling speed under any given set of conditions (i.e. no change to aerodynamic properties or other components of drag on the cyclist, mass, or alterations to technique or technical ability) is inextricably linked to the athletes ability to generate power (Driss & Vandewalle, 2013; Martin et al., 2005). A higher power output will result in a higher speed and ultimately it is this higher speed and low event time that will determine the overall performance of the athlete. The progression towards higher power outputs, both peak power output and mean maximal power outputs that can be sustained for any duration of time indicate a global improvement as a result of training. It would be expected that an athlete failing to display this trend is unlikely to perform as well on race day as they could. Dorel et al., (2005) demonstrated a significant correlation between maximal power related to frontal surface area and 200m time trial performance velocity. They failed to see a significant relationship between absolute maximal power and velocity which would suggest substantial relevance of the contribution of aerodynamic drag. Equipment aside, the influence of aerodynamic drag may also be indicative of the contribution of differences in riding technique. Performance outcome has previously been linked to the athlete's ability to produce power (O'Bryan et al., 2014) and a reduction in power production is almost certain to have a negative impact on performance (Martin et al., 2006). McLean, Petrucelli, and Coyle, (2012) used inertial load testing to detect staleness and overreaching in female soccer players and demonstrated sensitivity to changes in training load in these athletes. Given the importance of power output and the ability of inertial load testing ergometer to detect meaningful change in peak power (Chapter 3); it would be expected that the concurrent use of the inertial ergometer for monitoring throughout this study could potentially provide reliable information on the acute physiological state of athletes.

Understanding the training progression and impact of the training stimulus is critically important for coaches and sports scientists. Tracking and monitoring athletes to determine their progress and the physiological impact of the training stimulus continues to become more detailed and more precise with ergometers and instrumentation to measure physiological outputs. Increasing application of sports science has enhanced the ability to understand and describe athletes, the requirements of the event and their physiological responses to training beyond 'appearance and feel' by providing robust quantification of how the athlete is performing and tracking over time.

Cycling, as in many sports, has historically prescribed training and conditioning protocols based on what has been done previously, or worked to copy what is seen to be done by other more successful nations and athletes. Typically in track sprint cycling it is accepted that a more linearly periodised approach is taken working through blocks of endurance, strength, and power phases and then a period of speed work as the athlete tapers into competition (unpublished observations). Through the later phases (strength, power, speed) there is a reduction in endurance work; higher gear ratios are generally used during the strength and power phases with a typical mirroring of the on and off bike work. During the speed and taper phases gear ratios are reduced and motorised pacing employed to assist in the generation of higher speeds, work intensity is high with volume reduced (unpublished observations).

As discussed in previous chapters track sprint cycling provides a unique “sprint” athlete and overall the sprint cyclist is not analogous to the 100-400m track and field sprinter. Much of the literature concerning sprint cycling or investigating sprint cycling has been carried out on more sub-elite recreational endurance oriented athletes performing sprint testing or training; Tomas et al., (2010) described participants as category 2-3 amateur road and expert level mountain biker (maximal powers do not suggest any sprint athletes). Tomaras and Macintosh, (2011) have researched using highly trained male track cyclists from local league (peak powers reported appear to be sub elite) while Barnett, Jenkins, and Mackinnon (1996) studied repeated ten second bouts of sprinting on an ergometer describing their participants as “physically active men”. O’Bryan et al., (2014) investigated muscle activity in ten active males who were a mixture of team sport athletes, individual sport athletes and one who undertook resistance training. Racinais et al., (2007) listed nine healthy males in their study and Weyand et al., (2006) recruited seven subjects, four males and three females who ranged from recreational to trained competitive cyclists. Crampton et al., (2011) included 16 healthy male Gaelic football players in their study which looked at contrast water immersion on sprint cycling performance. A small amount of research has investigated the physiological characteristics of elite level international class track sprint cyclists (Dorel et al., 2005; Dorel et al., 2012; Gardner et al., 2005; Gardner et al., 2007; Gardner et al., 2009; Martin et al.,2006). The mixed-muscle requirement of sprint cycling and the need for performance of aerobic prior work in all but one Olympic discipline further exacerbate the challenge to the coach prescribing the training. Performance at pinnacle events such as Olympic Games will direct the progression and prescription of the training programme regardless of the particular approach to periodisation taken.

The pinnacle event is the end-point from which the training plan and progression is worked back from regardless of the particular approach to periodisation taken. It is the goal of any programme to peak at this predetermined time. A careful and structured approach to this training progression will allow continual improvement in the physiological ability of the athlete. Often the application of a blind training overload can mislead improvements in performance and physiological ability. Typically the withdrawal of this training overload and subsequent freshening of the athlete as competition approaches brings improvements in their ability to perform simply because they are no longer under load (Mackinnon, 2000). It is reasonable to accept that application of a training stress in this manner cannot guarantee improvement once the athlete has freshened for competition. A training stimulus designed to attain optimal adaptation and administered and executed correctly will see performance ability, once fresh, rise to a level greater than previously possible. It would be expected that an appropriate training progression and approach will see an athlete reach their pinnacle event capable of performing at new personal best levels. Developing an understanding of the impact of the prescribed training stimulus and its effectiveness in achieving the desired physiological adaptation is crucial in planning for each athlete to be able to arrive at race day in the best physical and physiological state possible.

The current study was a longitudinal evaluation of internationally competitive track sprint cyclists from the beginning of the 2011-2012 season through to the 2012 Olympic Games. Therefore the purpose of this study was to investigate the impact of the prescribed training stimulus and its effectiveness in achieving the desired physiological progression to positively impact on performance in elite track sprint cyclists. This study was also intended to create a greater understanding of the physiological responses to the training achieved prior to the London Olympic Games and determine the appropriateness of the training stimulus in achieving this adaptation and its influence on the performance outcome.

Methods

Participants

The participants were five male (mean ± SD, weight 89.7 ± 8.1kg, height 181.6 ± 1.9cm) and three female (mean ± SD, 69.3 ± 4.9kg, 168.7 ± 6.0cm) track sprint athletes, all members of the national sprint squad. They were monitored for key training variables from November 2011 to July 2012 (the commencement of the London Olympic Games).

Training Programme

The training programme was supplied by the coach to the athletes. Typically during a training camp a copy was also provided to the researcher. Table 5.1 indicates the typical programme schedule during a race week while Table 5.2 indicates a more typical non-competition week. The programmes contained in Tables 5.1 to 5.5 outline typical training from mid-April 2012.

Tables 5.1 to 5.5 indicate the typical training undertaken through the significant phases of training prior to both pinnacle events and in the phases of training leading into the London Olympic Games. They are indicative of the training dose prescribed by the coach. Gearing is indicated relative to the athlete concerned with typical small gearing 88-92”, moderate 94-100”, race gearing 96-104” and large gear 108-112”. Cycling gear inches are calculated by finding the gear ratio (divide front chain ring by the rear sprocket) and multiplying by 27 (inches). It bears little relation to the rollout of the bicycle but is a historically descriptive system (when larger road cycling wheels were 27” in diameter) which remains in use today and is a common language among athletes, coaches and mechanics.

Table 5.1. Typical training programme prior to 2012 World Track Cycling Championships.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	12-Mar	**13-Mar**	**14-Mar**	**15-Mar**	**16-Mar**	**17-Mar**	**18-Mar**
AM	Rest	Rest	Gym	Track - F250m x 4, 2 x S60 race gearing	Rollers 30min	Gym	Rollers 30min
PM	Rest	Rest	Power Jumps x 4 2-4" above race gearing plus 2 x 30-50m start race gearing	Road 60min (optional)	Pre-Race Hit Out for trial tomorrow	Standing lap Trial - 2 x S250 race gearing	Rest
	19-Mar	**20-Mar**	**21-Mar**	**22-Mar**	**23-Mar**	**24-Mar**	**25-Mar**
AM	Pre-Race Hit Out - S60, S100, F100 race gearing	Gym potentiation	Rest	TS Starts x 2-3	Rest	Gym	Rollers 30min
PM	Gym – Upper Body Only	S750m Trial moderate gear	Rest	F200m plus 2 x keirin (race simulation) race gearing	Rest	Erg 5 x 20s:5min recovery	F100 x 4 – 2-4" below race gearing
	26-Mar	**27-Mar**	**28-Mar**	**29-Mar**	**30-Mar**	**31-Mar**	**1-Apr**
AM	Rest	Rollers 30min	Gym				Gym
PM	1:3:1 500m effort x 3 small-moderate gearing	F200m lead in x 1 race gearing	S180m TS Start, 2 x flying 200 motor lead in race gearing		Travel	Track Familiarisation incl 2 x TS Starts moderate gear	Track - light roll no specific efforts
	2-Apr	**3-Apr**	**4-Apr**	**5-Apr**	**6-Apr**	**7-Apr**	**8-Apr**
AM	Rollers	Rest		Track - rollers	Potentiation	Track - rollers	Potentiation
PM	Power jump 300m x 2 race gearing	Full race warm up - S60, F100 on race gearing	Team Sprint Race Day, compete evening - potentiate mid PM	Rest	Sprint	Rest	Keirin

Table 5.2. Typical training programme post 2012 World Championships during designated low intensity endurance training phase.

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
	16-Apr	**17-Apr**	**18-Apr**	**19-Apr**	**20-Apr**	**21-Apr**	**22-Apr**
AM	Rest	Gym	Road 120min moderate intensity (RPE 6-7)	Erg - 5min on:5min off x 4 - $\dot{V}O_2$ intensity	Rollers 30min high cadence	Road 120min moderate intensity (RPE 6-7)	Erg - 3min on:3min off x 6 - $\dot{V}O_2$ intensity
PM	Rest	Road 75min moderate intensity (RPE 6-7)	Rollers 30min high cadence	Rollers 30min high cadence	Gym	Rollers or coffee ride self-directed (RPE 3)	Rest

Table 5.3. Typical training programme post 2012 World Championships during designated strength training phase.

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
	14-May	**15-May**	**16-May**	**17-May**	**18-May**	**19-May**	**20-May**
AM	Track - Starts (2 sets from gate 1 set from 2nd wheel) - 15, 100, 180m x 3 – moderate to large gearing, increase by 2” in second set	Gym (including specific eccentric work) followed by rollers (30min)	Gym (including specific eccentric work) followed by rollers (30min)	Track - F250 x 2 moderate gear, F500 x 2 increase by 2-4”	Gym (including specific eccentric work) followed by rollers (30min)	Gym (including specific eccentric work) followed by rollers (30min)	Rest
PM	Road 75min or rollers 30min	seated 500m x 3 – large gear increase by 2” each rep, 750m x 1	Erg - 3min on:3min off x 8 - $\dot{V}O_2$ intensity	Rollers 30min high cadence	Road 75min or rollers 30min	Erg - 3min on:3min off x 8 - $\dot{V}O_2$ intensity	Rest

Table 5.4. Typical training programme and progression during early precompetition phase prior to 2012 London Olympic Games.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	18-Jun	**19-Jun**	**20-Jun**	**21-Jun**	**22-Jun**	**23-Jun**	**24-Jun**
AM	Gym	F200 x 4	Rest	Rest	Gym	Rest	Rest
PM	Power Jumps x 5 - 250m x 1, 375 x 2, 500m x 2 moderate gear increase 2” each rep	Rest	TS Starts x 4 – 125m, 180m, 250m, 375m – all 2” below usual race gearing	Rest	Power Jumps x 4 - 250m x 1, 375 x 2, 500m x 1 moderate gear increase 2” each rep	F250 x 2, F500 x 2	TS Starts x 3 125m, 180m, 250m plus 3 x 60m starts individual – all race gears
	25-Jun	26-Jun	27-Jun	28-Jun	29-Jun	30-Jun	1-July
AM	Rest	Gym	F100 x 4	Road 45mins – easy (RPE 4)	Rest	Gym	F100 x 4 – moderate gearing
PM	Rest	Power Jumps x 4 - 250m x 1, 375 x 2, 500m x 1 moderate gear increase 2” each rep	Flying TS x 5 – 500m – ½ lap turns – all race gears	Specific technical/tactical drills moderate gearing	Rest	TS Starts x 5 – 125m, 180m, 250m, 375m, 500m – all race gears	Flying TS x 5 – 500m – ½ lap turns – all race gears

Table 5.5. Typical training programme late precompetition and competition phases immediately prior to 2012 London Olympic Games.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	16-Jul	**17-Jul**	**18-Jul**	**19-Jul**	**20-Jul**	**21-Jul**	**22-Jul**
AM	Plyometrics	F500 x 2, F750 x 2 moderate gearing increase 2' each rep	Power Jumps – 375m x 4 on race gear	Rest	Gym	Gym – potentiation session	Rest
PM	Track familiarisation plus easy FTS x 1, F200m line x 1, 3 x 15m gate starts at max intensity small gearing	Road recovery ride – 45min	Derny lead out F100 x 3 moderate gearing	Rest	Flying TS x 4 375-500m ½ lap turns – all race gearing	TS Race Simulation - 3 full distance (750m) rides in 85min – all race gearing	Rest
	23-Jul	**24-Jul**	**25-Jul**	**26-Jul**	**27-Jul**	**28-Jul**	**29-Jul**
AM	Rollers 30min plus 3 x inertial sprints	Coffee/fresh air ride	Power Jumps x 2 375-500m	Rest/Travel	Rest	Flying TS 375m x 2 - 1/2 lap each moderate gearing	Gym - Upper body +
PM	TS Starts, 100m x 2, F500m with last 250m on own x 2	TS start 20m, 100m technical, F 500m with motor lead out x 1	Pack	Rest/Travel	Rest	Rest	TS x 2 - start only – 60m – 2" below race gear and race gear
	30-Jul	**31-Jul**	**1-Aug**	**2-Aug**	**3-Aug**	**4-Aug**	**5-Aug**
AM	Rest	Rollers 30min	Rest	Potentiation	Rest	Sprint Race Day	Sprint Race Day
PM	Rest	TS Starts, 125m x 2 plus F250m on race gearing	Rest	Race Day TS	Rest	Sprint Race Day	Sprint Race Day
	6-Aug	**7-Aug**	**8-Aug**	**9-Aug**	**10-Aug**	**11-Aug**	**12-Aug**
AM	Rest	Keirin Race Day	Rest	Rest	Rest	Rest	Rest
PM	Rest	Keirin Race Day	Rest	Rest	Rest	Rest	Rest

Monitoring of Training

Inertial testing

Inertial-load testing was regularly performed at all training camps between October 2011 and July 2012 as a monitoring tool. During June and July 2012 the inertial ergometer was transported with the athlete equipment to Europe to continue testing. Inertial testing was carried out as previously described (Chapter 3) with athletes completing two tests and the average of the two tests used for reporting at each occasion. The protocol was adjusted at the request of the coach during the European training phase where athletes completed a single inertial test during their warm up prior to each track session. It was intended that this testing contributed a portion of the warm up for that track session. Where two track sessions were scheduled on one day the inertial test was included in the session which fell in the afternoon. This was not expected to compromise data capture as the testing procedure had been shown to be reliable (Chapter 3).

Field Training - Power

Athletes bikes were instrumented with SRM power meters (SRM - Schoberer Rad Meßtechnik GmbH, Jülich, Germany) with data captured via an in-house data logger and analysed using an in-house software package written using MATLAB (MathWorks, Natick, Massachusetts, U.S.A.). A regular static calibration of the SRM instrumented cranks was carried out using a known mass and first principles to calculate the instruments slope (Hz/Nm) and ensure accurate data collection. Data from every track training session when in training camps in New Zealand, international race meetings (where available) and the European training phase prior to the Olympic Games was collected and analysed for physical and performance variables. Race data was not captured during the Olympic Games as all instrumentation was removed prior to racing. All physical variables relating to the athlete and the machine: torque, speed, cadence and time were collected and analysed. Calculated metrics such as power and mean maximal power were computed from the data. Mean maximal power was described for time periods of five, ten, 15, 20 and 30 seconds and represented the highest mean power for each specified duration during a training or competition effort during the file.

Non-Track Bike Sessions

Given the relatively small component of non-track sessions completed by the sprint athletes, power training files were captured for all road rides over the first month of monitoring and tracking. As a result of the low intensity of these rides and the relatively small component of their training a low level of intensity was assumed for all subsequent rides and only time ridden was considered and outlined. Riding the rollers was also considered in this manner. Typically riding on the rollers was carried out at a low intensity due to the small amount of resistance offered by this training device therefore only duration of time engaged in riding the rollers was considered with an assumed intensity. The analysis of road riding and any power files captured and downloaded by the athletes was carried out using Training Peaks WKO+ (Peaksware LLC, Boulder Colorado, USA).

Any ergometer sessions which were carried out in place of, or to simulate track sessions, were analysed in the same manner as a training session on the track with peak power and mean maximal powers over the same durations as the track based sessions also using Training Peaks WKO+. While work time is more a component of the ergometer simulations rather than the time taken to cover a set training distance, this was accepted as a major difference between the two types of sessions and power throughout the work durations was tracked and reported.

As there was the ability to track athlete variables through training and competition in detail, and the maximal nature of the majority of the training programme, it was requested that specific test batteries to ascertain physiological status of the athlete were not used. It should be noted that for pinnacle competition the athletes racing bikes had all instrumentation removed to reduce weight and create a psychological enhancement for the athlete going into competition. For this reason power data is unavailable for pinnacle events.

Gym Based Resistance Training

Resistance training through the period was monitored by session RPE using the modified Borg scale; which rates work from zero to ten with zero being rest and ten being maximal (Figure 5.3) (Foster et al., 2001). Athletes recorded RPE using a custom designed training diary iPhone app (High Performance Sport New Zealand, Auckland, New Zealand). Session RPE has been shown to be a reliable method of quantifying resistance training and other modes of training (Day, McGuigan, Brice, & Foster, 2004). Included in this was any off-bike potentiation on race day as athletes would potentiate in the weights room approximately 5 hours prior to competition on selected race days.

Rating	Descriptor
0	Rest
1	Very, Very Light
2	Light
3	Moderate
4	Somewhat Hard
5	Hard
6	-
7	Very Hard
8	-
9	-
10	Maximal

Figure 5.1. Modified Borg Scale for session RPE (Day, McGuigan, Brice, & Foster, 2004).

Survey Data

Athletes were required to complete a daily survey which had been constructed using application software for the iPhone by High Performance Sport New Zealand (or other suitable Apple device). Athletes were required to complete an RPE for their gym sessions, recording their body weight and how "energised" they were to train that day. Athletes responded by selecting one of: not at all, feeling wrecked; a little, feel flat; moderately, feeling ok; very, feeling pretty good; extremely, I'm on fire! This data was then used to generate a report and was downloaded into Microsoft Excel for analysis. Once downloaded a numeric identifier (one to five) was assigned to each level of training readiness.

Evaluation of training

The training programme prescribed for the athletes was assessed based on what the intended mesocycle phases were targeting as indicated by the coach. Each phase was then further evaluated quantify the distribution of frequency of each training component. Within this the content of the track session was also broken down to best differentiate the stress on the rider (Table 5.6).

Table 5.6. Breakdown of track training components.

Training Component	Additional Information
Standing Starts	Included hand held starts from a starting gate
Acceleration	Included maximal acceleration work with or without a motor bike or another ride and acceleration work completed solo.
Sustained effort 500-1000m	Included submaximal work sustained for 500-1000m.
Flying Speed	Included efforts which were begun at maximal velocity with the riders either alone or completing a team effort (i.e. a team sprint from a flying start)
Motor-paced flying speed	Included efforts which were paced up to maximal speed with a motor bike or derny.
Specific lactic/metabolic	Included efforts which were targeted specifically at inducing a significant acidic metabolic stress.
Track based technical	Included efforts/training sessions which were based around submaximal work to focus on a technical element of riding. This also included track familiarisation sessions upon arriving at a new location following a long period of travel.
Race	Included all racing in competition, international or national, and any race sessions in training specifically intended to mimic a competition day.
Rollers	Included specific programmed roller work which appeared as a separate session or following a gym session. Roller work which may have formed a portion of a track session to warm up or warm down has not been included in this.
Rest	Included all programmed rest periods which were prescribed into the training programme.
Travel	Included any domestic air travel and all international travel.

Power training variables were evaluated each month to track the highest mean maximal powers through several durations of time. Peak power, five second, ten second, 15s, 20s and 30s mean maximal power durations were decided to adequately cover most relevant work durations for all riders. While a team sprint will result in a competition time of approx. 44s only one rider travels this distance. As many of the efforts completed in training fall short of this duration it was decided that a 30s cut off would give an indication of changes in work duration relevant to speed endurance and metabolic work and tolerance.

Inertial testing data was analysed for peak power and cadence at peak power; an average of the results for each session was used when multiple tests were carried out

Data Analysis

Mean maximal power data was reported for each month. For each MMP duration the highest power value achieved in that month has been reported and compared. Inertial peak power and optimal cadence have also been reported in this manner with the highest values achieved during the calendar month reported and compared. The training programme was assessed for the distribution of frequency of each training component and reported as a relative proportion of the training information collected for that period.

Statistical Analysis

Group mean (± SD) and individual data for all variables are reported. Power data was evaluated according to the SWC required to influence performance. The SWC in field power data was assessed based on that reported by Flyger (2009); 1.5% for elite track cyclists during a field or laboratory based physiological test. Smallest worthwhile change in peak power and optimal cadence from inertial load testing was evaluated based on SWC determined from reliability testing based on methods of Hopkins (2004).

Results

Table 5.7 outlines the competition schedule throughout the 9 month build up tracked in the study.

Table 5.7. Competition Schedule November 2011 to August 2012.

Date	**Event**	**Location**
21-24 November 2011	Oceania Track Cycling Championships	Invercargill, NZ
30 November to 3 December 2011	UCI Track Cycling World Cup	Cali, Columbia
13-15 January 2012	UCI Track Cycling World Cup	Beijing, China
4-6 February	NZ National Championships	Invercargill, NZ
17-19 February	UCI Track Cycling World Cup	London, UK
4-8 April	UCI Track Cycling World Championships	Melbourne, Australia
7-8 July	Round 2 of Sprinters Cup – Sprint Grand Prix	Cottbus, Germany
2-7 August	Olympic Games	London, UK

Overall data summary

For readability and reference Tables 5.8 and 5.9 provide a global summary of the changes to variables tracked overtime for the group of athletes. Comparison of February and March with June and July showed a reduction in almost all power values. An exception to this was the inertial peak power at these points (males: 1938.5W, compared with 2079.4W ES = 0.90; females: 1318.5W, compared with 1433.5W ES = 1.53). The improved optimal cadence in the female participants also represented a real change; it was greater than the noise in the measurement, 2.42rpm (raw TE from reliability work, Chapter 3) and exceeded the SWC, 1.4rpm.

Table 5.8. Mean male summary data from October 2011 to July 2012 for on-bike power, inertial testing and off-bike monitoring undertaken in 2012. Standard deviation is shown in parentheses. Training distribution indicates a proportional representation of the occurrence of each training stimulus for each month.

	Oct-2011	Nov-2011	Dec-2011	Jan-2012	Feb-2012	Mar-2012	Apr-2012	May-2012	Jun-2012	Jul-2012
Track Power										
Peak Power (W)	1960.6	2113.7	1991.6	2111.6	2072.4	2070.9	2114.4	-	2070.5	2043.5
(mean±SD)	(125.6)	(163.4)	(159.8)	(22.6)	(169.6)	(157.4)	(167.4)	-	(170.8)	(178.3)
5s MMP (W)	1829.2	1964.0	1860.7	1918.5	1949.6	1936.6	1850.3	-	1918.2	1893.2
(mean±SD)	(90.6)	(133.7)	(131.2)	(95.5)	(171.2)	(135.6)	(107.5)	-	(169.6)	(155.5)
10s MMP (W)	1690.4	1791.0	1717.0	1775.0	1799.0	1775.4	1658.8	-	1774.8	1725.8
(mean±SD)	(92.2)	(105.2)	(106.6)	(79.2)	(158.3)	(137.8)	(175.5)	-	(153.1)	(155.3)
15s MMP (W)	1531.2	1607.2	1537.3	1549.5	1628.2	1610.4	1512.5	-	1620.2	1544.4
(mean±SD)	(77.6)	(83.7)	(86.6)	(120.9)	(136.8)	(120.3)	(126.6)	-	(124.2)	(143.3)
20s MMP (W)	1329.4	1426.6	1333.5	1380.0	1386.0	1450.0	1334.0	-	1415.8	1361.2
(mean±SD)	(84.0)	(56.3)	(30.4)	(32.5)	(105.1)	(132.2)	(107.4)	-	(110.0)	(101.6)
30s MMP (W)	1127.8	1183.4	-	1218.0	1127.6	1199.8	1093.3	-	1111.0	1106.8
(mean±SD)	(92.5)	(110.9)	-	-	(139.6)	(200.3)	(154.1)	-	(118.5)	(167.8)
Inertial Testing										
Inertial Peak Power (W)	2021.6	1890.8	-	-	1730	1938.5	-	1943.5	2077.1	2079.4
(mean±SD)	(135.8)	(208.0)	-	-	(25.3)	(147.1)	-	(172.1)	(172.1)	(146.6)
Inertial OC (rpm)	134.5	132.2	-	-	134.7	138.1	-	134.8	142.6	137.4
(mean±SD)	(3.7)	(2.6)	-	-	(4.6)	(4.9)	-	(3.7)	(6.9)	(6.6)
Off-Bike										
Gym RPE	-	-	-	-	-	4.5	6.5	5.9	5.4	3.3
(mean±SD)	-	-	-	-	-	(0.7)	(1.7)	(2.3)	(2.2)	(1.9)

Table 5.8 Continued

	Oct-2011	Nov-2011	Dec-2011	Jan-2012	Feb-2012	Mar-2012	Apr-2012	May-2012	Jun-2012	Jul-2012
Training Energy	-	-	-	-	-	3.2	3.3	3.2	3.1	3.7
(mean±SD)	-	-	-	-	-	(0.2)	(0.7)	(0.5)	(0.3)	(0.8)
Bodyweight (Kg)	-	-	-	-	-	88.5	89.1	89.4	89.1	85.7
(mean±SD)	-	-	-	-	-	(8.7)	(8.8)	(9.1)	(9.0)	(7.5)
Training Distribution										
Standing Starts	-	16.2	0.0	31.3	10.0	10.6	3.2	4.2	11.1	9.7
Acceleration	-	5.4	7.7	6.3	0.0	4.5	1.6	0.0	6.7	6.9
Sustained effort (500-1000m)	-	0.0	0.0	0.0	0.0	1.5	0.0	2.8	0.0	0.0
Flying Speed	-	10.8	15.4	25.0	7.5	12.1	3.2	6.9	13.3	16.7
Motor-paced Flying Speed	-	2.7	0.0	6.3	0.0	3.0	0.0	4.2	0.0	5.6
Specific Lactic/Metabolic	-	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0
Track based Technical	-	2.7	0.0	0.0	0.0	3.0	0.0	1.4	4.4	6.9
Race	-	21.6	46.2	0.0	30.0	0.0	15.9	0.0	0.0	9.7
Gym	-	8.1	0.0	6.3	12.5	16.7	14.3	22.2	17.8	6.9
Road	-	0.0	0.0	0.0	5.0	6.1	11.1	12.5	11.1	2.8
Erg	-	0.0	0.0	0.0	0.0	7.6	6.3	12.5	6.7	1.4
Rollers	-	13.5	0.0	0.0	10.0	7.6	11.1	19.4	2.2	2.8
Rest	-	8.1	0.0	0.0	5.0	19.7	33.3	12.5	22.2	22.2
Travel	-	10.8	30.8	25.0	20.0	6.1	0.0	1.4	4.4	8.3

* Training distribution is expressed as a relative proportion of the total engagement in each training activity which was either captured during a training camp or reported by the athlete. Training distribution is the % of reported training sessions where each component was undertaken by the athlete.

Table 5.9. Mean female summary data from October 2011 to July 2012 for on-bike power, inertial testing and off-bike monitoring undertaken in 2012. Standard deviation is shown in parentheses. Training distribution indicates a proportional representation of the occurrence of each training stimulus for each month.

	Oct-2011	**Nov-2011**	**Dec-2011**	**Jan-2012**	**Feb-2012**	**Mar-2012**	**Apr-2012**	**May-2012**	**Jun-2012**	**Jul-2012**
Track Power										
Peak Power (W)	1376.4	1425.5	-	1334.1	1435.7	1427.6	1445.9	-	1364.9	1389.1
(mean±SD)	(37.4)	(73.2)	-	(40.0)	(57.9)	(41.6)	(5.7)	-	(25.2)	(40.9)
5s MMP (W)	1211.3	1302.0	-	1210.5	1327.0	1329.7	1305.5	-	1266.0	1281.0
(mean±SD)	(31.9)	(74.5)	-	(31.8)	(41.9)	(48.6)	(54.4)	-	(25.2)	(14.0)
10s MMP (W)	1102.3	1206.0	-	1100.5	1219.3	1209.3	1181.5	-	1066.3	1163.3
(mean±SD)	(27.6)	(58.8)	-	(21.9)	(19.5)	(37.5)	(101.1)	-	(189.4)	(21.0)
15s MMP (W)	1016.0	1060.0	-	1000.0	1110.3	1094.0	1079.0	-	1070.0	895.0
(mean±SD)	(27.0)	(27.8)	-	(39.6)	(16.3)	(56.8)	(60.8)	-	(11.3)	(48.1)
20s MMP (W)	927.3	914.0	-	923.5	1031.5	990.3	1002.5	-	797.0	841.0
(mean±SD)	(24.0)	(97.7)	-	(9.2)	(74.2)	(37.9)	(43.1)	-	-	-
30s MMP (W)	732.3	675.3	-	723.5	822.0	779.0	842.0	-	656.0	750.0
(mean±SD)	(59.7)	(138.9)	-	(147.8)	(240.4)	(124.7)	(48.1)	-	-	-
Inertial Testing										
Inertial Peak Power (W)	1345.8	1241.7	-	-	1222.3	1318.5	1244.9	1303.0	1459.4	1433.5
(mean±SD)	(59.5)	(38.5)	-	-	(10.7)	(29.1)	-	-	(60.2)	(71.4)
Inertial OC (rpm)	124.5	120.2	-	-	124.2	127.5	122.0	123.0	133.5	130.5
(mean±SD)	(2.3)	(6.8)	-	-	(4.8)	(4.1)	-	-	(4.9)	(4.9)
Off-Bike										
Gym RPE	-	-	-	-	-	5.1	4.5	5.3	6.1	3.3
(mean±SD)	-	-	-	-	-	(1.7)	(0.4)	(1.6)	(1.5)	(0.4)

Table 5.9. Continued.

	Oct-2011	Nov-2011	Dec-2011	Jan-2012	Feb-2012	Mar-2012	Apr-2012	May-2012	Jun-2012	Jul-2012
Training Energy	-	-	-	-	-	-	3.4	3.6	3.2	3.5
(mean±SD)	-	-	-	-	-	-	(0.7)	(0.3)	(0.1)	(0.3)
Bodyweight (Kg)	-	-	-	-	-	70.3	69.5	70.8	71.9	71.3
(mean±SD)	-	-	-	-	-	(5.7)	(3.6)	(5.2)	(4.1)	(3.8)
Training Distribution										
Standing Starts	-	11.3	0.0	12.8	8.6	6.8	1.9	7.1	4.5	4.5
Acceleration	-	1.6	7.7	6.4	1.7	4.1	1.0	6.1	6.4	4.5
Sustained effort (500-1000m)	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flying Speed	-	8.1	15.4	17.0	6.9	9.5	1.0	4.0	7.3	10.9
Motor-paced Flying Speed	-	1.6	0.0	0.0	0.0	1.4	0.0	0.0	0.9	3.6
Specific Lactic/Metabolic	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Track based Technical	-	0.0	0.0	0.0	0.0	4.1	0.0	2.0	0.0	0.0
Race	-	14.5	30.8	10.6	20.7	0.0	9.5	1.0	1.8	8.2
Gym	-	4.8	0.0	2.1	3.4	1.4	8.6	14.1	9.1	1.8
Road	-	0.0	0.0	0.0	0.0	2.7	1.9	4.0	5.5	4.5
Erg	-	0.0	0.0	0.0	0.0	4.1	1.9	6.1	0.9	0.0
Rollers	-	6.5	0.0	2.1	0.0	1.4	6.7	4.0	3.6	1.8
Rest	-	4.8	0.0	0.0	0.0	14.9	19.0	8.1	10.0	9.1
Travel	-	3.2	0.0	8.5	13.8	5.4	0.0	0.0	5.5	5.5

* Training distribution is expressed as a relative proportion of the total engagement in each training activity which was either captured during a training camp or reported by the athlete. Training distribution is the % of reported training sessions where each component was undertaken by the athlete.

Power Data

Field data – Power Tracking

Figures 5.2, 5.3 and 5.4 display the profile of power durations comparing the two key build up phases to both the World Championships in 2012 (Feb and March) and the London Olympics 2012 (June and July). All data points for July, prior to the London Olympics are below those recorded for March, prior to the 2012 World Championships.

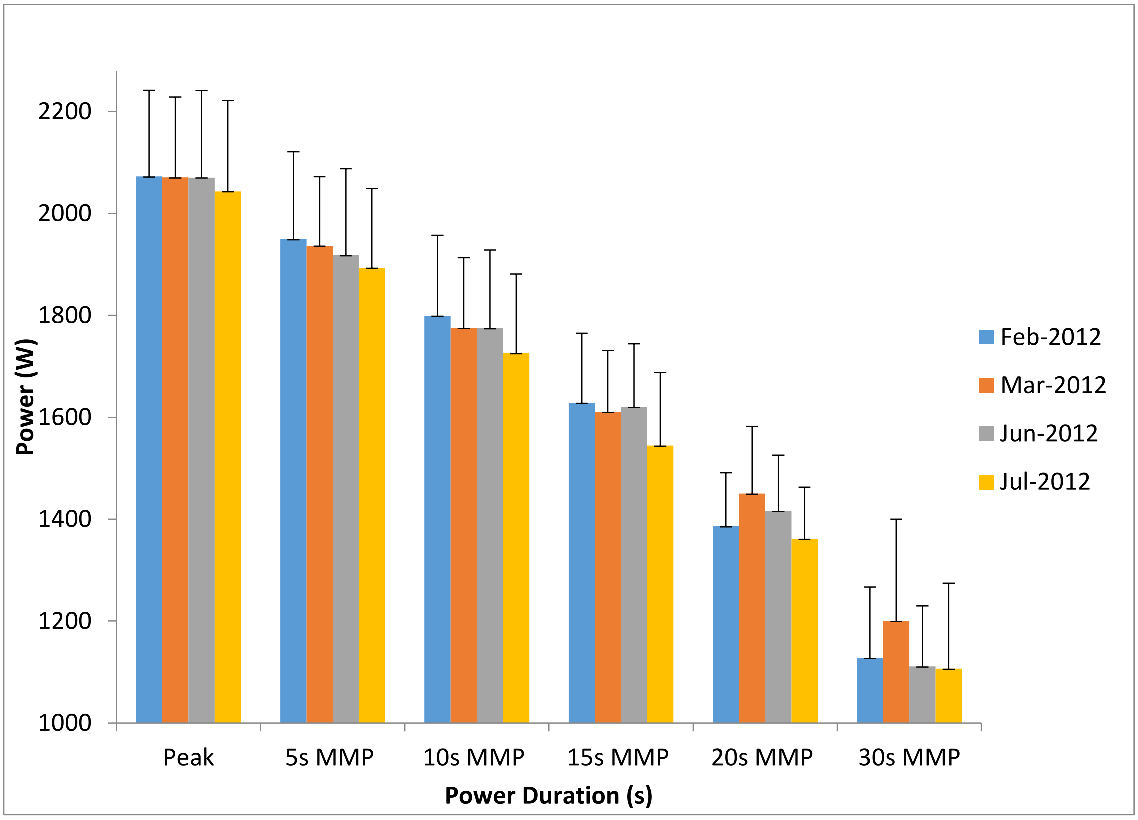


Figure 5.2. Comparison of male mean maximal power profiles (mean ± SD) during the two months prior to two pinnacle events in 2012, World Championships and Olympic Games.

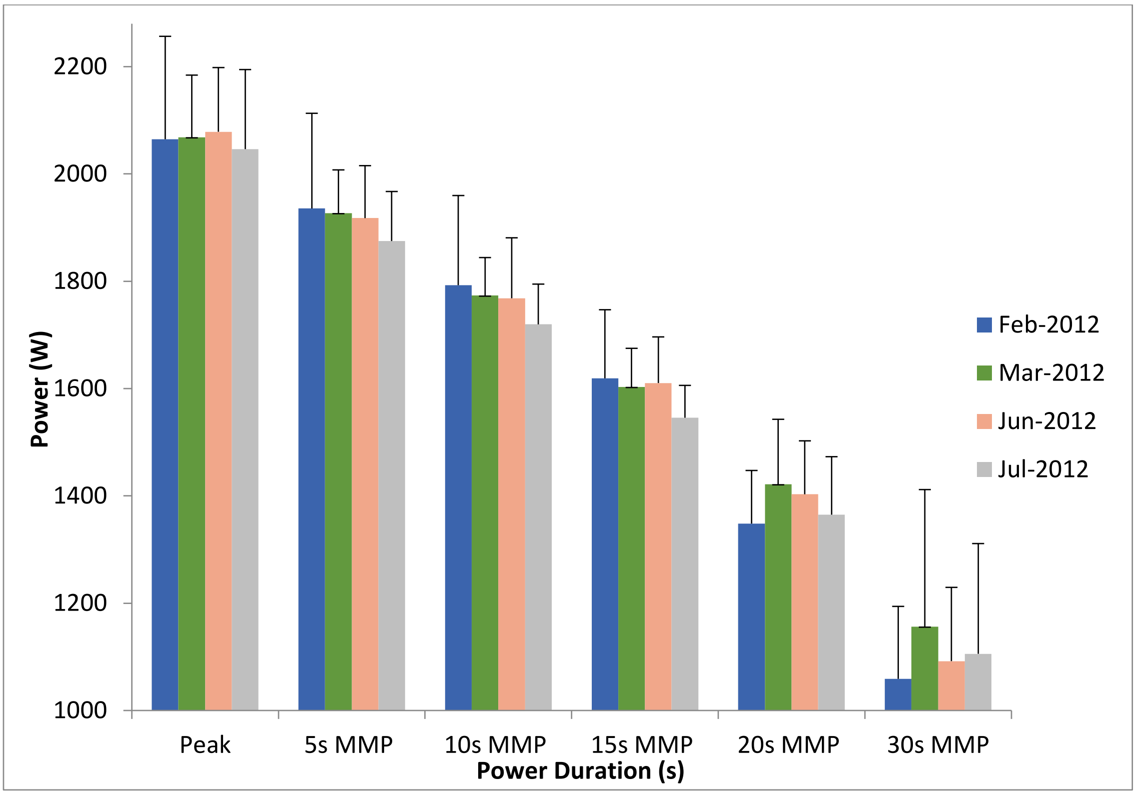


Figure 5.3. Comparison of Olympic representative male athlete mean maximal power profiles (mean ± SD) during the two months prior to two pinnacle events in 2012, World Championships and Olympic Games.

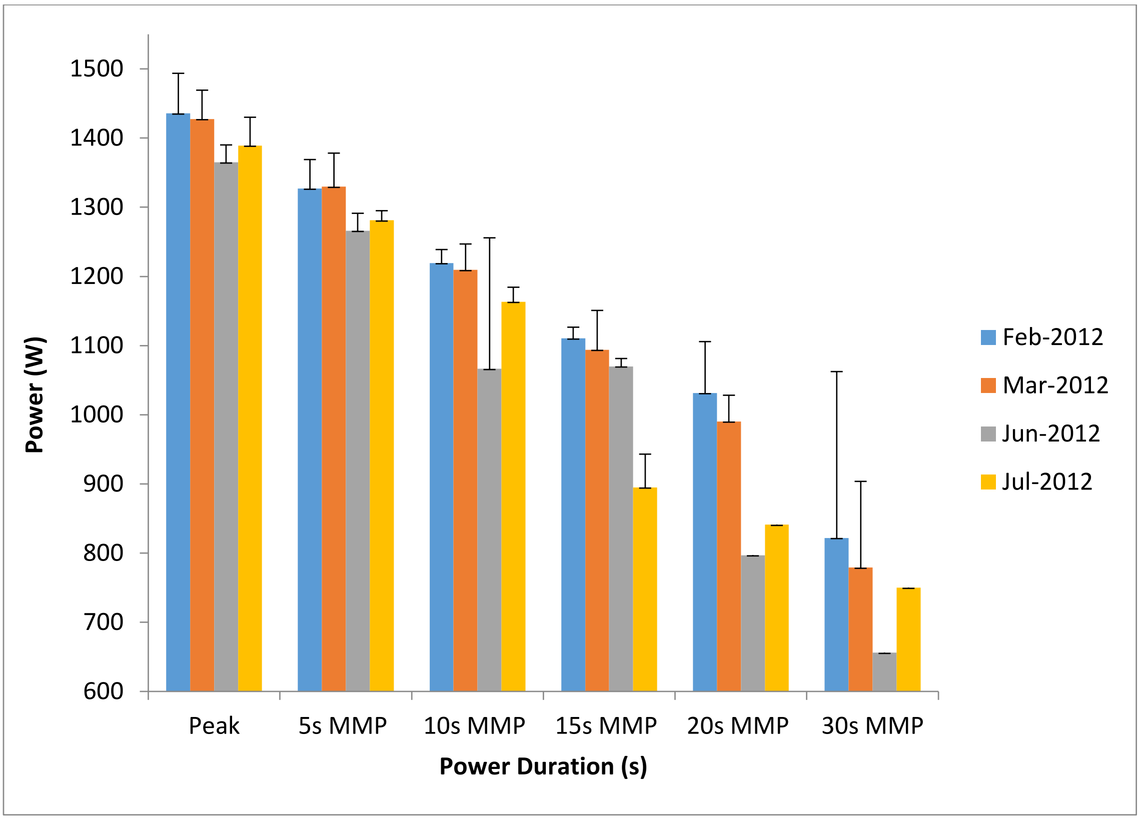


Figure 5.4. Comparison of female mean (±SD) maximal power profiles during the two months prior to two pinnacle events in 2012, World Championships and Olympic Games.

Figure 5.5 indicates an absence of training completed in the power durations above ten seconds during June and therefore there is no data to plot into this power range. Longer duration powers (15-30s) in July are much lower than March.

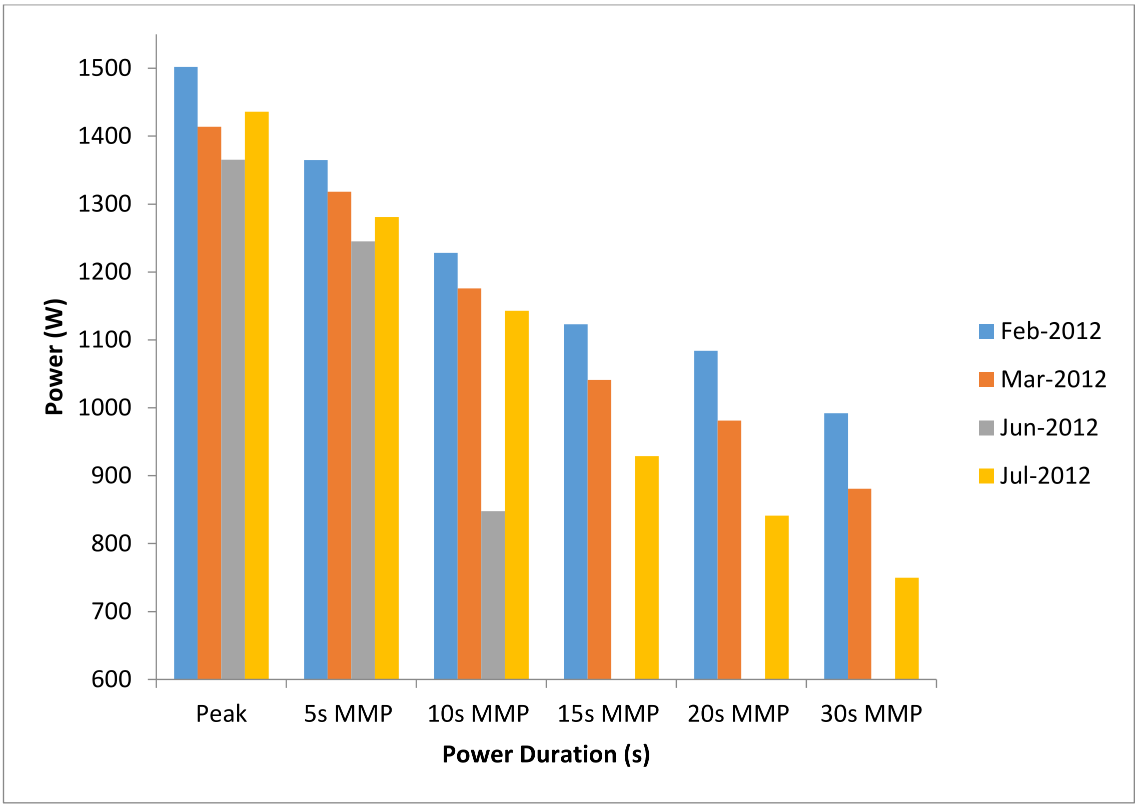


Figure 5.5. Comparison of female (competitor at London Olympic Games) mean maximal power profiles (mean data displayed only) during the two months prior to two pinnacle events in 2012, World Championships and Olympic Games.

Inertial Testing Data

Inertial testing Figures 5.6, 5.7 and 5.8 all reflect increases in both peak power and optimal cadence in June above that seen in March. Figure 5.9 is the only plot to not demonstrate this trend with values for June below those seen in March.

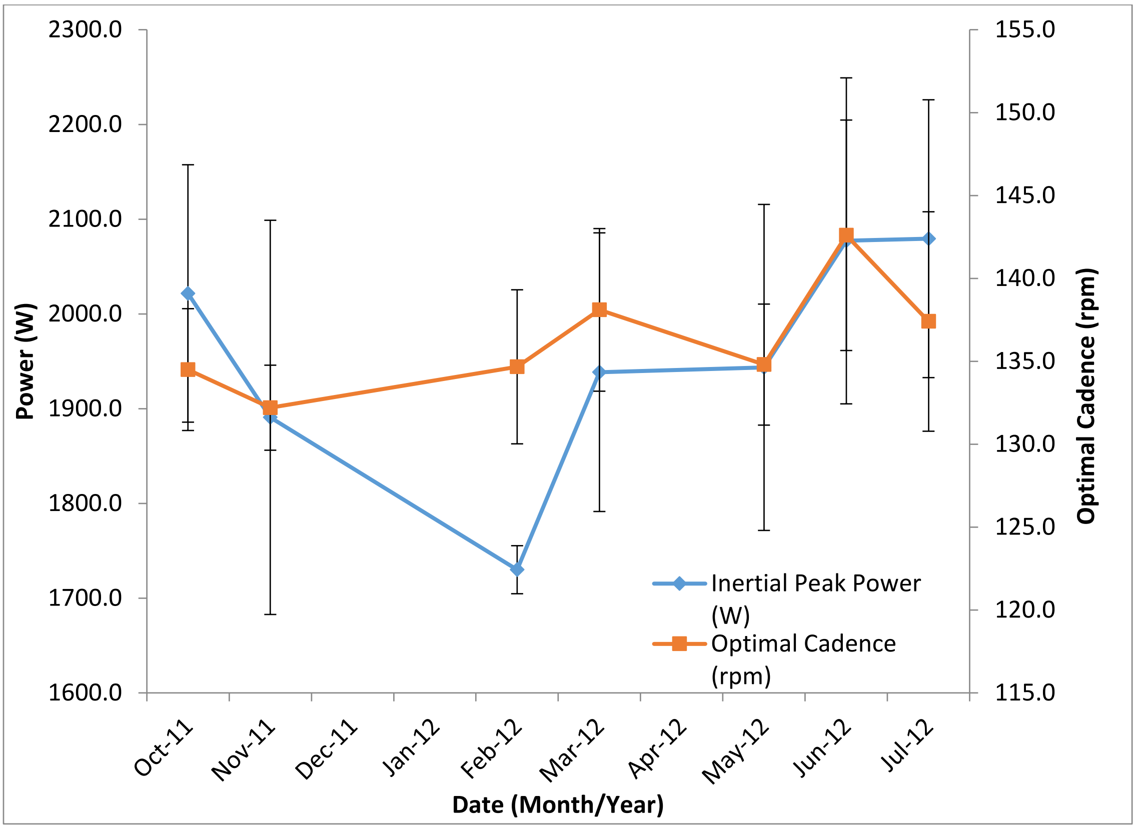


Figure 5.6. Mean (±SD) male inertial peak power and optimal cadence progression from October 2011 to July 2012.

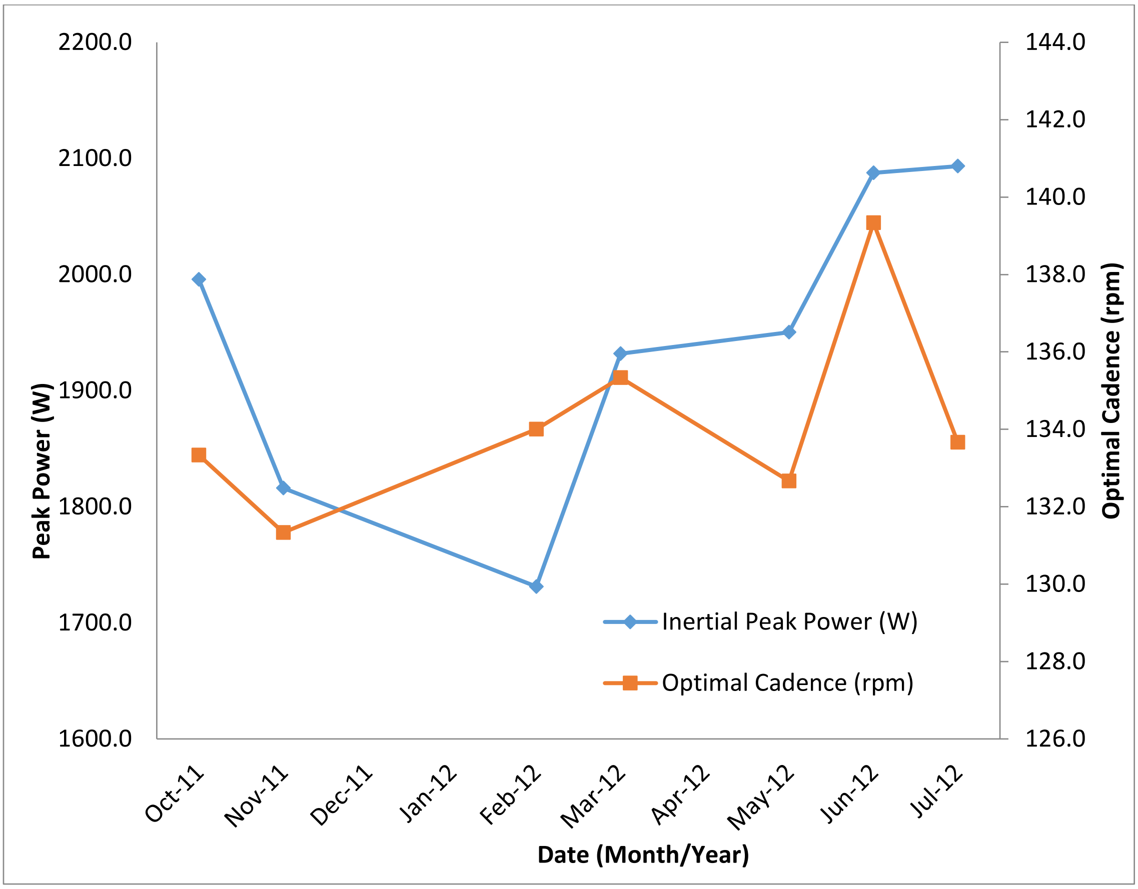


Figure 5.7. Mean Olympic male inertial peak power and optimal cadence progression from October 2011 to July 2012.

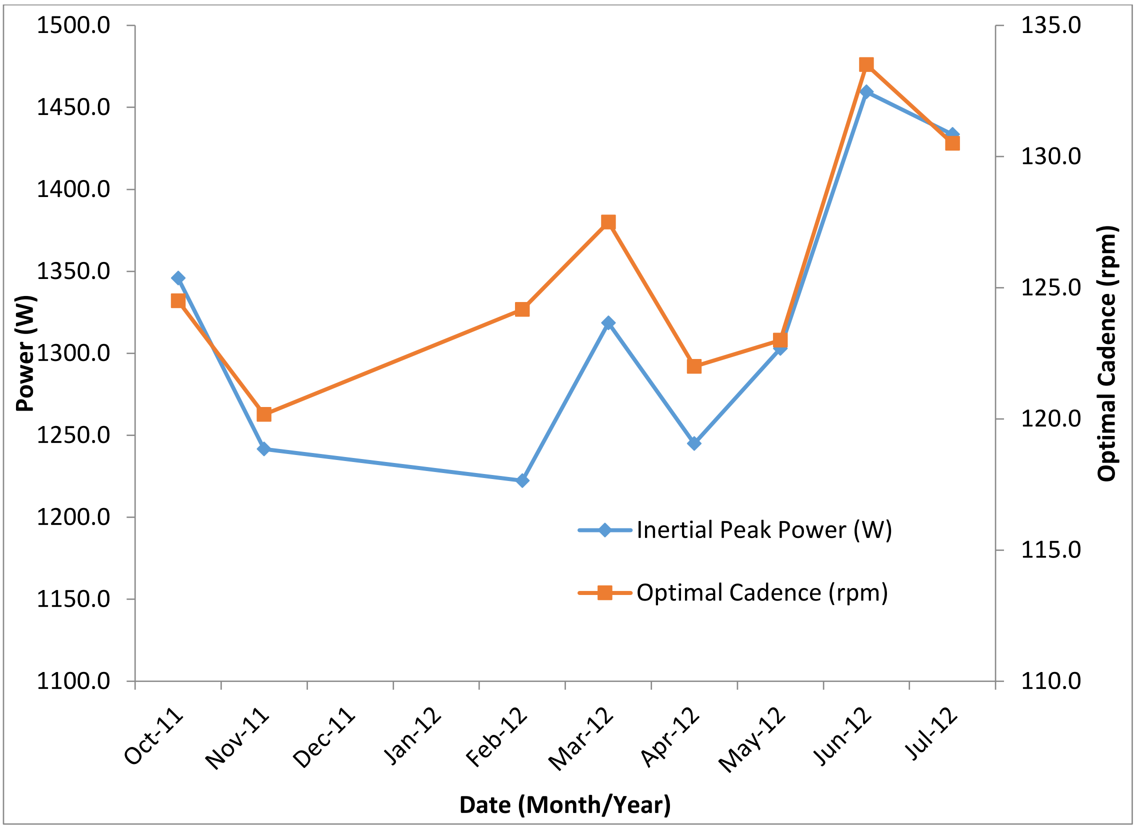


Figure 5.8. Mean female inertial peak power and optimal cadence progression from October 2011 to July 2012.

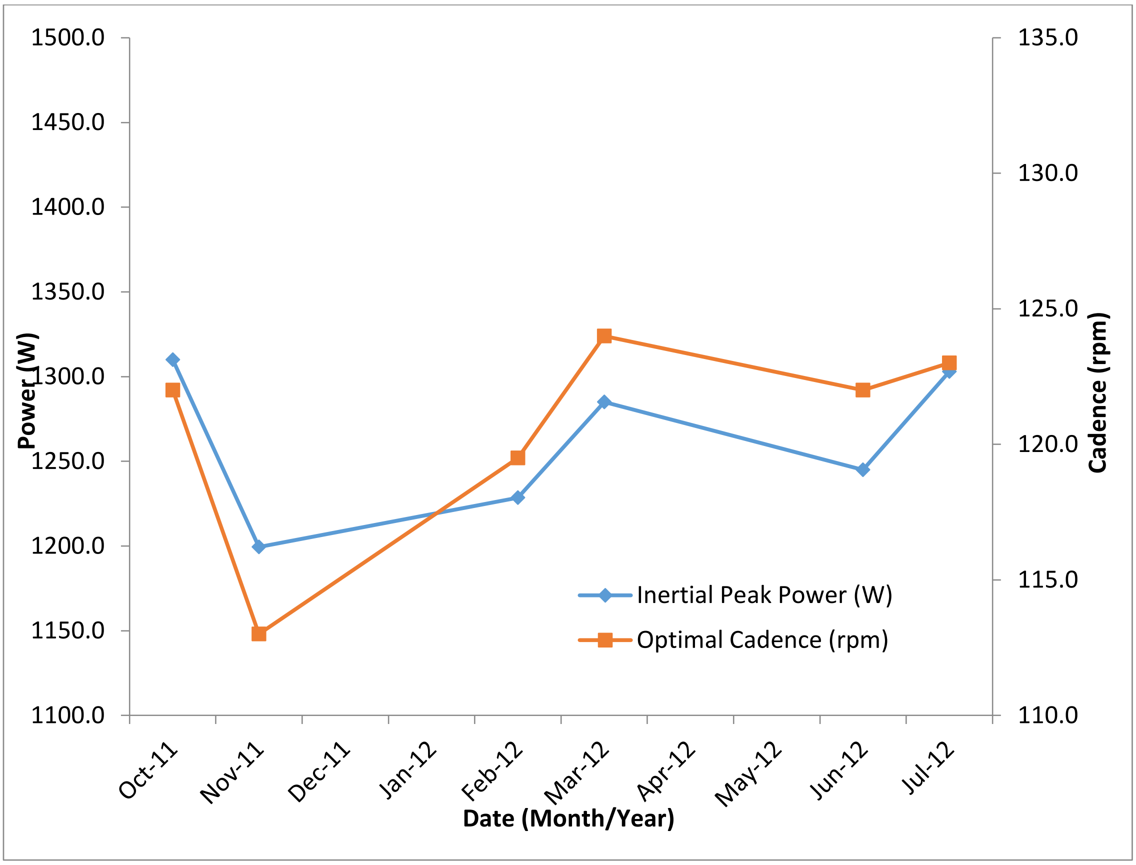


Figure 5.9. Olympic female inertial peak power and optimal cadence progression from October 2011 to July 2012.

Off-Bike Survey Data

Tables 5.8 and 5.9 show the BYOS application data collected between March 2012 and July 2012. Athlete compliance for completing the BYOS survey was 52.3% (±25.2). The female athletes had a mean compliance of 68.1% (±30.1) and the male athletes a mean compliance of 42.9% (±19.1).

Additional results Olympic Games – pinnacle performance event – (see Appendix C)

Discussion

The aim of the study was to investigate the impact of the prescribed training stimulus and its effectiveness in achieving the desired physiological adaptation in elite track sprint cyclists. In addition, the study was designed to give a greater understanding of the physiological responses to the training prior to the London Olympic Games and, determine the appropriateness of the training stimulus in achieving the adaptation. It is important to note the study was not an experimental study but an observational study where training and performance were tracked and monitored as prescribed by the coach.

Key findings of the study indicated differences in lactic and alactic power qualities. Despite the athletes presenting to the Olympic Games with an upward trend in inertial testing results they also displayed less favourable longer duration powers leading into competition when compared with data collected before 2012 World Championships. The relevance of the relationship between field (lactic) and inertial (alactic) power data is explored in more detail later in this discussion. The athletes concluded the Olympic campaign with a relative under performance and largely inconsistent results. The improvement shown with the inertial ergometer testing data however was not realised in competition or reflected in the field data, which also did not show the same improvement. The field data indicated little or no change when mean maximal power profiles were analysed and compared and any trend from June to July leading into competition tended to be negative. One key difference to the stress prior to the Olympic Games was the relative absence of a racing stimulus. It is highly likely this contributed a detrimental impact on the preparation and performance of the male athletes competing in London. Evaluation and interpretation of this data was based according to the premise that the physiological trend prior to a pinnacle event will represent the performance potential of the athletes at the pinnacle event.

Field data

In the male athletes field data typically showed little change in mean maximal power at almost all reported MMP durations (Figures 5.5 and 5.6). There was slight increase from

February to March in the longer durations and interestingly a corresponding decline in the longer durations from June to July. The female participants demonstrated a consistent decline in March. Mean maximal power data for both male and female participants in the present study showed very little progression between March and July with the males tending to remain relatively similar while the females, depending on the MMP duration, were substantially higher or lower. The smaller number of female participants in the study did contribute to the large variation, especially when the single female Olympian was looked at individually (Figure 5.8). Data from the male Olympians demonstrated more pronounced increases in 20s and 30s MMP between Feb and March 2012, something which is not present in the data from June to July (Figure 5.5). While July power data appears to be lower than June this magnitude of difference is small enough to be insignificant for the 30s MMP duration (ES for 30s MMP difference = -0.03) but a moderate difference seen at the 20s MMP duration (ES for 20s MMP duration = -0.53). The ES in the difference between 30s MMP duration March and July at both 20 and 30s is moderate (ES, 20s = -0.53, 30s = -0.74). It would be expected that there would be a moderate physiological progression between March 2012 and July 2012 assuming a relatively good training programme was in place, particularly given the ages of the athletes. In the context of the other sprint athletes competing at both the 2012 World Championships and 2012 Olympic Games there would appear to be very little progression in any nations' athletes, assuming the times were indicative of power changes, except those from Great Britain (environmental conditions were almost identical). It is likely that the inertial testing data could allow for a better understanding of this field progression and will be outlined in detail later in this discussion.

Potential limitations existed with the reporting of power data: mean maximal and peak power data reported were the best power numbers achieved for the month within those MMP durations. This method of reporting data was chosen as it gives an indication of the athletes highest power potential during the time was and should remove the influence of training fatigue and accumulated training stress that would potentially mislead the interpretation of the results if only training averages were considered. Inertial ergometer testing data was reported in the same manner. The inclusion of the competitive data that was captured through the 2011/2012 season did influence the power profile through February given the higher powers elicited during racing. There was no racing during March 2012, preparation for the World Championships in April or any racing in June prior to the Olympic Games. Racing in July consisted of a Sprint Grand Prix (Sprint and Keirin racing). These comparisons remain valid, however, given the contribution of the racing towards the overall training stimulus. It has been noted that the absence of racing in the training stimulus during June and July may have resulted in a weaker performance state at the Olympic Games.

Inertial erg results

Inertial erg data showed peak power and optimal cadence values in June and July above what was seen prior to the World Championships in Feb and March. Potentially this is indicative of an insufficient training stimulus as shown by McLean et al., (2012). McLean et al., (2012) demonstrated sensitivity in the use of ergometer derived peak power to assess and monitor fatigue in female collegiate soccer players. In addition, they observed a decline in the P_{max} of female collegiate soccer players who had a greater amount of game time, interpreting this as evidence of fatigue with the increased stress/strain imposed on these players. The interpretation of data in the current investigation is that field data was largely indicative of a maintenance of performance from World Championships to Olympic Games with a slight trend downwards from June to July at some mean maximal power durations. Inertial testing data did indicate improvement in alactic ability with higher peak power outputs from March to July. McLean et al., (2012) showed that this decrease in P_{max} to be indicative of overreaching and staleness as a result of a greater game and training load seen by the athletes who started more games during the season. Wehbe, Gabett, Dwyer, McLellan, and Coad (2014) performed an ergometer test on Australian Rules football players in season and found cycling peak power to be a reliable and sensitive method for monitoring neuromuscular fatigue. Inertial testing was performed on every training day through June and individual results were often observed to be declining. The increase in inertial testing results during this long period may also be the result of more subtle chronic adaptations to this test and ergometer. Martin, Diedrich, and Coyle (2000) found the time course for learning to produce stable peak power values to be three to four days in active men and one day with cycle trained men. They found no change in optimal cadence over this time.

It is also reasonable to interpret that the constant improvement in alactic qualities was the result of a training stimulus which did not adequately address the requirements of the athletes. Data from both the male and female riders indicated an upward swing in inertial peak power and optimal cadence two months prior to both pinnacle events, continuing to increase through March while declining in July prior to the Olympics. Inertial power and optimal cadence in both male and female athletes trended upwards from February to March. While there was a continued progression upwards to June in both groups the drop in both metrics in July most likely indicates unsuitable loading in this month which had had a detrimental impact on the performance ability of the athletes. The spike in inertial testing results seen in June was present in almost all athletes. The female athlete who attended the Olympic Games is the single person who did not demonstrate this visible spike in peak power and optimal cadence in June, travelled home to New Zealand during the European phase, and was the only athlete not to complete an eccentric gym training phase prior to leaving NZ in June. It is possible that the inclusion of the eccentric training prior to leaving New Zealand (and subsequent rest and travel to Spain) specifically enhanced the performance of the type II muscle pool (Paddon-Jones, Leveritt, Lonergan, & Abernethy, 2001; Vogt and Hoppeler, 2014) which was evidenced with the spike in the inertial testing results. The shift from relatively low ambient temperatures in New Zealand (early winter) to a very hot climate in Valencia, Spain may have also contributed to the sharp increase in inertial results. Temperatures when training in the Luis Puig Velodrome in Valencia Spain were typically above 28°C with ambient temperatures outdoors ranging from 27°C to 37°C. Ball, Burrows, and Sargeant, (1999) and Girard, Bishop, and Racinais, (2013) reported higher peak power outputs with short duration maximal sprint cycling in the heat without any detectable alteration to fatigue characteristics. If optimal cadence is thought of as an indicator of muscle fibre composition (Hautier et al., 1996) and acute changes in optimal cadence are not due to fibre type shifts given the time course for changes in fibre cross sectional area (Vogt & Hoppeler, 2014); it is likely that optimal cadence data quantifies a component of fatigue (either presence or absence).

Training programme

The training programme content should be carefully considered given the lack of compliance by athletes and coach in collecting and providing the information. While both male and female athletes worked largely together through the time the female athletes in the sprint squad had a dedicated coach responsible for their planning and preparation and did differ slightly in their approach to the men. Key differences from the training prior to World Championships and Olympics (for all athletes) were the smaller amount of racing through July, with none at all in June and therefore much less travel when compared with February/March. It would seem reasonable to expect this had a more positive impact on the ability to complete training prior to the Olympic Games. It may also be reasonable that the intensity of the racing through the 2011/2012 track season (November-February) and the large amount of travel facilitated a greater positive adaptation by forcing more sedentary time while travelling with a more specific intermittent stimulus (racing). This hypothesis is typically not supported, the literature citing the additional stress associated with travel: time zone changes, dehydration and potential for exposure to illness (Grandjean & Ruud, 2000). It does however remain a time where periods of maximal effort task specific sprint cycling competition was engaged with forced periods of rest while travelling, i.e. very high quality non-linear periodised training.

There was a greater amount of road work included during the training phase through June when compared with training prior to the World Championships in Melbourne. Gym based resistance training (Tables 5.8 and 5.9) appeared to have increased from February to March for the male athletes (12.5% to 16.7% of training reported) while decreasing for the female athletes (3.4% to 1.4% of training). From June to July the male athletes dropped the relative proportion of gym based training (17.8% to 6.9%) which was similarly mirrored in the female athletes (9.1% to 1.8%). It is likely that the hectic racing schedule for the male athletes in February made it logistically more difficult to complete an ideal amount of gym work. Racing commitments were not present in the time leading into the Olympic Games and reflected more of the build-up intended by the coach. Interestingly while these are considered relatively anaerobic athletes there is little specifically dedicated in the male programme for lactic/metabolic work and nothing with this specified intention for the females. Some of the longer duration track-based efforts (30-45s) were likely to elicit this stimulus (Häkkinen, Komi, & Alén, 1985), however, the intention of these efforts were most often focused around speed endurance and technical work specifically related to the event and included longer duration recovery to get quality out of the subsequent efforts. It is likely that through the 2011/2012 World Cup season the racing stimulus was providing an adequate amount of this lactic/metabolic work. Without the compensation for this loss in the overall programme prior to the Olympics it is likely to have impacted the training adaptation achieved in this build-up.

Tables 5.1 to 5.5 highlights the approach taken within each phase of training. There were similarities in the work completed immediately prior to racing at each pinnacle event (comparing Tables 5.1 and 5.5) where volume of work was reduced and athletes were phased to allow a relative 'freshening up' physically and mentally. Typical endurance work completed by the athletes (Table 5.2) focused on a greater duration and amount of road riding along with longer duration aerobic interval ergometer work. Strength phasing (Table 5.3) included a greater proportion of standing start and over gear work with a focus on greater crank torque. Through this period shorter aerobic interval work was also included. Early precompetition phase (Table 5.4) showed evidence of a very high volume of all aspects of track work operating on a rotation of three days on to one day off. Given the contrast with the racing stimulus prior to World Championships (April 2012) it is clear that the approach to a large volume of work would not have provided the same stimulus as the intermittent racing schedule between November 2011 and February 2012.

It would appear that key differences: the much smaller amount of racing prior to the Olympics than prior to World Championships, much less travel, potentially a greater amount of low intensity road riding, similar volume of standing starts and a greater volume of flying speed work before the London Olympics are predominantly responsible for the lack of overall progression and inconsistency seen in the results at the Olympic Games. Inertial peak powers and optimal cadences were higher prior to the London Olympics than they were prior to the World Championships in April. This would indicate that, on average, these athletes were capable of performing overall to a higher level than earlier in the year when evaluated on the basis of a higher optimal cadence and inertial peak power are favourable indicators of a low level of fatigue.

Performance Results

The physiological power data prior to each pinnacle event was interesting in the context of the performance data available at both World Championships and Olympic Games, for those athletes competing in both events. The team sprint time in qualifying was 44.175s (7th fastest) as a result of a technical error and was the first event of the competition. During the second round a new NZ best time was achieved 43.495s. Comparison to the time ridden at the 2012 World Championships in Melbourne, Australia, is difficult given the difference in team composition. While the first wheel rider remained unchanged the second and third wheel riders were not the same. The physiological and performance differences between the athletes make comparison of the rides difficult. The other event results, the sprint and the keirin are mixed. Both athletes in the sprint competition failed to produce performances at the Olympic Games which were consistent with performances at the World Championships in Melbourne, with both rides slower. However this tended to be the trend with most other athletes who competed at both events. For athletes who competed at both events it would appear that the most successful at the Olympic Games were those who were able to produce a performance more closely matched to their performance at World Championships.

In context with the other sprint competition athletes in the top 5 (or those athletes who competed at both events as only one athlete pre country could compete in both the sprint and keirin at the Olympics) there was a tendency to produce a slower time (Appendix C), with the exception of the athletes from Great Britain. Both the British athletes in the sprint competition (male and female) went considerably faster in London, both breaking respective Olympic records in their 200m qualifying rides. Pendleton rode 3.2% faster and Kenny 2.4% faster in London than they did in Melbourne earlier that year, they both also went on to win gold in their respective competitions.

Paton and Hopkins, (2001) have shown that a 1% change in performance time will require a 3% change in average power (with either a positive or negative impact on performance). This analysis was repeated by Flyger, (2009) who demonstrated a power change of between 2.89 and 2.94% for a one percent change in performance time in a more elite sample of international track cyclists. Flyger, (2009) also indicated that a change in performance time of more than 0.5% represented the smallest worthwhile difference needed to assume a positive or negative effect. In the context of the performance changes seen by the British athletes this would represent substantial improvements in power output (7.0% and 9.6% respectively for Kenny and Pendleton) which does seem unlikely for an athlete at this level. It is highly likely that any change in power production was accompanied by changes in drag for these athletes. For the male and female athletes in the study who rode the sprint at the Olympic Games both achieved personal best times at the preceding world championships in April 2012. Times of 9.963s and 11.166s respectively for the selected male and female athletes would therefore require times outside of 9.913-10.012s and 11.110-11.222s (0.5% difference in time to the World Championships) to be considered either performance improvement or detriment. Race times in London for both athletes were 10.201s and 11.241s respectively, both greater than 0.5% different to previous best times earlier that same year. This would again substantiate what we saw with the physiological progression between these two pinnacle events with the athletes. Time differences of 2.4% and 0.7% respectively would indicate the generation of lower average powers during the 200m qualifying time trial of 7.2% and 2.1%. Environmental conditions were almost identical at both times and locations (Melbourne 6th April: Temp 27°C, Pressure 1015hPa, Relative humidity 48%; London: 30th July Temp 27.3°C, Pressure 1013hPa, relative humidity 29%) with very little movement during competition which gave very similar air density at each competition. These equivalent environmental conditions will contribute little to the difference of event time between the two pinnacle events making the variation in times relative to athlete power and any technical or equipment variation which has impacted on performance of the task or the aerodynamic drag component.

Body mass changes

Body weight for the male athletes remained largely unchanged (Table 5.8) until July when a mean drop of 3.4kg was observed. While this is less important in flying events, which are more reliant on power relative to frontal surface area and the influence of drag (Dorel et al., 2005), it is important in standing start events (Martin et al., 2006). This is highly relevant to the team sprint and will likely represent some influence over the ability to produce an NZ best ever time in this event. Female body weights remained approximately the same, however, the lone female Olympian raced at 67kg in April and 73kg at the Olympics. While this will have a detrimental impact on relative power outputs the influence over both the sprint and keirin (as they are not from a standing start) will be small. Lower relative power output will however have implications for acceleration (greater inertia) when it is required in these two events.

It does appear that there was an increased amount of flying speed work leading into the Olympic Games. From what is outlined leading into London 2012 it would appear that the reduced amount of racing in the build-up may have impacted on the physiological progression through to the event. There was a similar relative proportion of standing starts, greater technical work, more acceleration and flying speed work (with and without a motorbike) and a greater reduction in gym work closer to the Olympic Games than Worlds along with similar proportions of prescribed rest. It may be that the increased proportion of flying speed work, greater reduction of gym and the smaller amount of racing had a detrimental impact on the physiological expression of longer duration power leading into the Olympic Games. When coupled with no apparent sustained duration work or specific lactic work and more low intensity road riding it would indicate the athletes were not well enough prepared for peak performance in London.

There was a perceived contradiction in the inertial testing data indicating the ability to perform prior to the Olympic Games was greater than that in April for the World Championships. Given the performance of a new best time for the team sprint and a successful medal performance in the keirin it is possible that the alactic performance ability was present but not at a consistent level for the duration of the competition.

Certainly if the hypothesis of Dorel et al., (2005), that arrival at competition with a high optimal cadence will result in an enhanced performance ability applies was supported, the relationship should have been seen with the athletes in the current study. The alternative mechanism discussed earlier relating to ATP sparing through alterations to SR calcium release, resequestration and increases in sensitivity to calcium were potentially demonstrated with a chronic lowering of optimal cadence. If it is accepted that inertial testing provides information on the alactic physiological state of the athletes and the field data represents the performance ability in an ecologically valid task (with alactic, glycolytic and aerobic elements) the discrepancy between the two could indicate that the physiological potential was there but unable to be realised consistently. It may also support the training load immediately prior to the Olympics (July) had been too severe and the training undertaken had not been appropriate to confer the adaptation required for optimal performance at the Olympic Games. More specifically the training had not provided the stress required to stimulate a resistance to fatigue in the athletes which would likely have caused the reduction in optimal cadence values seen in March 2012. Again it is likely that the stress imposed by the intermittent racing and travel schedule prior to the 2012 World Championships assisted in conferring a fatigue resistance (improved ATP sparing through regulation of calcium ions) which was seen in both the lower optimal cadence values and greater longer duration power production.

Individual athlete case study – First wheel rider in the team sprint

The team sprint starter could be considered track sprint cycling's only "sprinter", given they are the only athlete who performs maximally with no prior submaximal work and their contribution to the event lasts a little more than 17s. The nature of their ride being both simple and complex requires a gearing selection to achieve the greatest acceleration from a standing start and top speed. They will benefit from having a high power relative to body mass (W/kg) during their acceleration phase (Martin et al., 2006) and similarly a power output relative to drag to ensure generation of the highest velocity possible at the end of their lap (Dorel et al., 2005). While these qualities are desirable for all track sprint cyclists the relative importance shifts depending on the athlete and event.

Athlete characteristics

The athlete tracked here had a peak power relative to body mass of 25.8 W/kg in March prior to the track cycling World Championships, and 24.0 W/kg in July leading into the Olympic Games. Drag was not calculated but qualitative assessment of rider position and consequential fontal surface area would indicate suboptimal aerodynamic qualities. Some of the decrease in relative power between the two time points will be due to body mass changes for the athlete of approximately 2.5kg (increased in July from March) and a small difference in field derived peak power values (the best power recorded being 65W lower in July than in March a reduction of 3.2%).

Athlete training programme

Typically the training programme of the athlete mirrored the work being done by the other athletes in the squad but over shorter distances and durations. There were considerations for improving different aspects of the total 250m lap ridden by the athlete which were addressed through changes to, but no stark contrasts to, training approach when compared to the other athletes in the squad. The priority for the athlete at the Olympic Games was the first lap of the team sprint, however there was not a greater proportion of standing starts in training compared to the athlete’s team mates. There was a small amount of specialist work dedicated to emphasising the second half of the lap which involved motor paced and specific cadence work in the range encountered during a single lap effort in competition. Training through the pre-Olympic period comprised of three double days of training followed by one rest day which was then repeated (Table 5.4).

Athlete physiological progression

Overall there was a consistent increase in peak power through to the end of July with a concomitant increase in optimal cadence before peaking mid-June and then beginning to decline. An increase of 8 rpm (130-138 rpm) was observed from the inertial testing carried out prior to leaving New Zealand before the World Championships in Melbourne, Australia through to the peak values obtained from testing in Valencia, Spain. Optimal cadence then trended downward to the middle of July (124 rpm) before improving at the end of July (134 rpm). The degree of variability in optimal cadence through this period would fit with the argument presented indicating the relationship between optimal cadence and fatigue and freshness.

Track power captured from training for the athlete showed a contradictory relationship to that seen in the other members of the squad with a decrease in mean maximal power values (five second, ten second and 15s) from February to March and also from June to July. Comparing February to June and March to July indicated February power levels were superior with March and July much closer in absolute power values.

Athlete performance progression

The performance improvement in the 250m ride from the athlete was steady throughout the period. Sea level performance during the 2011/2012 international track season saw best times for the 250m distance fall from 17.601s at the London round of the World Cup Classics in February to 17.516s (in the bronze medal ride) at World Championships in Melbourne in April. This dropped again to 17.396s during the first round ride at the Olympic Games (after riding 17.545s in the qualifying ride) which was a new personal best time for this athlete.

Conclusions

Close monitoring of field data through training progression is important and necessary to understand global performance ability as it relates to competition and performance tasks in elite athletes. Inclusion of inertial testing data can provide information on underlying alactic physiological potential and some expectation around performance ability. Greater compliance with providing data is needed to make more definitive conclusions about the cause and effect of training stimulus and adaptation outcomes. A global approach to quantifying the stress and strain on and off the bike may be enhanced by using session RPE as described by Day et al., (2004).

It can be concluded after closely following this group of athletes that a number of mitigating circumstances resulted in the relative underperformance at the London Olympic Games, 2012. It can be reasonably concluded that they were in a similar physiological state, based on the availability of inertial testing data from February and March of 2012, to that of the World Champs in April. Some deterioration in the collected field data through July and the drop in optimal cadence could potentially indicate a slight compromise in the physiological state through July and reflect a greater level of fatigue in the group of athletes. However, the competitive outcomes are no doubt multifactorial and the Olympic results could be indicative of more inconsistency in performance than an inability to deliver results. Determining just what is responsible for this is difficult with a lack of available training data, however, a key component of the build up to the 2012 World Championships is the volume of racing which was undertaken and this was not present prior to the Olympics.

6. Single Leg Training Intervention Study

Prelude

The ability to resist fatigue is a critical quality for success in competition for any athlete. Improving resistance to fatigue is an important goal of the physiological development of a track sprint cyclist. Single leg ergometer training is a training method used typically with endurance cyclists to provide a novel stimulus to bring about adaptation in muscle respiratory capacity but has yet to demonstrate improvement in athletic performance. This study utilised a high intensity counterweighted single legged cycling training protocol manipulating training cadences, 70rpm and 130rpm, to stress the underlying muscle respiratory processes in the athletes without negatively influencing their maximal power producing capability.

Introduction

While the performance ability of the track sprint cyclist requires the development of high levels of power, acceleration and speed (Gardner et al., 2005), overall performance during competition will require these qualities to be performed multiple times over multiple days (Tomaras & Macintosh, 2011). The ability to resist fatigue is therefore a quality of paramount importance to the athlete and coach. To highlight this need to produce multiple performances; during a sprint tournament an athlete who makes the quarterfinal round may have to race between eight and thirteen times to get through to the final races in the medal rides in a sprint tournament at a World Championships (24 riders are taken from qualifying to the first round of competition). It takes three successful rides to make it to the quarter finals (a qualifying/seeding time trial over 200m, a first round match sprint and a 1/8th round match). It may take four rides if the rider has a 1/8th round loss and requires a repecharge. Given athletes will ride more than one event at a competition the ability to produce consistent performances over multiple events and consecutive days is a high priority. This is a quality which is identified as being critical for the track sprint cyclists and was observed as lacking previously in these athletes (Chapter 5). It was the intention of this study to investigate a training modality to address and expedite necessary adaptation to overcome this deficit.

Improving the ability of the track sprint cyclist to tolerate repeated bouts of maximal effort was investigated using a counterweighted single legged cycling training stimulus similar to that outlined by Abbiss et al., (2011). To date this training approach has not been investigated with sprint cyclists and while it has failed to show enhancement of endurance cycling performance (Abbiss et al., 2011; Turner, 2011) it has elicited improvement in muscle oxidative capacity (Abbiss et al., 2011). Single legged cycling utilising a counterweight applied to the contralateral pedal has been shown to preserve biomechanical properties of pedalling with two legs (Thomas & Martin, 2009). The consequences of employing a system where only half of the metabolically active tissue is working creates a situation where oxygen supply is not a limiting factor (Abbiss et al., 2011). Abbiss et al., (2011) demonstrated enhancements in aerobic processes over and above those seen with comparable two legged cycling. The stress able to be placed on the cyclist when using only one leg is far greater per leg than can be placed when using two legs together and introducing a limitation of metabolic substrate supply (Abbiss et al., 2011). This research using endurance cycling performance tasks (16-40km time trial) and longer interval duration (four to five minutes) failed to show performance improvements (Abbiss et al., 2011). Given the improvements seen in muscle respiratory capacity and GLUT-4 protein concentration (Abbiss et al., 2011) it is still reasonable to expect a benefit in athletes providing energy predominantly via anaerobic glycolytic pathways.

Typically single legged cycling has been investigated in relation to endurance cycling performance (Abbiss et al., 2011; Turner, 2011) and rehabilitation (Burns, Pollock, Lascola, & McDaniel, 2014). Abbiss et al., (2011) investigated the effects of four minutes of work with six minutes of rest in trained cyclists with more than two years of cycling experience. Turner, (2011) alternated working legs every 5mins in trained cyclists with greater than 4 years cycling experience. Participants in the study of Turner, (2011) performed their single legged training at 50% of the double leg training intensity. Abbiss et al., (2011) reported that single leg training intensity was performed at 58% of the double leg intensity. Given the single legged training intensity of Turner (2011) (training performed at ~35% of W_{max}), it is possible the participants in the study were insufficiently stressed with their single leg training intensity. Turner, (2011) found no difference in time trial performance between either the single legged or double legged training groups. Abbiss et al., (2011) saw significantly greater increases in cytochrome c oxidase subunits II and IV and GLUT-4 protein concentration but no significant difference in double leg time trial performance following a single legged training intervention. Bundle et al., (2006) utilised counterweighted single legged cycling to determine the influence of anaerobic metabolism on force production during sprint cycling. They compared counterweighted single legged cycling and double legged cycling using all out efforts over a time range from 15 to 400s. While the authors investigated sprint cycling, they carried out their sprint tests as constant load trials at a set constant cadence (100rpm) using intensities between 100% and 300% of VO_2 peak. In another novel investigation single legged cycling was used to determine the presence of inhibition in voluntary neuromuscular function in the rested contralateral limb following high-intensity endurance exercise (Elmer et al., 2013). The study did not find any evidence of the performance of a maximal single leg cycling effort impairing the function of the (contralateral) rested leg, after performing a ten minute fatiguing cycling time trial, when compared to fatigue induced in the ipsilateral leg. The training modality therefore appears to be a practical means for investigating the potential for improving underlying overall fatigue resistance of the track sprint cyclist as determined by enhancement of power output.

High intensity interval training has been shown to induce a similar training adaptation to a lower intensity longer duration training stimulus (Gibala et al., 2006; Kohn, Essén-Gustavsson, & Myburgh, 2011; Tabata, Irisawa, & Kouzaki, 1997). Gibala et al., (2006) demonstrated similar improvements in muscle buffering capacity and muscle oxidative capacity with substantially different training times and volumes. Gibala et al., (2006) compared four to six repetitions of 'all out' 30s (cycling) work periods with four minutes of rest with 90-120min of continuous cycling over a fourteen day period (participants completed six training sessions). Tabata, Irisawa, and Kouzaki, (1997) compared two different intermittent exercise protocols, one working for 20s (at approx. 170% VO2max) and resting for ten seconds repeated six to seven times, the other working for 30s (at approx. 200% of VO2max) with two minutes rest repeated four to five times. This protocol (Tabata) has been popularised in recent times (Olson, 2014). More recently Kohn, Essén-Gustavsson, and Myburgh, (2011) found increased lactate dehydrogenase activity, particularly in type IIA muscle fibres following six weeks of HIIT working at 94% of peak treadmill speed for approximately 2.7min. Duration was individualised based on 60% of time to exhaustion at 94% of PTS in well trained endurance athletes (runners). While these high intensity training modalities have been demonstrated to benefit both endurance (aerobic) performance and anaerobic indices it is intended that they also represent a more ecologically valid training stimulus for the sprint cyclist.

To date there is very little research investigating counterweighted single legged cycling in elite level cyclists and none with sprint cyclists. While Bundle et al., (2006) looked into the energetics of sprint cycling their subject pool consisted only of recreationally active participants and (two) trained cyclists. Application of single legged training utilised for endurance based athletes in this population is considered potentially beneficial and complimentary to the training periodisation and prescription of the sprint cyclist. Single legged cycle training and HIIT were used here to utilise the positive aspects of these training modalities. It was expected that the high intensity training approach used here would induce sufficient training stress to create similar changes to muscle oxidative qualities as has been seen previously with endurance trained participants (Gibala et al., 2006; Tabata et al., 1997).

It was expected this extremely stressful training stimulus would elicit noticeable improvements in resistance to fatigue. It was hypothesised that there would be a greater torque in the slower training condition (70rpm) which would elicit an increase in two-legged cycling torque at the same cadence without significant metabolic disturbance and stimulus. The higher cadence work (130rpm) was hypothesised to result in a greater metabolic training stimulus than the pilot work completed at 100rpm due to the higher pedal/contraction frequency and result in a greater training induced resistance to fatigue.

Methods

Experimental Approach to the Problem

A counterweighted single legged cycling training stimulus utilising two contrasting training cadences and HIIT was used to investigate the influence of an alternative training method to classic long distance low intensity work for aerobic development in elite track cyclists. This aerobic development was targeted towards improving the ability to resist fatigue during periods of training or competition where multiple efforts of maximal intensity are required. Typically the aerobic development of bike sprint athletes has centred on long duration low intensity endurance work thought to confer a fatigue resistance by way of general aerobic fitness improvement and resilience over the duration of a sprint race competition. Participants were all members of the national track sprint cycling squad and performed two blocks of three weeks of single legged ergometer training included with their usual training programme. A three week block of single legged training working at 70rpm was followed by a low volume training week with no single leg training and then a three week block of 130rpm single legged ergometer training. It was hypothesised that the novel alternative approach would preserve the fast twitch muscle properties, determined by inertial load testing of optimal cadence, while still creating an improvement in fatigue resistance.

Participants

Seven participants, five male (mean ± SD, weight 87.1 ± 14.3kg, height 177.4 ± 9.4cm) and two female (mean ± SD, 65.8 ± 8.6kg, 167.3 ± 6.7cm) who were all internationally competitive track sprint cyclists were recruited to participate in the trials. All the athletes were currently competing internationally in track sprint cycling and included world medallists, at senior and junior level, and Olympians. All participants were provided study information and gave their consent to participate in the research. The study was approved by the Auckland University of Technology Ethics Committee (AUTEC 11/315).

Based on pilot work (Appendix D) it was determined that two contrasting cadence ranges, relevant to the training prescription of these athletes, would be investigated; 70rpm and 130rpm. Pilot work initially carried out used a cadence of 100rpm. To satisfy the training requirements of the athletes as they prepared for competition it was necessary to work through each cadence in successive training blocks. During this time athletes were training in the gym, on the track and undertaking other ergometer training. All other training performed at this time was very familiar to the athletes and the only novel inclusion in their training plan was the contrasting single legged ergometer work.

Testing

During the initial session the participants had baseline measurements taken (height, weight) and completed the first testing session. Testing sessions were scheduled prior to the first three week training block, one week after the first three week training block (70rpm) was completed and then one week after the second three week training block (130rpm) was completed. The two single legged training blocks were separated by a low volume week of training during which no single legged training was completed and overall volume was reduced. A schematic representation of the intervention is shown in Figure 6.1.

	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5	Wk 6	Wk 7	Wk 8	Wk 9
				Low Volume *No single legged training completed*				Low Volume *No single legged training completed*	
Testing	**Monday:** Inertial testing, 3 x 30s ergometer testing				**Monday:** Inertial testing, 3 x 30s ergometer testing				**Monday:** Inertial testing, 3 x 30s ergometer testing
Single Legged Training cadence	**Wed and Sat:** 70rpm	**Wed and Sat:** 70rpm	**Wed and Sat:** 70rpm		**Wed and Sat:** 130rpm	**Wed and Sat:** 130rpm	**Wed and Sat:** 130rpm		

Figure 6.1. Single-legged erg training intervention overview

Inertial Testing

Participants performed a self-paced warm up as detailed previously (Chapter 3) (approx. 100-120W @ 100-120rpm for five minutes). During the testing battery participants were permitted to continue warming up for up to ten minutes if they desired. Once warm, participants completed two inertial tests (four second maximal acceleration efforts from a motionless start) with three minutes recovery between each test (data was captured and analysed as previously described). The mean of peak power and cadence at peak power was assessed from the two tests and from each testing session peak torque was plotted against cadence for each of the six and a half pedal strokes to establish the torque pedal rate relationship. A linear regression describing the torque pedal rate relationship allowed extrapolation to find maximal torque (T_0), and maximal pedalling rate ($ƒ_0$). Following a rest period of 8min the athletes then performed the fatigue testing of three x 30s repeated maximal trials.

3 x 30s Fatigue Testing

Fatigue testing was carried out using a repeated 30s maximal protocol with two minutes of self-paced active recovery between the maximal 30s bouts. The testing protocol was utilised as it had been used previously by the group and was currently in use as a component of the testing battery to determine improvements in fatigue characteristics. The testing was carried out on the participants own road training bicycle instrumented with a power meter (SRM - Schoberer Rad Meßtechnik GmbH, Jülich, Germany) and data was captured at two hertz. The participant's road bicycles were fixed to a LeMond Revolution Bike Trainer (LeMond, Powered by Hoist – Hoist Fitness, CA, USA) and a gear selected based on achieving a maximum cadence during testing of between 140-150rpm. Participants were instructed to bring their cadence up to 60rpm ten seconds prior to the commencement of the maximal work period; on the signal to start they accelerated to maximum and were verbally encouraged to hold the highest intensity they could for the 30s work period. This process was repeated for each 30s work period following the two minutes of active recovery. Average and maximum power was used to determine magnitude above or below the average power for the three working efforts at each test period. Maximum and minimum power was used to determine fatigue index as a percentage drop at each testing point. Reliability assessment of the initial three x 30s testing data resulted in a TE of 45.6W and CV of 5.8%.

The day prior to each testing day was a rest day and the week prior to testing and commencing the next block of single-legged work was performed at a lower overall volume (prescribed reps and sets of work in training) by approximately 35%. A gym based training session was performed on the morning of each testing day with lower loading and training volume. In the training session lifting volume was reduced by approximately 50-60% and the total session time was no longer than 45 minutes. No maximal lifts were performed on these days and higher velocity lifts were prioritised.

Training

Participants were required to complete two single-legged training sessions per week for three weeks at each target cadence. Each training session consisted of a self-directed ten minute warm up and then five repetitions per leg of 30s duration with a rest of 40s. All repetitions were carried out consecutively for each leg. The intended work:rest was based on an initial goal to work and rest for 30s, however the time taken to accelerate the flywheel and counterweight up to the desired cadence impacted negatively on the amount of rest and subsequent work interval. All training was performed on the athletes own road training bicycle instrumented with a power meter (SRM - Schoberer Rad Meßtechnik GmbH, Jülich, Germany). These mobile ergometers were regularly statically calibrated as per the procedures outlined previously (Chapter 3). The participant's road bicycles were fixed to a LeMond Revolution Bike Trainer (LeMond, Powered by Hoist – Hoist Fitness, CA, USA) to complete the training and to standardise the equipment used for training and testing. Each single legged training session was performed in the afternoon and to provide a consistent training stimulus one session of single legged work was performed following a gym based training session (performed in the AM) and another after a bike based training session, either track or an ergometer session (performed in the AM). Each morning session began at approximately 10:00AM and the afternoon session approximately 3:30PM (after a 90 minute morning training session this gave approximately four hours of recovery between training sessions). Average power per repetition, per leg, was tracked during each session along with cadence and average pedal torque per repetition per leg.

During the single legged ergometer training the crank arm of the non-working leg was counterweighted to obtain biomechanical similarity to two legged cycling. During the 70rpm work the counterweight mass totalled 113N (11.5kg), this was reduced to 64N (6.5kg) during the 130rpm work. The reduction of mass at the higher cadence was out of regard for the athletes own equipment at the request of the coach due to the potential for this equipment to be damaged as the training was being carried out on their own personal road bike. When cycling with one leg the non-working leg was placed on a box or a chair behind the participant to maintain the leg itself in its usual pedalling plane. This was found to be more comfortable to the athletes than the typical practise of placing this non-working leg on a chair to the side which was found resulted in an unfamiliar level of abduction. Training was undertaken during this time according to the typical weekly schedule outlined in Table 6.1. A more detailed schedule of training is shown in Table 6.2 which outlines the overall progression in volume throughout the single legged training period with specific on and off bike training and the reduction in volume during the recovery week.

Table 6.1. Typical training week for athletes during the single legged ergometer training intervention.

	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
AM	Gym	Bike – Track Starts	Gym	Bike – Track or Erg Acceleration	Gym	Bike – Track or Erg – Speed Endurance	Rest
PM	Bike – Speed/Inertial Testing	Rest/Active Recovery	Bike - SLE	Rest/Active Recovery	Rest/Active Recovery	Bike - SLE	Rest

*SLE – Single Legged Erg

Table 6.2. Detailed four weekly training schedule during the single legged ergometer training intervention. This outlined training prescription was repeated during both the 70rpm training block (weeks one to four) and the 130rpm training block (weeks five to eight).

Week		**Mon**	**Tues**	**Wed**	**Thurs**	**Fri**	**Sat**	**Sun**
1,5	**AM**	Gym – moderate volume – 75mins	Bike – Track Starts – 60m, 60m, 125 x 3 sets, moderate gear increase 2” each set	Gym – moderate volume – 60mins	Bike – Acceleration chasing motorbike 375m x 2 500m x 1, big gear, increase 2” each effort	Gym – heavy – 90mins	Bike – Erg – Speed Endurance – simulated flying 500m (32s) x 4, 140rpm, 4min 28s recovery	Rest
	PM	Inertial and 3 x 30s Testing	Rest/Active Recovery	**Bike – SLE 70 or 130rpm x 5 each leg**	Rest/Active Recovery	Rest/Active Recovery	**Bike – SLE 70 or 130rpm x 5 each leg**	Rest
2,6		**Mon**	**Tues**	**Wed**	**Thurs**	**Fri**	**Sat**	**Sun**
	AM	Gym – moderate volume – 75mins	Bike – Track Starts – 60m, 125m 250m x 2 sets, moderate gear increase 2” each set, motorbike carrot with 250m	Gym – moderate volume – 60mins	Bike – Acceleration chasing motorbike 375m x 3, 500m x 1, big gear, increase 2” each effort	Gym – heavy – 90mins	Bike – Track – Speed Endurance – flying 500m x 4, moderate gears change after 2 efforts by 2”	Rest
	PM	Inertial Testing x 2 Bike, roller sprints on track bike x 5 10s with 2min 50s recovery	Rest/Active Recovery	**Bike – SLE 70 or 130rpm x 5 each leg**	Rest/Active Recovery	Rest/Active Recovery	**Bike – SLE 70 or 130rpm x 5 each leg**	Rest
3,7		**Mon**	**Tues**	**Wed**	**Thurs**	**Fri**	**Sat**	**Sun**
	AM	Gym – moderate volume – 75mins	Bike – Track Starts – 60m, 60m, 125m x 2 sets, 60m, 125m 250m x 1 set, moderate gear increase 2” each set, motorbike carrot with 250m	Gym – moderate volume – 60mins	Bike – Acceleration chasing motorbike 375m x 2, 500m x 2, big gear, increase 2” each effort	Gym – heavy – 90mins	Bike – Track – Speed Endurance – motorbike lead flying 500m x 4, moderate gears change after 2 efforts by 2” motorbike pulls out 250m on own	Rest
	PM	Inertial Testing x 2 Bike, roller sprints on track bike x 5 10s with 2min 50s recovery	Rest/Active Recovery	**Bike – SLE 70 or 130rpm x 5 each leg**	Rest/Active Recovery	Rest/Active Recovery	**Bike – SLE 70 or 130rpm x 5 each leg**	Rest
4,8		**Mon**	**Tues**	**Wed**	**Thurs**	**Fri**	**Sat**	**Sun**
	AM	Gym – moderate volume – 45mins	Bike – Track Starts – 60m, 60m, 125 x 1, 60m, 125m, 250m x 1 sets, moderate gear increase 2” each set	Rest	Bike – Acceleration chasing motorbike 375m x 2 500m x 1, big gear, increase 2” each effort	Gym – moderate volume – 45mins	Bike – Road 60mins easy spin	Rest
	PM	Inertial Testing x 2 Bike, active recovery – rollers followed by self-directed stretching	Rest/Active Recovery	Rest	Rest/Active Recovery	Rest/Active Recovery	Rest	Rest

Statistical Analysis

Means (±SD) for the participant groups at each time point were calculated. Proportional power differences for each of the three x 30s test efforts was expressed as a percentage of the mean of all three tests at that time to give an indication of how far above or below the average for that test each effort fell (Equation 6.1). Reliability of the three x 30s ergometer testing protocol was assessed using log transformed data to determine TE and CV and reported with 90% confidence intervals. ICC was also reported at the 90% CI level.

Proportional Power Difference =

(Individual Effort Mean Power/Mean Power of all Three Efforts) x 100 (Equation 6.1)

Inertial testing of peak power and optimal cadence was expressed as mean (±SD) and torque values at 110, 120, 130, 140 and 150rpm calculated from the raw data. Regression of the data then gave the equation which represented the relationship and the data was extrapolated to find T_0 and f_0 (maximum torque and maximum pedal frequency/cadence) consistent with the methods of Dorel et al., (2005). ES was also calculated for the mean power changes in the 3 x 30s test and evaluated using the scale defined by Hopkins (2000). Values were interpreted as 0.0-0.2 showing a trivial effect, 0.2-0.6 showing a small effect, 0.6-1.2 a moderate effect, 1.2-2.0 a large effect and 2.0-4.0 a very large effect. On-bike training was evaluated by the grouping of training data into 200W bands of power output and tabulated to show time spent in each band (mean ±SD). This was done to quantify training load by providing an intensity (power output range) and a duration of time spent at this intensity (time in seconds).

Results

3 x 30s ergometer fatigue testing

Following the initial testing period reliability was determined for the three x 30s testing protocol using the data obtained during the initial (pre intervention) testing. The CV for average power of 5.8% (4.3-10.0%, raw TE = 49.49W) and ICC = 0.97 (0.90-0.99) and average cadence CV of 1.6% (1.2-2.7%, raw TE of 1.82rpm) and ICC = 0.96 (0.88-0.99).

Table 6.3 (below) shows the changes in mean powers for each testing occasion, pre, post 70rpm training intervention (mid-point of intervention) and post 130rpm training intervention. Table 6.4 shows ES magnitude changes ranging from small to very large. Post 70rpm to post 130rpm testing changes in effort one for all and male participants and pre to post 130rpm changes for all participants at effort three did not show even a small magnitude of change. Table 6.5 displays the peak power for all participants during all 30s test efforts, the male values exhibited less variation than the female values for each testing time point.

Table 6.3. Mean (±SD) of mean power (W) for each 30s work bout for all, male and female participants.

		Effort 1 (W)	Effort 2 (W)	Effort 3 (W)	Mean
Pre	All	834.4 (201.0)	662.3 (152.4)	534.9 (112.1)	677.2 (150.2)
	Male	924.0 (159.1)	726.2 (128.3)	580.4 (88.9)	743.5 (188.5)
	Female	610.5 (26.2)	502.5 (44.5)	421.0 (86.3)	511.3 (96.2)
Post 70rpm	All	924.0 (204.4)	721.3 (162.6)	572.4 (137.5)	739.2 (161.0)
(Mid)	Male	1032.2 (103.9)	813.2 (51.5)	643.4 (79.5)	829.6 (181.1)
	Female	653.5 (51.6)	491.5 (13.4)	395.0 (0.0)	513.3 (119.3)
Post 130 rpm	All	905.7 (256.9)	680.3 (149.3)	522.2 (92.1)	702.7 (160.3)
	Male	1043.8 (183.4)	759.5 (109.5)	570.8 (65.9)	791.3 (234.2)
	Female	629.5 (16.3)	522.0 (17.0)	425.0 (32.5)	525.5 (93.2)

Table 6.4. Effect Size (ES) summary for differences between means of average working powers at each testing time point.

		Effort 1	Effort 2	Effort 3
Pre-Post 70rpm	All	-0.45	-0.38	-0.31
	Male	-0.78	-0.85	-0.73
	Female	-1.03	0.40	0.50
Post 70 rpm-Post 130rpm	All	0.08	0.27	0.43
(Mid)	Male	-0.09	0.66	0.92
	Female	0.70	-1.41	-1.17
Pre-Post 130rpm	All	-0.32	-0.12	0.13
	Male	-0.70	-0.29	0.13
	Female	-0.91	-0.66	-0.08

Table 6.5. Mean (±SD) of peak power (W) at each work bout for all, male and female participants.

		Effort 1 (W)	Effort 2 (W)	Effort 3 (W)
Pre	All	1293.7 (347.3)	1179.6 (333.4)	884.0 (233.8)
	Male	1450.6 (270.6)	1331.2 (256.9)	974.6 (208.6)
	Female	901.5 (16.3)	800.5 (26.2)	657.5 (101.1)
Post 70rpm	All	1380.9 (318.8)	1158.9 (287.4)	892.6 (301.6)
	Male	1527.6 (239.1)	1299.6 (193.0)	996.8 (298.0)
	Female	1014.0 (66.5)	807.0 (9.9)	632.0 (18.4)
Post 130rpm	All	1260.4 (493.1)	1016.8 (335.1)	765.1 (248.3)
	Male	1694.5 (429.0)	1343.3 (292.7)	989.3 (250.5)
	Female	989.0 (7.1)	867.5 (50.2)	690.0 (24.0)

Table 6.6 shows the proportional power difference in the average power for all three 30s work periods during each individual 30s work period. At each point effort one gave a larger magnitude of difference from average than for effort three. Effort two was always slightly below average. A range from 22.95% above average to 20.64% below average power at the initial testing point (pre) was observed. At the completion of the intervention this increased to 27.53% above average in the first effort and fell to 24.57% below average in the third effort.

Table 6.6. Mean (±SD) proportional power differences (%) for each 30s work bout for all athletes, male and female are shown.

		Effort 1 (%)	Effort 2 (%)	Effort 3 (%)
Pre	All	22.95 (7.89)	-2.31 (2.79)	-20.64 (6.44)
	Men	24.19 (6.52)	-2.51 (3.24)	-21.68 (5.08)
	Women	19.85 (13.29)	-1.80 (2.01)	-18.05 (11.28)
Post 70rpm	All	25.16 (7.52)	-2.59 (2.18)	-22.57 (7.24)
	male	24.34 (8.74)	-1.94 (2.17)	-22.40 (8.71)
	female	27.21 (4.68)	-4.22 (1.43)	-22.98 (3.25)
Post 130rpm	All	27.53 (9.59)	-2.97 (2.40)	-24.57 (8.48)
	male	31.38 (9.14)	-4.11 (1.99)	-27.27 (9.16)
	female	19.85 (5.62)	-0.68 (1.14)	-19.17 (4.49)

Table 6.7 shows mean cadence for both male and female participants. It should be noted that the male who selected the incorrect gear for his post 70rpm training block (midpoint) testing was left in the data to maintain consistency with the power data reported earlier.

Table 6.7. Mean (±SD) cadence (rpm) for each 30s work bout at each testing point for all participants, male and female subgroups.

		Effort 1	Effort 2	Effort 3
Pre	All	131.4 (7.5)	121.3 (6.3)	112.4 (8.1)
	Male	133.0 (8.2)	122.2 (6.3)	113.4 (7.3)
	Female	127.5 (4.9)	119.0 (9.9)	110.0 (12.7)
Post 70rpm	All	124.9 (10.4)	113.7 (8.8)	104.1 (8.6)
	Male	125.0 (11.2)	114.4 (8.1)	104.2 (7.9)
	Female	124.5 (12.0)	112.0 (14.1)	104.0 (14.1)
Post 130rpm	All	129.5 (4.5)	117.5 (5.6)	107.0 (7.2)
	Male	128.3 (5.1)	114.3 (3.0)	103.0 (3.9)
	Female	132.0 (1.4)	124.0 (1.4)	115.0 (4.2)

Inertial Testing Results

Figure 6.1 indicates a trend within the group towards an increasing inertial testing peak power with Figure 6.2 indicating a concurrent decline in optimal cadence.

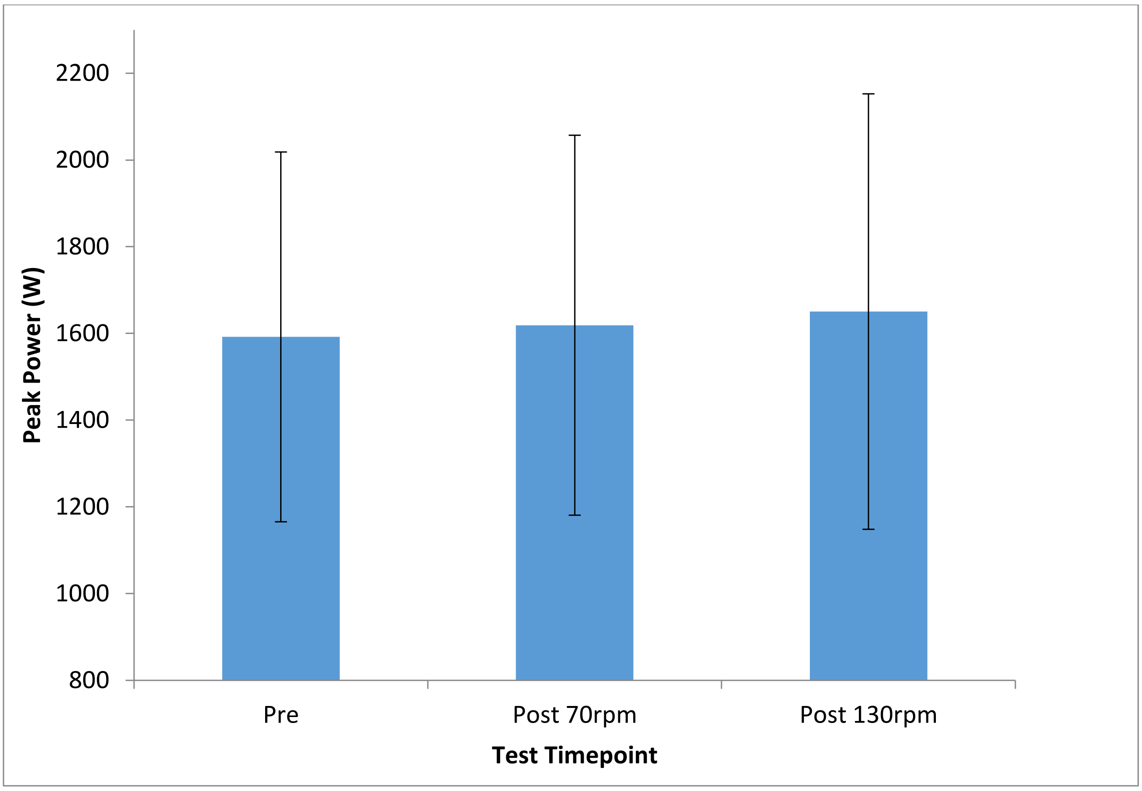


Figure 6.1. Group mean (±SD) inertial testing peak power at each testing time point.

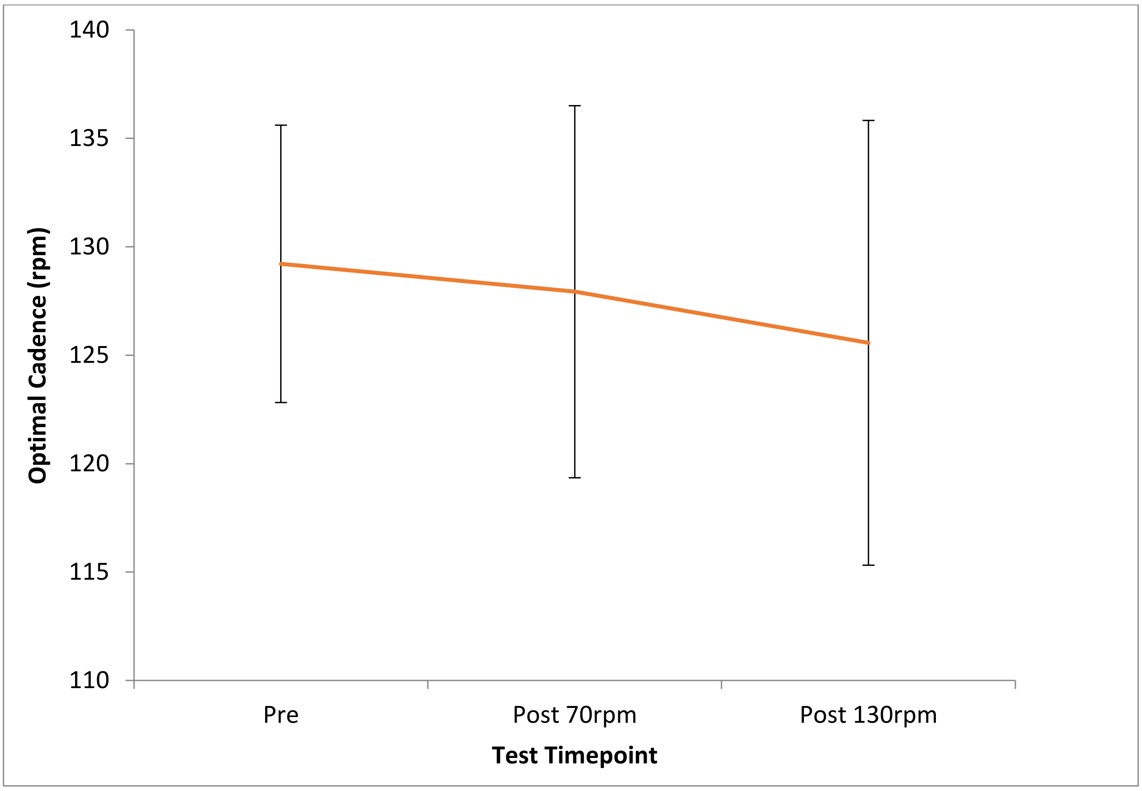


Figure 6.2. Group mean (±SD) inertial testing optimal cadence at each testing time point

Figure 6.3 indicates the peak power changes and Figure 6.4 the optimal cadence changes in male athletes during the SLE intervention.

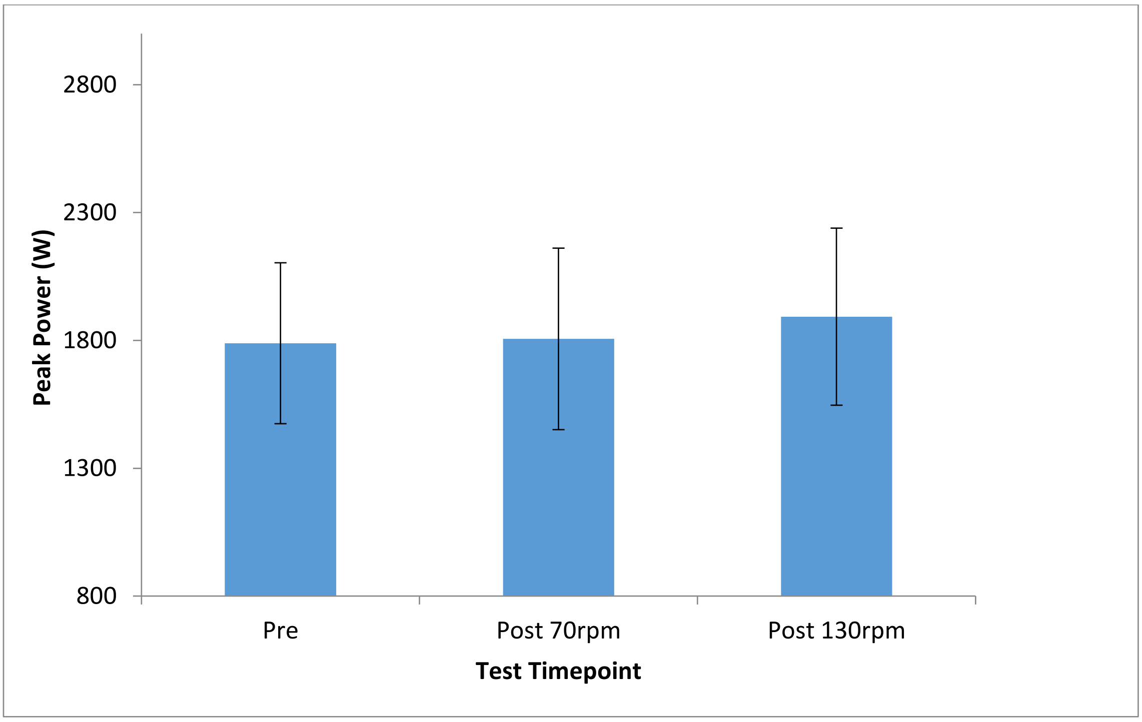


Figure 6.3. Male mean (±SD) inertial testing peak power at each testing time point.

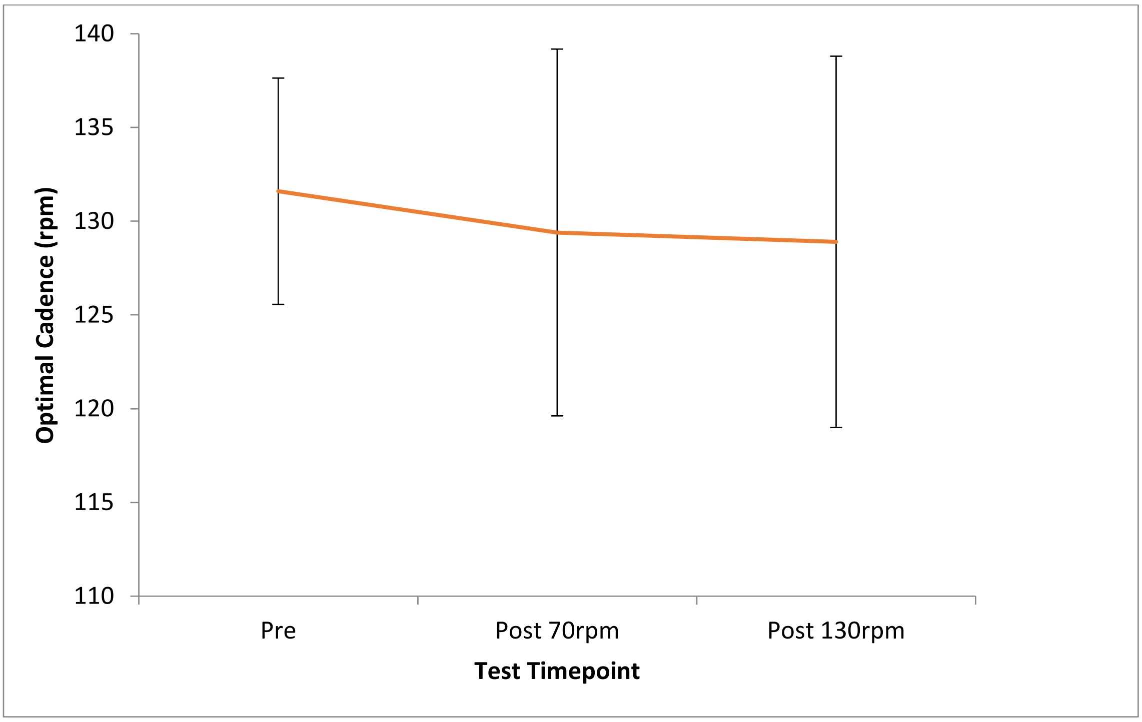


Figure 6.4. Male mean (±SD) inertial testing optimal cadence at each testing time point.

Figure 6.5 indicates the peak power changes and Figure 6.6 the optimal cadence changes in female athletes during the SLE intervention.

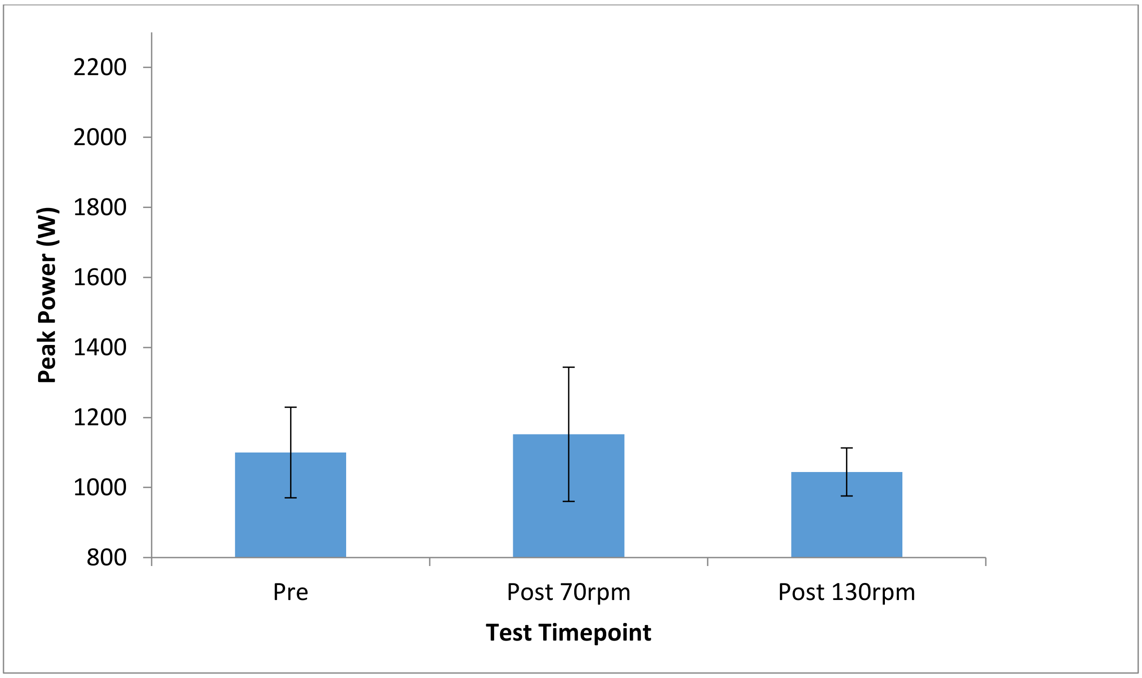


Figure 6.5. Female mean (±SD) inertial testing peak power at each testing time point.

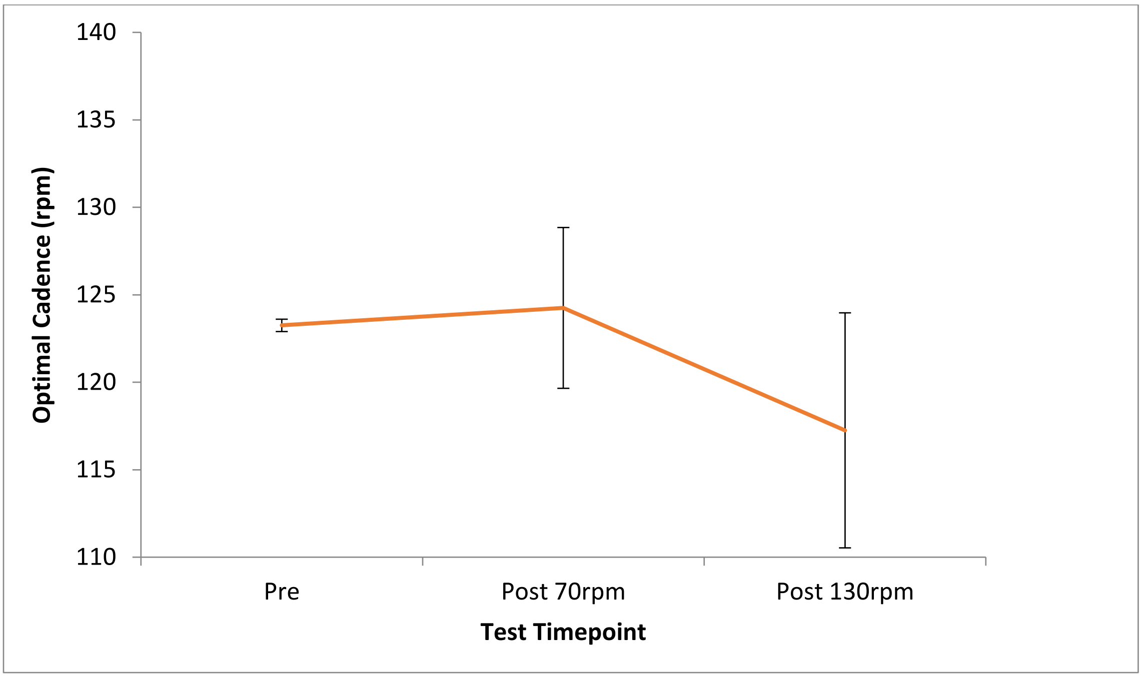


Figure 6.6. Female mean (±SD) inertial testing optimal cadence at each testing time point.

Figures 6.7, 6.8 and 6.9 indicate improvement in crank torque during the three x 30s testing for all participants (Figure 6.7), male participants (Figure 6.8) and female participants (Figure 6.9). It should be noted that one male participant was removed from the analysis as they selected one gear higher at their mid testing point and this elevated crank torques greatly. This did not appear to influence power as the athletes cadence was understandably impacted on by this different gear selection so the athlete's power data remained included in this section.

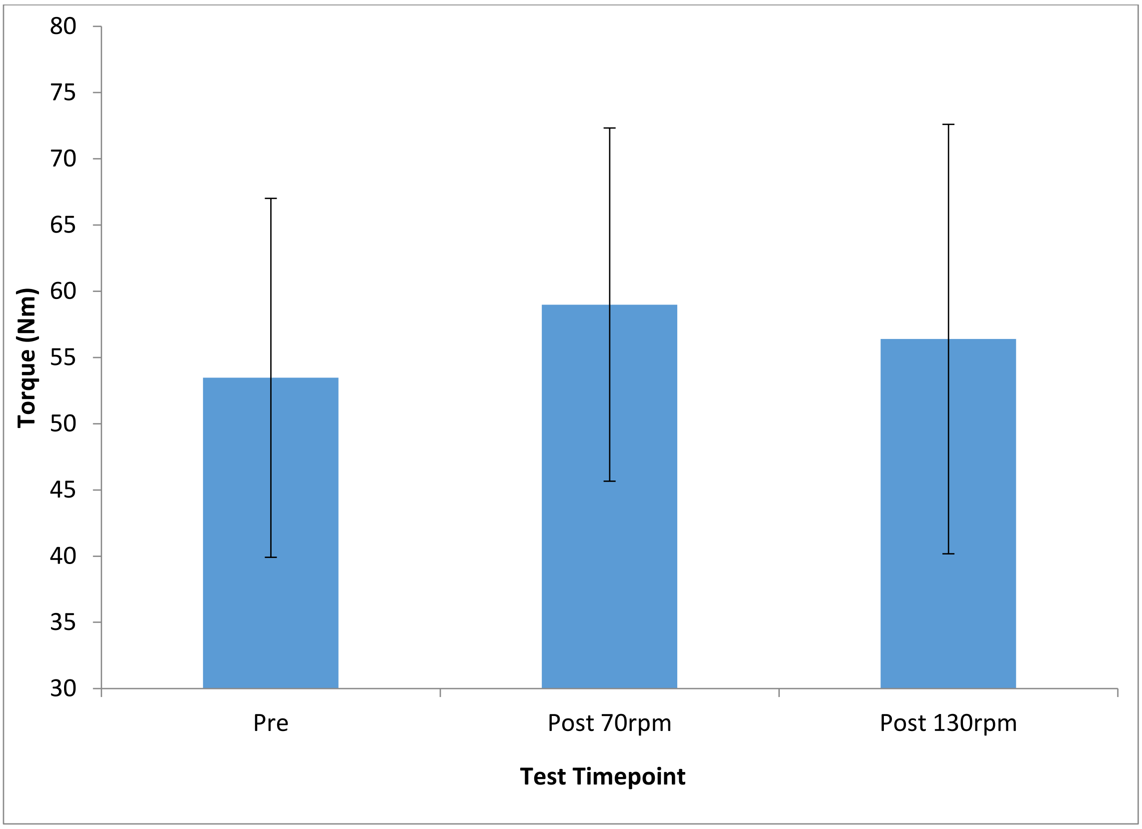


Figure 6.7. Mean crank torque for all working efforts for all participants for the 3 x 30s ergometer testing at each testing point (±SD).

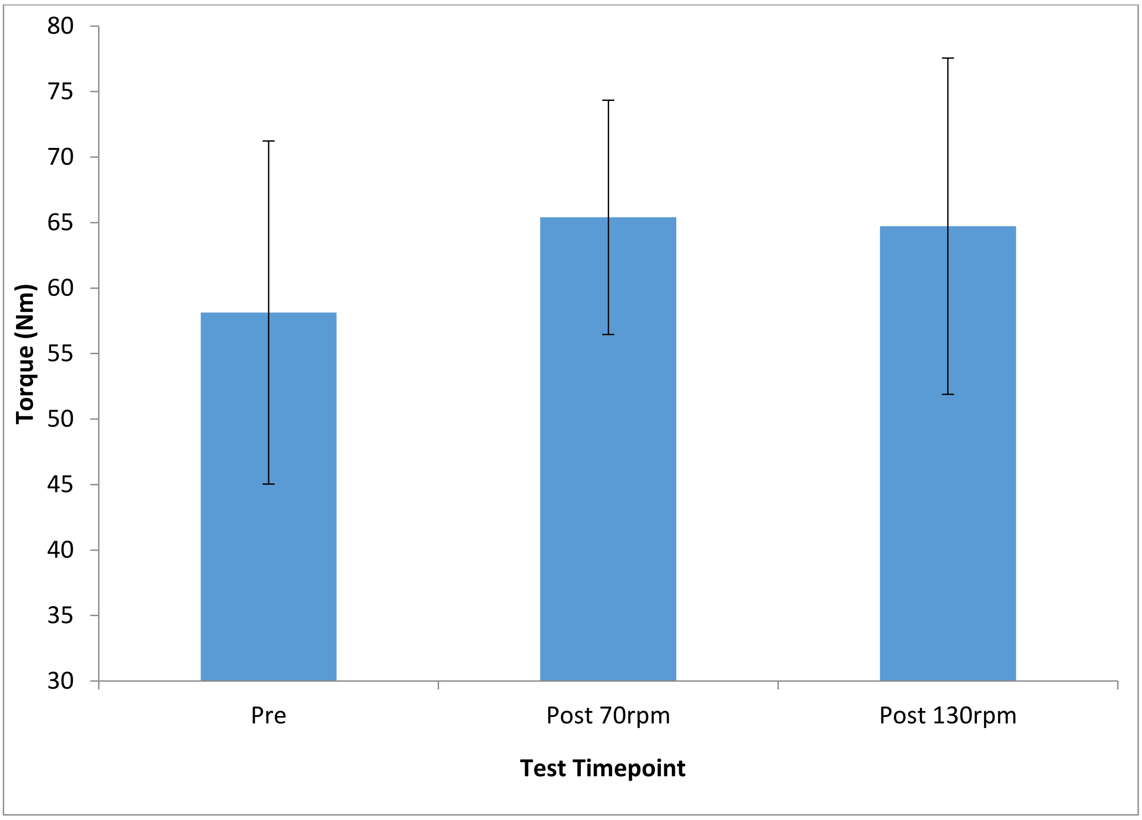


Figure 6.8. Mean crank torque for all working efforts for the male participants for the 3 x 30s ergometer testing at each testing point (±SD).

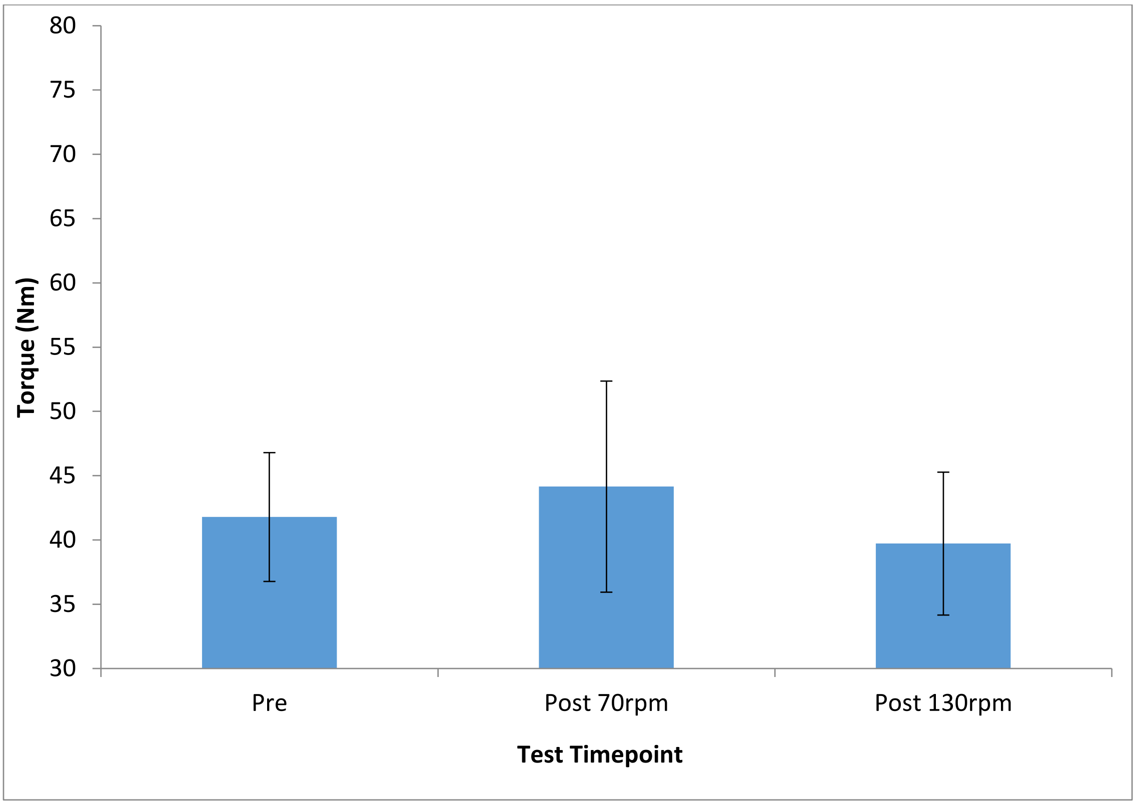


Figure 6.9. Mean crank torque for all working efforts for the female participants for the 3 x 30s ergometer testing at each testing point (±SD).

Figures 6.10, 6.11 and 6.12 display torque pedal-rate relationships obtained by inertial testing pre and post training at 70rpm and 130rpm for male participants. Torque pedal-rate relationships were plotted from data obtained between 80 and 220rpm.

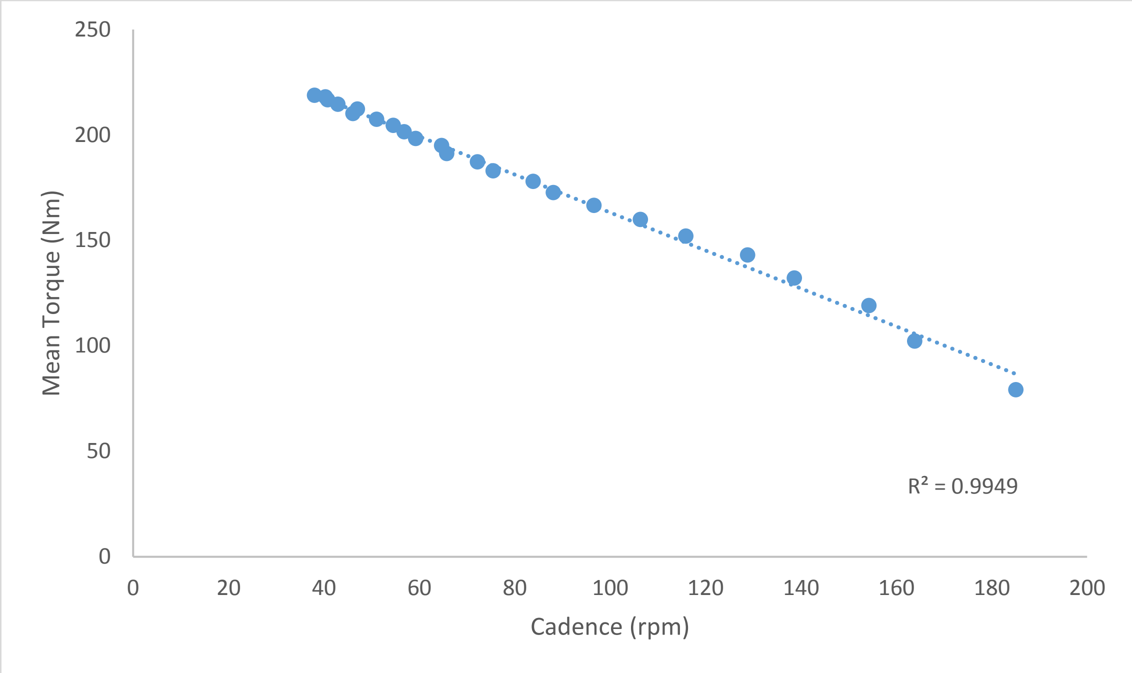


Figure 6.10. Plot of mean torque cadence relationship for male inertial testing prior to commencing training intervention.

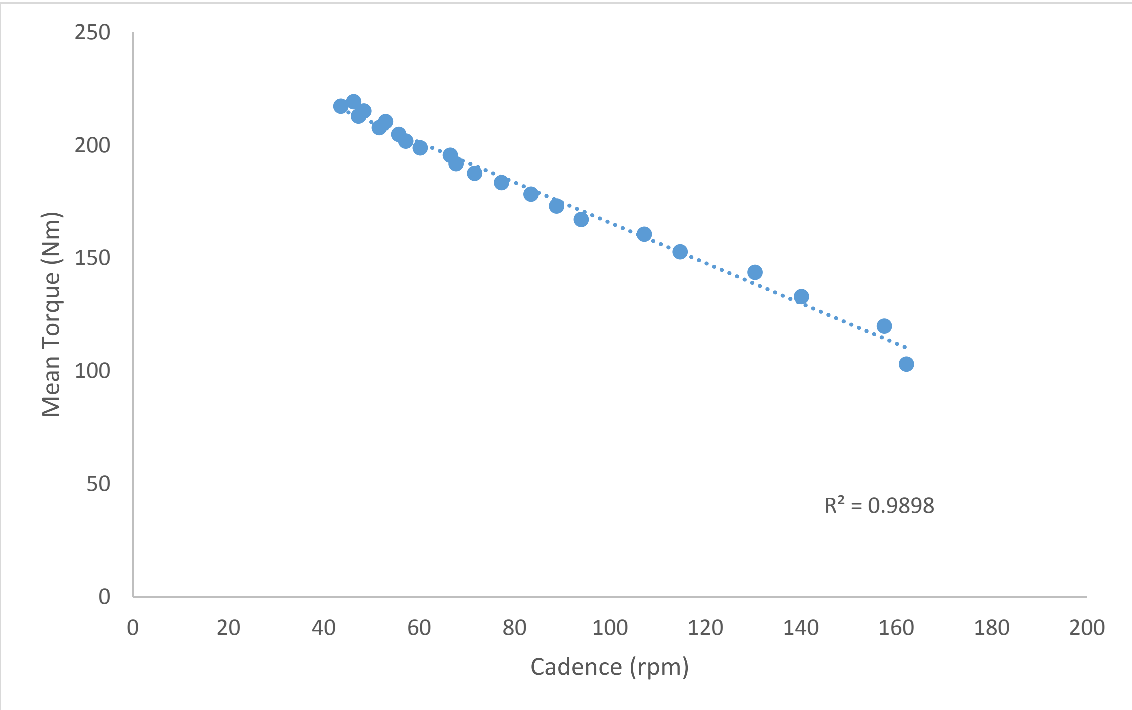


Figure 6.11. Plot of mean torque cadence relationship for male inertial testing post 70rpm training intervention.

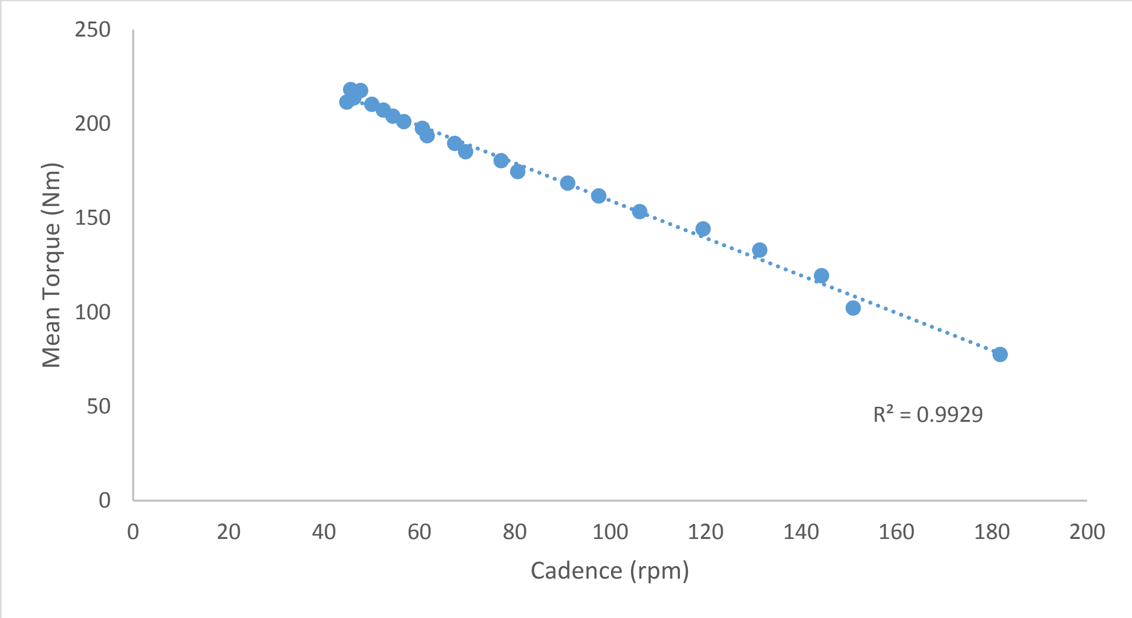


Figure 6.12. Plot of mean torque cadence relationship for male inertial testing post 130rpm training intervention.

Exploration of the force velocity relationship (Table 6.8) indicates extrapolated values for mean male maximal torque (T_0), maximal pedalling rate (f_0). Table 6.8 also includes interpolated torque pedal rate data to obtain 70 and 130rpm torque values from inertial testing at the pre, post 70rpm and post 130rpm testing sessions. Extrapolated T_0 and f_0 and interpolated 70 and 130rpm torque values were described from the relationships between torque and cadence plotted in Figures 6.10, 6.11 and 6.12.

Table 6.8. Extrapolated values for maximal torque (T_0), maximal pedalling rate (f_0), torque at 70rpm and torque at 130rpm for male participants from each inertial testing occasion.

		T_0 (Nm)	f_0 (rpm)	T_{70} (Nm)	T_{130} (Nm)
All	Pre	246.1	236.2	173.2	110.6
	Post 70rpm	249.8	237.2	176.1	100.2
	Post 130rpm	249.4	242.2	177.3	108.3
Male	Pre	253.3	281.3	190.2	136.2
	Post 70rpm	254.7	285.9	192.4	138.9
	Post 130rpm	258.6	260.3	189.1	129.5

Training Data

Tables 6.9 and 6.10 indicate the time in seconds spent within each 200W training band which includes the mean representation of all of on-bike or ergometer work. Power outputs below 200W are not displayed for male athletes.

Table 6.9. Mean (±SD) of male training data captured during each week of the training intervention. Data represents time (in seconds) spent in each 200W powerband during each week.

Powerband (W)		Week							
From	To	1	2	3	4	5	6	7	8
200	400	1120.8 (446.5)	1676.8 (357.9)	994.3 (591.8)	551.3 (307.6)	1044.5 (573.2)	767.5 (315.4)	765.3 (275.1)	115.8 (138.8)
400	600	73.8 (39.5)	181.0 (160.6)	110.5 (50.4)	116.8 (16.5)	148.0 (144.3)	73.3 (43)	93.5 (73.2)	47.3 (54)
600	800	43 (20.5)	25.8 (21.6)	45.8 (40.9)	77.5 (23.6)	95.5 (55.2)	28.0 (13)	29.3 (± 46.3)	34.8 (± 34.1)
800	1000	27 (10.1)	25.3 (25.3)	28.3 (27.1)	62.5 (13.3)	49.3 (21)	37.0 (22)	25 (± 29.8)	31.3 (± 29.1)
1000	1200	21.3 (9.9)	27.8 (29.6)	41.3 (21.3)	42.3 (17.3)	59.5 (29.4)	33.5 (16.5)	25.5 (± 19.6)	27.0 (± 14.7)
1200	1400	15.3 (6.7)	23.5 (19)	43.0 (27.9)	23.0 (15.6)	37.5 (15.9)	34.5 (11.4)	21.5 (± 11.5)	18.5 (± 9.5)
1400	1600	16.75 (9.6)	18.5 (10.1)	40.0 (13.6)	17.0 (14.7)	27.0 (4.5)	24.3 (14)	22.5 (± 7.4)	21.8 (± 10.9)
1600	1800	12.3 (13.3)	16.5 (7.2)	35.25 (9.1)	15.8 (12.3)	22.3 (7.6)	24.5 (3.4)	20.8 (± 13.5)	20.8 (± 11.8)
1800	2000	8.5 (6.4)	10.3 (7.8)	24.3 (13.1)	21.0 (23.1)	10.5 (12.6)	24.5 (11.6)	18.8 (± 11.1)	12.8 (± 7.6)
2000	2200	1.0 (1.4)	6.8 (8.6)	7.0 (8.7)	5.3 (6.1)	7.0 (8.1)	7.3 (8.1)	4.8 (± 5)	0.8 (± 1.5)
2200	2400	0.0 (0)	0.3 (0.5)	0.3 (0.5)	0.3 (0.5)	1.3 (1.5)	0.5 (0.6)	0.0 (± 0)	0.0 (± 0)

Table 6.10. Mean (±SD) of female training data captured during each week of the SLE training intervention. Data represents time (in seconds) spent in each 200W powerband during each week.

Powerband (W)		Week							
From	To	1	2	3	4	5	6	7	8
0	200	5075.5 (1133.5)	6162.5 (2648.1)	7843.5 (5044.0)	2988.5 (784.2)	5861.5 (1026)	7843.5 (4960.4)	3888.5 (400.9)	1916.5 (47.4)
200	400	564.5 (41.7)	506.5 (119.5)	549.5 (234.1)	228.0 (267.3)	390.5 (149.2)	549.5 (265.2)	122.5 (118.1)	29.0 (8.5)
400	600	45.5 (61.5)	5.0 (4.2)	47.5 (44.5)	103.5 (91.2)	21.5 (13.4)	47.5 (2.1)	20.5 (29.0)	38.0 (7.1)
600	800	36.0 (31.1)	17.5 (6.3)	33.5 (33.2)	33.0 (1.4)	77.5 (34.6)	33.5 (16.3)	24.0 (33.9)	20.5 (2.1)
800	1000	31.5 (20.5)	40.5 (33.2)	26.5 (13.4)	25.0 (22.6)	44.5 (10.6)	26.5 (9.2)	17.0 (24.0)	12.5 (5.0)
1000	1200	13.5 (19.1)	23.0 (32.5)	3.5 (4.9)	4.0 (5.7)	14.0 (0.0)	3.5 (8.5)	4.0 (5.7)	0.0 (0.0)

Discussion

In the present study the influence of a counterweighted single legged training stimulus on optimal cadence, peak sprint power and resistance to fatigue in elite sprint cyclists was investigated. Key findings from the study included: no meaningful change in optimal cadence or peak power derived from inertial ergometry, an increase in the work performed (average power) during the first and second 30s efforts of the three x 30s ergometer (fatigue) testing and an increase in peak power during the first of the three x 30s efforts at each time point. Increases were also noted in T_0 (maximal torque) during inertial testing in male participants following the 130rpm single legged training. Based on the findings, it does not appear that the single legged ergometer training improved the athletes' resistance to fatigue. It is possible that the absence of changes to optimal cadence and peak power derived from inertial ergometry confirm there were no shifts in muscle fibre type. Considerable improvement in mean crank torque was observed in the 3 x 30s testing at the study midpoint following the 70rpm single legged training (Figure 6.7). Given the problems encountered with the ability to complete this study with female participants due to illness and injury much of the discussion focuses on the results of the male participants due to the low number of female participants.

It would have been expected that an increase in the ability to resist fatigue would result in an increase in the power/work output during the third working effort over the course of the study. Results from the three x 30s testing showed the average power attained during the final effort remained largely unchanged. There were however large effects seen from pre testing to mid testing and pre testing to post testing in average power during the first 30s effort. It may be reasonable to expect that the greater metabolic disturbances in the initial 30s effort (effort one) impacted on the ability to demonstrate a performance enhancement in the third 30s effort during each test. Mendez-Villanueva et al., (2008) who looked at anaerobic power reserve in participants performing ten, six second maximal sprints with 30s of recovery between also saw increased work performed in earlier sprint efforts. Mendez-Villanueva et al., (2008) observed that as work output in the earlier sprints increased this compromised the ability to complete as much work in the later sprint efforts. It may be possible given the nature of the competitive environment that an ability to sustain greater work capacities later in an event is able to be demonstrated.

While an improvement in crank torque following the 70rpm training condition and improvements in fatigue resistance following the training completed at the higher pedal frequency had been anticipated, this was not seen in the results. Figure 6.7 indicated a larger magnitude change in crank torque during the three x 30s testing at the study midpoint following the training completed at 70rpm. Interestingly from the torque-pedal rate relationships plotted (Figures 6.10, 6.11, 6.12) the results for the male participants tended towards larger improvements in maximal torque as determined by inertial load testing following the higher cadence training (Table 6.8). However, it is also possible that the training adaptations following the intervention were delayed and not fully manifested at the testing points. Interestingly, the interpolated torque values at 130rpm were reduced following the 130rpm training (Table 6.8) for the male participants, the slope of the line indicating a lower maximal cadence after the training block.

Tables 6.9 and 6.10 shows the on-bike and ergometer training completed over the duration of the intervention. While all of the relevant training efforts were completed as prescribed in Table 6.2 there was a certain degree of peripheral work that contributed to the variation in training. All relevant training sessions were completed as originally prescribed where weather did not intervene. Despite this variation in training outputs there does appear to be a consistent impact of the training intervention on the male athletes participating in this study. The intended changes in overall workload and percentage reductions in the lower volume period do not appear to have been achieved based on the changes in quantified mean training outputs from week to week (Tables 6.9 and 6.10).

Given that the single legged ergometer training was maximal, creating a progressive overload with this stimulus was challenging. It was necessary to sufficiently motivate athletes verbally and focus on improving output from their previous session. Additional analysis has indicated that a mean progression in training outputs across all athletes of

6.0% (±7.8) and 7.6% (±5.1) was achieved through the 70rpm and 130rpm training blocks respectively. Individual differences were noted following each cadence block. The small sample size and individual nature of the responses to this training intervention are responsible for the large amount of variation. Again, the influence of the highly varied female data on the overall group results and having only two female athletes available for this study provides limited meaningful data for comparison.

The changes in crank torque observed in the study is thought to be notable and worthwhile and related to improvements in muscle coordination as a result of the single legged training stimulus. To date there has been no specific report of changes in torque applied or muscle coordination as a consequence of single legged cycling training. Paton, Hopkins, and Cook, (2009) showed improvements in a number of physiological variables following training completed at either low (60-70rpm) or high (110-120rpm) cadence to be greater in the lower cadence group. They did not discuss torque specifically but did indicate that the larger pedal forces in the lower cadence group were likely to be responsible for the greater magnitude of improvement seen in this group. To an extent this does support what was seen in the current study with improvements in crank torques following the 70rpm training block however more discussion for the improvements seen following the training completed at 130rpm is required. Single leg cycling training without a counterweight has been shown to emphasise the upstroke disproportionately (Thomas & Martin, 2009) emphasising the more easily fatigued hip flexors (Burns, Pollock, Lascola, & McDaniel, 2014). O'Bryan et al., (2014) showed a decrease in the activity of the rectus femoris (hip flexor) musculature as a consequence of fatigue. While the use of a counterweight aims to reduce the work of the hip flexors on the active leg when cycling single-legged and mimic the biomechanical requirements of double leg cycling there is still likely a component of hip flexor loading. Intensive single-legged cycling training at high pedal frequencies, and as carried out here with a lower counterweight mass may assist with training fatigue resistance in the hip flexor musculature and ultimately assist the recovering leg and contribute to cycling power production. It would seem reasonable to expect that improvements in this phase of the stroke (upstroke/recovery) at such pedal frequencies may result in positive changes in net crank torque as was seen here given the potential for a negative torque to be effected by inadequate rectus femoris activity. In the current study there is a potential reduction in the negative torque contributed by the recovering leg after intensively training the musculature responsible for controlling recovery of the pedalling leg. Indeed given the relationship between torque and power an increase in torque produced at any given cadence will result in an increase in power output. The changes in maximal torque and maximal cadence likely contributed to the increases in power and the lowering of optimal cadence observed throughout the course of the intervention. The improvements in torque in the inertial testing were also reflected in the 30s testing session (Figure 6.7); however, the magnitude of increase for each of the testing modalities was observed to be opposite. Considering only the male participants there appeared to be a slight increase in maximal torque at the mid study testing and a larger magnitude of increase in maximal torque at the post study test point. The three x 30s ergometer testing showed a greater magnitude of increase in average crank torque at the mid study testing and a maintenance (in the male participants) of an increase in the post testing data (Figure 6.7).

While a reduction in optimal cadence (Figures 6.2, 6.4, 6.6) would not be deemed desirable (Dorel et al., 2005) the increase in inertial crank torque may offer explanation for the concomitant improvements in peak power production. From the data deriving the torque pedal rate relationships (Figures 6.10, 6.11, 6.12) present values of f_0 (Table 6.6) were consistent with those reported by Martin at al., (1997) and Dorel et al., (2005). Values for T_0 (Table 6.6, range for elite male participants 253.3-258.6 Nm) were also consistent with those reported previously by Dorel et al., (2005) and similarly higher than that reported by Martin et al., (1997). Dorel et al., (2005) reported a range in their ten participants of 215-270Nm while Martin et al., (1997) had a mean T_{REV} value of 209 ± 9 Nm. The same relative relationship between f_0 and optimal cadence as described by Dorel et al., (2005) has been shown here, with optimal cadence being 50% of f_0. The optimal cadence data reported over the testing time points of the study was associated with a large degree of variability (Figures 6.2, 6.4, 6.6) however the concomitant reduction in f_0 does tend to support the lowering of optimal cadence in the athletes, although this has not been able to be confirmed given the sensitivity already reported for this test procedure (Chapter 3). The practical implications for an increase in the ability to produce peak power and increase in torque in the competitive sense would be expected to be related to an improved ability to accelerate the bike and rider system. Improvements in acceleration are desirable to the sprint cyclist. The data have made determining an improvement in fatigue resistance difficult, however the argument introduced earlier in this thesis (Chapter 4) may indicate a positive impact on fatigue resistance. It is likely the chronic decrease in optimal cadence and subsequent improvements in crank torque are potentially related to sparing of ATP through a reduction in SR calcium release and Ca^{2+}-ATPase activity and an improvement in MRLC sensitivity to calcium. These have been shown to maintain contraction forcefulness (MacIntosh et al., 2012).

Conclusions

Training responses to the single legged ergometer were highly varied. The use of single legged ergometry to improve resistance to fatigue is not supported with the findings of this study. Increases in work performed during the first and second stages of the 3 x 30s test protocol does indicate a positive response to the training intervention. There appeared to be a potential neuromuscular improvement with high cadence single legged ergometer training exposure seen with improved torque production from the inertial testing in most male athletes. There were no detectable changes to optimal cadence which potentially indicate a lack of fibre type shift. From the data presented it appears likely to be related to adaptation in muscle coordination and sequencing from the counterweighted single leg approach, particularly the hip flexors and musculature involved with the upstroke of the pedal cycle. The single legged training approach did not appear to have improved the athlete’s ability to resist fatigue following a period of maximal exercise by creating an ability to produce greater amounts of power in subsequent work bouts. However, increases in peak and average power in the first bout during the post testing could have masked improvements in the ability to resist fatigue due to a greater metabolic disturbance from the first work bout. It is unclear whether a testing battery consisting of three maximal 30s efforts separated by two minutes of recovery is suitable to determine improvements in resistance to fatigue in a way that is valid for sprint cycling (CV for three x 30s test procedure 5.8%). It could be expected that increases in peak power production and an ability to produce more torque would likely result in an improved ability to accelerate in a real world setting.

7. General Discussion

General Summary

Performance improvement and enhancement are critically important factors in the progression of an athlete. Understanding the athlete, the sport, the desired adaptation of the training and the impact of the training stimulus applied are all critical to creating performance improvement. This thesis consisted of a series of studies on elite level track cyclists with a focus on addressing ways to optimise and enhance performance. Central to the work was the utilisation of inertial load testing to monitor chronic changes in peak power and optimal cadence in response to training. Use of this ergometer also allowed an understanding of the impact of the prior submaximal work performed during the sprint and keirin. Tracking and monitoring the progression through training towards a major pinnacle event and subsequent impact of a novel training stimulus to address performance deficits was also helped by the use of this ergometer. Progression of the research in this thesis was intimately linked with the phases of preparation for the elite group of athletes through their international race season and build up for the 2012 World Championships and London Olympic Games. It is very rare to focus research on elite level performers and this collection of studies further support the work done by other researchers who have conducted research on elite level track sprint cyclists (Craig, Pyke, & Norton, 1989; Dorel et al., 2005; Dorel et al., 2012; Flyger et al., 2013; Flyger, 2009; Gardner, Martin, Martin, Barras, & Jenkins, 2007; Gardner, Martin, Barras, Jenkins, & Hahn, 2005).

Throughout the thesis specific use has been made of an inertial testing ergometer and protocol to measure changes in fatigue free peak power and optimal cadence and provide information on the changes observed in these athletes. The inertial ergometer demonstrated strong reliability (CV for optimal cadence 1.7% (1.4-2.3), power 0.9% (0.8-1.2) for all participants, including the elite only group (CV for optimal cadence 1.6% (1.2-2.7) and power 0.7% (0.5-1.0) and validity for elite group only (r= 0.81, 0.73-0.88). The validity is consistent with previous studies (Gardner et al., 2007) which have shown strong relationships between laboratory and field based testing data for torque and power pedalling rate relationships (0.99±0.01 and 0.99±0.02). The reliability data was also in agreement with Martin, (1997). The testing tool was then applied to an investigation into the prior submaximal work completed in the sprint and keirin and highlighted the mixed muscle characteristics and requirements of track sprint cycling. As sprint athletes they are unique given the prior submaximal aerobic work which is a part of every ride and every event. The track sprint cyclist requires a substantial capacity to deliver and tolerate the aerobic work which occurs prior to executing the maximal "sprint" portion of their ride.

There is a clear indication of the downward and leftward shift in the power cadence curve with a greater magnitude of change in the sprint prior work condition. Magnitude of change for differences in peak power were almost double in the sprint prior work condition compared to the keirin prior work condition (mean change in all athletes = 10.52% for sprint compared with 5.93% for keirin). MacIntosh et al., (2004) showed a much larger magnitude of difference in both optimal cadence and peak power between non-fatigued and fatigued conditions (33% lower OC and 45% lower power) with a maximal 30s fatiguing protocol. This provides support for the magnitude of change in peak power and optimal cadence following sufficiently fatiguing prior work to be the result of the intensity and duration of that prior work. Investigation into the relationship between optimal cadence and sprint qualifying performance was carried out by Dorel et al., (2005). They found a significant relationship between 200m velocity (V_{200} ($m.s^{-1}$)) and optimal cadence (f_{opt} (rpm)). The relationship provides support for the hypothesised benefit of arriving at competition with a high optimal cadence.

Also important in time trial performance is the magnitude of aerodynamic drag the rider is required to overcome. Dorel et al., (2005) found a significant relationship with power expressed per unit drag (A_p – frontal surface area) r=0.75 (p=0.01). A case study approach to the specific relationships of peak power and optimal cadence to performance gives a diverse array of relationships between the elite male participants in this study. Alterations to the gearing selection and time trial strategy, the anthropometric qualities of each athlete and their riding positions give way to large variances in their drag at high velocity. While it has not been addressed in the current study the relationship established by Dorel et al., (2005) does clearly indicate that the aerodynamic qualities of the individual play a significant role in determining performance. It is likely when force-velocity data is related to real world performance the drag qualities of the athletes contribute largely to the variation seen in the data.

Tracking the training and performance outputs through the 2011/2012 season and then through to the 2012 London Olympic Games failed to give clear indicators of causative relationships between training stimulus and achieved physiological progression, or lack thereof. There was an apparent trend in the data in the months prior to the 2012 World Championships that the field MMP's were improving heading towards the pinnacle event. The relationship did not appear in June and July prior to the Olympic Games with a downward trend in the field data in July. There were improvements in the alactic power metrics with inertial optimal cadence and peak power trending upwards during this time and exceeding values from February and March 2012 (Figures 5.9 and 5.11). While it was expected there would be some evidence of physiological progression heading into the Olympic Games, as this was the global priority event in 2012, there was little evidence that any country other than Great Britain managed to achieve this; although without knowing relevant power and physiological data on those athletes it is difficult to say for certain (Appendix C – additional performance results). It was expected that the influence of the racing, travelling and resting throughout the 2011/2012 World Cup racing season contributed a training adaptation which conferred a substantial conditioning of all of the MMP durations. The high volume of the stress, followed by travel and forced rest allowed the creation of an effective training stimulus.

The marked increase in peak power and optimal cadence in the inertial data captured in early June once arriving in Valencia, Spain could potentially be attributed to the ambient temperature increases and its impact on the ability to develop power. Sargeant, (1987) showed increases of ~11% in peak force and peak power following immersion in a water bath at 44°C for 45min. It is also possible that the increase through 2012 was related to more subtle learnings which take longer periods of time than have been acknowledged previously by Martin et al., (2000) who demonstrated that stability in peak power development with inertial ergometry was achieved within 3 days of consecutive testing and exposure to this task. It is also possible the latency in the withdrawal of the eccentric training stress in the gym coincided with the upswing in inertial testing data in early June. Cook, Beaven, and Kilduff, (2013) saw more pronounced improvements in upper and lower body strength measures when eccentric training was performed compared to traditional resistance training, regardless of whether it was accompanied by overspeed training. Participants performed four consecutive blocks of training: traditional resistance training only, eccentric only resistance training, traditional resistance training with overspeed exercises and eccentric resistance training with overspeed training. The potential benefits associated with the inclusion of eccentric training in the periodised plan were supported, despite the guaranteed overspeed stimulus employed with the on-bike training. Similarly Paddon-Jones et al., (2001) indicated an increase in type IIb muscle fibre proportion following a ten week eccentric training intervention. The increase was shown specifically in the group completing fast eccentric training and in contrast the eccentric training carried out by the athletes in the study was typically completed slowly. The subsequent decrease in the data in July 2012, immediately prior to the Olympic Games, appeared to agree with the longer duration field data indicating a deterioration in performance, stemming most likely from an inappropriate training stimulus through the month of June which created too much suppression in performance ability.

Given the overall results of the Olympic Games, a national best time in the team sprint second round ride (finishing overall in 5th place with a very poorly executed first round ride), a poorer flying 200m sprint qualifying time and a bronze medal in the keirin; it would appear that there was a lack of consistency in the performance ability of the athletes. The level of inconsistency seen at the Olympic Games prompted investigating a new approach to improving the ability to resist fatigue when performing repeated bouts of maximal work.

A novel single legged cycling training stimulus was used to induce a training stimulus that would improve resistance to fatigue. Previous research investigating this training model was based solely on endurance cycling performance (Abbiss et al., 2011; Turner, 2011). While findings do not indicate an improvement in resistance to fatigue following two blocks of single legged ergometer training the improvement in peak and average power in the first and second of the 3 x 30s testing work bouts was likely to contribute a greater metabolic disturbance in the follow up testing sessions. It was noted that the work output during the third of three work efforts was maintained at a similar level despite the increases seen during the first two work bouts when comparing pre and post testing power data. It is possible that in the competitive environment the increased capacity seen in the first two work bouts (of three) would translate into greater levels of performance and if racing did not sufficiently challenge the athletes metabolically this would leave more performance ability for later rounds. Certainly the data presented by Mendez-Villanueva et al., (2008), where increases in output during earlier completed sprint efforts compromised the ability to complete work in the later sprint efforts, would support this.

It was hypothesised that the 130rpm training cadence would induce a much greater metabolic disturbance given what was observed using this approach in previous pilot work (completed at 100rpm) and the influence of accumulated contraction cycles on fatigue development (Abbiss et al., 2011; Turner, 2011). What was not investigated specifically with the pilot work was changes in crank torque. This became a focus during the present study once the changes in torque were revealed. Crank torque improvements in the three x 30s testing efforts following the 70rpm training stimulus (study midpoint) were not seen at the same magnitude following the 130rpm training, however, following the 130rpm training block there was a greater magnitude of change in T_0 (Figure 6.6). Interestingly there was a decrease in $ƒ_0$ following the 130rpm training block and a corresponding large decrease in T_{130} indicating the slope of the relationship had changed for the male participants. These crank torque characteristics are also seen with reductions in optimal cadence and increases in inertial peak power. It does seem reasonable to conclude the training block resulted in improvements in generating greater maximal torque and higher peak powers at a lower optimal cadence with a corresponding increase in work output and the potential to resist fatigue. The contribution of the other training being undertaken during this time was likely to have complimented the improvements detected with the intervention testing, however, the specificity of improvements in crank torque in each block were closely aligned with the training cadences employed during the single legged training. While the other on and off-bike training would have complimented the improvements, it is unlikely that it would have resulted in the changes seen at either 70, or 130rpm specifically.

The discovery of the specific improvements in crank torque as a result of the single legged training again provides more questions than answers. It is however reasonable to expect an improvement in the ability to develop or express greater crank torque, detected by both lactic and alactic testing modalities, would result in an improved ability to accelerate and increase power production during maximal expressions of power when training or competing. These are both very attractive and helpful qualities to the sprint cyclist. Again it would seem reasonable to expect that based on the changes seen following the intervention gearing selection may need to be altered (increased) to optimise performance given crank torque and power increased while optimal cadence declined.

A multifactorial and multidisciplinary approach to the development of a track sprint cyclist is necessary. Inertial ergometry is a valid and reliable alactic testing and monitoring tool capable of providing valuable information to monitor and track progress.   This thesis showed that racing in the preparation phase of a pinnacle event is an important and necessary stimulus not to be missed. It has also been indicated sufficient tolerance of submaximal work is also an important attribute despite the athletes being the strength/power/anaerobic iteration of a cyclist. However, the aerobic ability and resistance to fatigue needs to be achieved beyond the historical approach of miles for the sake of miles. Specific development of resistance to fatigue, improvement in the ability to develop power and torque when cycling at a range of cadences and a cyclic approach to application of the training stress are likely the corner stones of performance improvement in this group. Not explicitly detailed here is the role of drag and air resistance on the ability to go faster. The physiological progression and development of the athletes will not realise the greatest level of performance if care and attention is not directed towards aerodynamics and drag.

Optimal cadence interpretation

Historically the concept of optimal cadence was developed to ensure that anaerobic athletes were being tested for peak power in a cadence range that they were most capable of producing maximal power output and avoiding underreporting of the measure (Tomas et al., 2010). There is no doubt of the merits of utilising this physiological concept to arrive at a true maximal power output. It was also discovered to be highly correlated with muscle fibre type and its association with providing insight into muscle composition (Hautier et al., 1996; Sargeant, Dolan, & Young, 1984). Its use in the field and the sport of cycling has applied these same concepts to understand the physical characteristics of cyclists, particularly track sprint cyclists. Indeed, the use of an inertial ergometer in tracking and monitoring throughout this thesis provided an easily obtainable metric; unfortunately it was not always easily interpreted.

At the outset of this thesis and based on the interpretation of historical literature (Dorel et al., 2005) the relationship between optimal cadence and muscle fibre type, as well as flying 200m time, would indicate that to perform most optimally optimal cadence must be as high as possible. While it is unlikely that there were acute changes in muscle morphology it could be argued that a higher optimal cadence gave at least the ability to express more fast twitch characteristics, which in the context of an anaerobic athlete must be considered desirable.

It could be thought that a lower optimal cadence would be indicative of a poorer state and less desirable for optimal performance in competition. Indeed this was the case at the outset of this thesis based on the findings of the historical literature on the subject (Dorel et al., 2005). With the large number of inertial tests completed over the duration of the thesis it is clear that an array of responses and test results can occur. An athlete can give a result where peak power is high and optimal cadence is low, peak power is high and optimal cadence is high (expected to be the most advantageous in regards to performance ability), peak power is low and optimal cadence is low (least advantageous in regards to performance ability), peak power is low and optimal cadence is high. All of these potential responses relative to the individual and it was not unusual to get an increase in either optimal cadence or peak power and a decrease in the other. This may highlight the potential for acute alterations in gearing selection to optimise performance ability based on the state the athlete presents in.

This gave two distinct situations, where interpretation of inertial test results in an acute and chronic context can provide important and useful information to the sports science team. Changes in peak power and optimal cadence are likely to be the result of a combination of acute and/or chronic fatigue of the neuromuscular system while chronic changes in optimal cadence and peak power are likely indicators of improvements in resistance to fatigue or potentially indicative of fibre type shift. In the situation where a deterioration in peak power and optimal cadence is the result of fatigue a downward and leftward shift in the power cadence curve is to be expected (MacIntosh et al., 2004). In the situation where the training stimulus has conferred an improvement in the resistance to fatigue it would appear likely that a reduction in optimal cadence will be observed.

Optimal cadence is related to intrinsic qualities of muscle and strongly correlated with muscle fibre type and can be observed to change acutely and chronically with the influence of fatigue and training adaptation. A weak or non-existent relationship between optimal cadence and peak power exists. It is likely this is the result of optimal cadence expression being dependent on the alterations and optimisation of intrinsic muscle properties depending on the state of the athlete to allow production of maximal powers. This would Indicate power production is the priority and does potentially explain how we are able to observe good powers with fluctuation in optimal cadence on a day to day or within session basis. In a situation of acute fatigue optimal cadence is reduced and power cadence curve shifted left – power maintained as high as possible by sparing ATP (through changes to SR calcium release and sensitivity) and optimising activation/relaxation kinetics. This will work to keep contraction force as high as able but reflect a compromise in contraction frequency/velocity therefore most likely contributing to a lower optimal cadence. This would indicate that optimal cadence is not the priority characteristic, it is dependent and required to change based on the state of fatigue. Dorel et al., (2005) took a lab based determination of optimal cadence (fatigue free) interpreting it as reflective of the intrinsic muscle qualities and made the assumption as to how stable this quality is and related it back to performance times. Despite analysing data in the current study the same relationship between optimal cadence and performance measures was not seen. The inertial testing data used in the analysis was from regularly collected monitoring data and not from specifically rested testing sessions and is more reflective of the state of the athlete at the time and not the maximal underlying capabilities of the athlete.

Does a chronic increase in optimal cadence reflect positive changes in the short duration power and ability to produce short duration power at the expense of maintaining or improving longer duration powers? Certainly the work targeted towards fatigue resistance saw a decrease in optimal cadence. If the relationship under speculation exists this would then indicate the increase in inertial values heading into the Olympic Games was achieved at the expense of the longer duration powers; supported by the field data. Again going into competition the expectation of achieving the highest optimal cadence values did not translate into superior performance ability as was evidenced with the longer duration powers (see Table 5.1 and 5.2). It is also likely that the increase in inertial testing values to June and then fall of both inertial results and field power data in July would indicate a large degree of inappropriate loading through the period.

In terms of real world performance implications, do we look to optimal cadence as a measureable indicator of the intrinsic muscle qualities and any changes to drive the manipulation of the athlete's race environment (equipment/gearing etc.)? For the athlete who has low optimal cadence or presents with chronic lowering optimal cadence leading into a pinnacle event it would seem reasonable to increase race gear to reduce cadence. This would serve two functions, lower pedal frequency to minimise the number of contraction cycles (Dorel et al., 2005) and increase the time over which the athlete can apply a larger torque, thus positively influencing power production. The athlete presenting with an acutely lowered optimal cadence (and concomitant reduction in power production) would appear to be in danger of a training induced fatigue and would be unlikely to preform to their best. This situation would indicate recovery is required.

Limitations

The main limitations throughout this thesis are the small numbers of participants and the inability to carry out additional physiological measurements. The ability to work with a group of elite, Olympic level athletes does in itself indicate a limited number of participants available. This is however an important and necessary trade off to enable an insight into this group to be able to better understand training and power progression. The lack of physiological measurements outside of power output data does limit conclusions that can be drawn from these findings. However, the relevance of power output as a primary metric for monitoring progression and performance cannot be understated even in the absence of supporting physiological measurements. It is important to note in the prior work investigation that only the field data was used to show the relationship between field derived optimal cadence and power values during 200m time trials ridden in competition. In this instance the performance of the prior work and subsequent maximal acceleration differ to the laboratory setting. Laboratory simulation of the influence of the prior work involves the cessation of pedalling on the ergometer to bring the flywheel and pedals to a complete stop for the performance of the inertial test. This gives relevant comparison between fatigue free values and the influence of the prior work performed in the simulation but it is important to note as this is out of context of the performance situation where there is no cessation of movement. Collection of additional physiological data and investigation of the cellular mechanisms responsible for such changes in available power output is also warranted in allowing for a more complete understanding of the impact of the submaximal work. Other differences resulting from the performance of the test when standing compared to the performance situation where the athlete will accelerate maximally out of the saddle will confound some of the interpretation of the data. It is also important to note too that no determination of muscle fibre type was undertaken and optimal cadence as an indirect indication of muscle fibre composition was based on previous work in the literature (Dorel et al., 2005). Given some of the limitations with accessing accurate training information during the build up to the 2012 World Track Championships and the 2012 Olympic Games most of the training programme was constructed from captured data files at training camps, training files captured by athletes outside of camp and infrequent provision of training programmes by staff. While this does mean it is accurate it also leaves a number of gaps in the information analysed. Remote administration of the training stimulus and variation in the application of this training stimulus with athletes working unsupervised also proved to be a limitation. Different geographical locations and a decentralised training environment also contributed to limitations in the ability to adequately control aspects of the overall training load. The order of the training cadences presented in the single legged training intervention study (70rpm then 130rpm) may potentially carry an effect.

Future Research

Future research on the impact of the inertial testing ergometer as a training modality would provide information on the usefulness of progressing quickly from a situation of maximal pedal torque to maximal pedal frequency. It is possible that targeted training on the inertial load ergometer where short, approximately four to five second, maximal efforts may be provide a useful training stimulus. Training of this nature essentially combines a training stimulus closest to both T_0 and f_0. Future research to investigate different pacing and gearing strategies in the 200m qualifying time trial in the sprint and time spent behind the pacer in the keirin to determine if an alternative strategy which has less impact on the power pedal rate relationship of the athlete. It would be interesting to determine if this is as simple as manipulating gearing to more closely align race cadence with optimal cadence during the flying 200m time trial. While the kerin is an unpredictable event exploration of energy saving pacing strategies while following the pacer still warrant investigation.

Another area for future research is a more detailed breakdown of the influence and consideration of racing as a training stimulus. Anecdotally there is a long held belief in cycling, possibly in many sports, that racing is the best training. Given the appearance of the importance of the racing stimulus during the build up to the World Championships in 2012 looking more closely into the efficacy of considering racing as training would provide valuable information. Research investigating the impact of different periodisation strategies for the track sprint cyclist is also important. While these are considered strength and power athletes the mixed muscle nature and substantial component of aerobic work required in each event indicates finding the best approach to combine the training stress for maximum performance gain is critical. Is there a better way?

Future research investigating single legged ergometer training would benefit from further study into higher training cadences more closely aligned with race cadences (130-150rpm). A test of the impact of the increase in work capability, as seen in this study during the first three x 30s repetition and on competitive performance during racing would also provide further understanding of the real world impact of this training stimulus. Investigating the biochemical changes to understand the stress this HIIT approach to SLE places on the underlying physiology of the athlete, is also a crucial next step. Improvements shown in muscle respiratory capacity in endurance cyclists will need to be undertaken with this sprint trained group to confirm whether there are similar improvements in cytochrome c oxidase subunits and GLUT-4 as seen with endurance populations. The determination of a potential order effect with the low then high presentation of the training cadences utilised will also be helpful to understand the impact of each individual training cadence. To date the previous research has been focused on endurance athletes and the potential for improvement of endurance performance, more specific investigation into the application of this training stimulus in the sprint athlete is necessary.

Future research investigating the physiological concept of optimal cadence is also necessary. To better understand the information this measure is providing in relation to fatigue and the underlying physiological changes and adaptation to training is the logical next step for this measure. Investigation into the involvement and influence of changes in calcium sparing and sensitivity via the SR and the information available on neuromuscular changes will also add further knowledge to this area. Future exploration of these characteristics and qualities in a sporting context (in this instance, track sprint cycling), will also contribute to a greater understanding of this athlete. Application of sports science research in the field will be an important output of any future research direction.

Conclusions and Practical Applications

The inertial testing protocols and hardware used in this thesis have been demonstrated to be both reliable and valid for the determination of peak power and optimal cadence/cadence at peak power. The testing was shown to have sufficient sensitivity to detect meaningful change in peak power but not optimal cadence. Given the magnitude of the observed changes in optimal cadence exceeded the values reported for TE there was sufficient confidence to detect large changes, and that these large changes were meaningful. This gives confidence that the data collected for tracking and monitoring of the athletes and the research outcomes and conclusions to be drawn from the use of the hardware and inertial testing protocol will be useful.

From the information presented on the prior submaximal work requirements in the keirin and sprint qualifying it is reasonable to expect the initial 1625m completed behind the motor bike in the keirin can be factored into the race preparation of the athlete as not sufficient to negatively impact on their ability to perform in the race proper. By exploring gearing and alternative pacing strategies for the 200m time trial it may be possible to optimise the ability to maintain a higher power and more closely align race cadence with optimal cadence; particularly in those athletes who demonstrate a positive relationship between peak power and a more optimal performance. Outside of race day performance construction of appropriate training periodisation entering racing situations with the highest optimal cadence possible is likely to have a positive impact on the physiological performance ability in both the keirin and the match sprint competition. Based on the research findings, athletes with a higher optimal cadence would expect a greater downward and left shift in the power-cadence curve when placing high demands on those muscle fibres.

Close monitoring of training progression with collected field data is important and necessary to understand global performance ability as it relates to competition and performance tasks in elite athletes. Inclusion of inertial testing data can provide information on underlying alactic physiological potential and expectation around performance ability. A global approach to quantifying the stress and strain on and off the bike may be enhanced by using session RPE as described by Foster et al., (2001). It could be concluded after closely following this group of athletes that a number of mitigating circumstances resulted in a relative underperformance at the London Olympic Games, 2012. It could be reasonably concluded that they were in a similar alactic physiological state, based on the availability of inertial testing data from February and March of 2012, to that of the World Championships in April. Some deterioration in the collected field data through July and the drop in optimal cadence could potentially indicate a slight compromise in the physiological state with respect to anaerobic glycolysis through July in this group of athletes. However, the competitive outcomes are without doubt multifactorial and the Olympic results could equally be indicative of more inconsistency than inability to deliver results. Determining just what is responsible for this is difficult with the lack of training data available, however a key component of the build up to the 2012 World Championships potentially was the volume of racing which was undertaken and this was not present prior to the Olympics.

There appears to be a neuromuscular improvement with high cadence single legged ergometer training exposure. It appears likely related to muscle coordination and sequencing from the counterweighted single leg approach and or superior conditioning for a potentially rate limiting muscle (hip flexors). This single legged training does not, however, appear to have improved the athletes' ability to resist fatigue following a period of maximal exercise. Nonetheless the ability to perform more total work during each testing occasion, improved. It is unclear whether a testing battery consisting of three maximal 30s efforts separated by two minutes of recovery is suitable to determine improvements in resistance to fatigue, though it was shown to be a reliable test. Increases in peak and average power in the first bout during the post testing may mask improvements in the ability to resist fatigue owing to a greater metabolic disturbance. Increases in peak power production and ability to produce more torque would likely result in an improved ability to accelerate.

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Appendix A – Ethical Approval

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To:	Mike McGuigan
From:	**Dr Rosemary Godbold** Executive Secretary, AUTEC
Date:	20 December 2011
Subject:	Ethics Application Number 11/315 **Optimisation of performance for track sprint cycling - Individual and event-specific considerations.**

Dear Mike

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 28 November 2011 and I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 23 January 2012.

Your ethics application is approved for a period of three years until 19 December 2014.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 19 December 2014;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 19 December 2014 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 6902.

On behalf of AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Dr Rosemary Godbold

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Damian Wiseman damian.wiseman@bikenz.org.nz

Appendix B – Inertial Load Calculations

Inertial characteristics of this ergometer have been worked back from the detailed and accurate analysis performed by Martin (Dorel et al., 2005) and a constant (*k*) introduced based on the inertial equation to give an estimate of the inertial characteristics of the ergometer system here.

Using the following equation:

$$I = mr^2$$

Gives from the (Day et al., 2004) data a flywheel inertia of 0.39621 kgm^2. Where moments of inertia were calculated from 9 constituent parts of the flywheel. Based on consultation the Monark (get manufacturer data) ergometer flywheel used here was found to have a mass of 9kg and a diameter of 0.52m. Given the extensive analysis and decomposition to understand the moment of inertia of the flywheel by (Tomas et al., 2010) the above equation was rearranged to give a constant which will allow an approximate calculation for and an understanding of the inertial properties of our flywheel and system without such decomposition as this was not necessary given torque was measured directly.

Where *k* is a constant derived from:

$$I = kmr^2$$

To give:

$$k = I/(mr^2)$$

Therefore (with data relative to Martin to solve for *k*):

$$k = \frac{0.3962}{(9 \times 0.26^2)}$$

$$k = 0.651216$$

Using data for this flywheel (mass 31.2kg, diameter 0.45m):

$$I = 0.651216 \times (31.2 \times 0.225^2)$$

$$I = 1.028596 \text{ kgm}^2$$

The assumption was made that the flywheel mass was similarly distributed, however on a smaller scale (diameter 0.45m compared to 0.52m). Mass was added to an off the shelf spin bike flywheel (mass 19kg) to give a similar overall total inertial loading.

Inertial Load Calculation (IL):

$$IL = \frac{1}{2}\ I\ G^2$$

Where *I* is the moment of inertia of the flywheel and *G* is the gear ratio of the system (C. Hautier et al., 1996). Gear ratio is calculated by dividing the crank chainring tooth number by the drive sprocket tooth number on the flywheel (62/13 = 4.769231).

Therefore:

$$IL = \frac{1}{2}\ (1.028596 \times 4.769231^2)$$

$$IL = 11.698$$

Appendix C – Additional Results – 2012 London Olympic Games

While no power data is available competitive results from the London Olympic Games have been provided below relative to the progression in the current season by the medal winners in the team sprint, keirin and sprint for both men and women.

Men's Keirin

Bronze medal won.

Women's Keirin

Rider did not advance past first round repecharge

Men's Sprint

Rider qualified 10.201s, 9th fastest did not advance past the first round.

Women's Sprint

Rider qualified 11.241, 9th fastest, did not advance past the first round.

Men's Team Sprint

Qualification – 44.175s, 7th fastest.

Fastest eight teams proceed to semi-final round where they ride against teams seeded in reverse order, 8th fastest against fastest, 7th fastest against second fastest etc. Winner to next round only and time is now not important only the first team to cross the finish line. NZ Vs France in semi-final.

Semi-final ride 43.495s, 5th overall (France 42.991, went on to finish 2nd overall) – Best ever time for an NZ team.

Previous Olympic Games – Beijing 2008, no track sprint team or sprint competitors selected for competition.

Comparison of Olympic Games to 2012 World Championships - Sprint

Table C.1. Comparison of Male results from World Championships to Olympic Games in 2012

Position[4]	World Champs	Time (s)	Olympic Games	Time (s)	% Change
1	Bauge (France)	9.854	Kenny[1](GB)	9.713	2.4
2	Forstemann (Germany)	9.873	Bauge (France)	9.952	-0.99
3	Sireau (France)	9.893	Perkins[2] (Australia)	9.987	-0.22
4	Hoy (GB)	9.902	Forstemann (Germany)	10.072	-2.02
5	Glaetzer (Australia)	9.902	Dmitriev[3] (Russia)	10.088	1.18

[1]Jason Kenny (GB) qualified 6th fastest in Melbourne, 9.953s

[2]Shane Perkins qualified 8th fastest in Melbourne, 9.965s

[3]Dennis Dmitriev was 30th fastest in Melbourne, 10.208s

[4]Position denotes qualifying position following 200m qualifying time trial

Only one athlete per nation was able to compete in the individual sprint events (sprint and keirin)

Table C.2. Comparison of Female results from World Championships to Olympic Games in 2012

Position[3]	World Champs	Time (s)	Olympic Games	Time (s)	% Change
1	Meares (Australia)	10.782	Pendleton (GB)	10.724	3.17
2	Guo (China)	11.004	Meares (Australia)	10.805	-0.21
3	Welte (Germany)	11.033	Guo (China)	11.020	-0.15
4	Lee (Hong Kong)	11.067	Vogel[1] (Germany)	11.027	0.53
5	Pendleton (GB)	11.076	Panarina[2] (Belarus)	11.080	-

[1]Kristina Vogel (Germany) qualified 6th fastest in Melbourne, 11.078s

[2]Olga Panarina did not compete at World Championships

[3]Position denotes qualifying position following 200m qualifying time trial

Appendix D – Single Leg Erg Pilot Study

Methods

Participants

Four male athletes participated in a pilot study investigating the use of a single legged training stimulus. Two of the participants were members of the Olympic Games team, two were reserves for the London Olympic Games 2012 and three of the athletes were world medallists in 2012.

Training

The training stimulus employed for this pilot study employed a variation in the stimulus with both number of repetitions and duration of effort being manipulated. The athletes worked through 30:60s (work:rest) aiming to complete the work intervals at a cadence of 100rpm, completing two sessions per week for three weeks beginning with five repetitions per leg and increasing by one additional repetition each week. Single legged training sessions also formed a part of the key bike session at each training occasion, essentially being performed after a fatigued state had already been created with the prior bike training stimulus. An outline of a typical training week is shown in Figure D.0.1.

A novel testing protocol to understand the training implications and adaptations for completing this work was used to assess a resistance to fatigue. The testing protocol had not been validated but was designed with the intention to address the ability to produce repeatable maximal performances specifically in these athletes. The testing protocol required the athlete to ride for 30s at absolute maximum, recover at a self-selected pace for two minutes and then repeat until three maximal work periods of 30s had been completed with two minutes of active recovery between (test referred to as 3 x 30s).

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
AM	Gym	Track - Speed Endurance – follow with SLE	Gym	Bike – Track Starts	Gym	Bike – Track or Erg – Power Endurance – follow with SLE	Rest
PM	Bike – Speed/Inertial Testing	Rest/Active Recovery	Erg - acceleration	Recovery road ride	Rest/Active Recovery	Recovery road ride	Rest

Figure D.0.1. Typical training week October, November 2012.

During Dec 2012/Jan 2013 a stimulus intended to maintain the adaptation was employed and the following training protocol utilised – 20:40, 30:60, 45:90, 60:120, 20s:end (work:rest). This was completed once per week and at the same working cadence of 100rpm.

Results

The main findings of this pilot investigation are shown in Tables D.0.1, D.0.2 and D.0.3 outlining the changes in power and cadence pre (Table D.0.1) and post (D.0.2) the pilot intervention. Energy expenditure has also been detailed in Table D.0.3.

Table D.0.0.1. Pilot Work – Single legged training 3 x 30s testing results prior to intervention including all participant data plus mean (± SD).

	Effort 1		**Effort 2**		**Effort 3**	
Athlete	**Mean Power (W)**	**Mean Cadence (rpm)**	**Mean Power (W)**	**Mean Cadence (rpm)**	**Mean Power (W)**	**Mean Cadence (rpm)**
1	1130	127	1016	123	803	111
2	1044	133	772	119	547	106
3	1263	132	887	118	658	106
4	1063	131	729	114	498	100
Mean (± SD)	1125 (99)	131 (3)	851 (129)	119 (4)	627 (135)	108 (3)

Table D.0.0.2. Pilot Work – Single legged training 3 x 30s testing results post intervention including all participant data plus mean (± SD).

	Effort 1		Effort 2		Effort 3	
Athlete	Mean Power (W)	Mean Cadence (rpm)	Mean Power (W)	Mean Cadence (rpm)	Mean Power (W)	Mean Cadence (rpm)
1	1090	127	875	117	771	114
2	1131	132	816	118	632	108
3	1068	129	893	119	714	111
4	1105	131	826	118	*	*
Mean (± SD)	1099 (26)	130 (2)	853 (37)	118 (1)	706 (70)	111 (3)

*Data unavailable due to a hardware malfunction for this athlete.

Table D.0.0.3. Mean power and mean energy expenditure during all three 3 x 30s work efforts pre and post for all participants including mean (± SD).

	Pre		Post	
Athlete	Mean Power (W)	Mean EE (kj)	Mean Power (W)	Mean EE (kj)
1	788.00	23.63	860.00	25.79
2*	896.00	26.88	966.00	28.97
3	936.00	28.08	892.00	26.75
4	983.00	29.49	912.00	27.36
Mean (± SD)	900.75 (83.15)	27.02 (2.50)	907.50 (44.49)	27.22 (1.34)

*As this athlete did not record any data in the last effort of the post testing only the average of the first two efforts have been compared

Looking at the mean power and energy expenditure over the three repetitions at each testing event it is clear to see the split between the four athletes with two showing an increase and two a decrease. It is expected that the training stimulus, while prescribed to be the same, was not equivalent with the two athletes who saw an increase in a different geographic location to the two who did not. Overwhelming response to training indicative of the metabolic overload and peripheral muscle stress seen in the literature associated with endurance trained athletes.

Limitations – use of multiple ergometers for testing does have implications for assessing and determining the effectiveness of changes observed with this intervention – for future use an ability to compare changes with athletes will require training to be completed on the same ergometer.

Pilot Conclusions:

Based on the pilot work carried out it was decided further work was required to better understand the impact of this training stimulus. Following feedback from the athletes participating in the pilot work it was decided that two contrasting cadences would be employed for further study using a training intervention. One cadence to represent the sensations experienced by a number of the athletes in the pilot study who felt as though they were completing a high repetition set of resistance exercises ("it feels like I am pedalling the leg press") – 70rpm. One cadence to be more closely aligned with the level of race cadences the athletes are frequently subjected to – 130rpm.

It was hypothesised that there would be less metabolic stress experienced at 70rpm and a greater metabolic stress with the increased number of muscle contractions required at 130rpm. Given these differences the changes seen with the 70rpm single legged work would be expected to increase acceleration up to max cadence with the 3 x 30s testing and a greater overall average power in the first and potentially second effort of the 3 x 30s test. The 130rpm training stimulus with a high number of muscle contractions would be expected to have a greater metabolic impact and therefore create a greater stimulus for underlying aerobic adaptation and lactic tolerance and increase resistance to fatigue following this training stimulus.