PACING STRATEGIES IN COMPETITIVE MIDDLE DISTANCE EVENTS

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Abstract

Pacing patterns vary between sports, between athletes and between competitions. There is much literature investigating pacing patterns in laboratory and staged competitive situations which have suggested that fast start, parabolic and even pacing patterns could be optimal for short, middle and long distance events, respectively, in elite athletes. However, there is little information about optimal pacing patterns to win medals in competitive situations in middle distance events and even less information specifically for female and developing athletes. This thesis describes and explains the variation in pacing needed to win a medal in swimming and running middle distance events for male and female elite athletes using data from international competitions. Pacing patterns seen in competitive middle distance events by developing swimmers were also investigated. Following a literature review, two methodological chapters developed a suitable video data capture method and then identified a suitable sample size for the collection of retrospective data. The first experimental chapter identified that a variable pacing pattern that included a conservation period of reduced relative pace and an end-spurt of increased relative pace was optimal in order to win a medal in elite men's 400 m freestyle swimming and 1500 m running. The second experimental chapter identified the same need for conservation of relative pace earlier in the race and an increase in relative pace for an end-spurt at the end of a race in order to win a medal in female elite 400 m freestyle swimming. The third experimental chapter identified that the same pacing patterns were optimal for age group swimmers at regional competitions but that the youngest swimmers needed to develop a more optimal performance template. The fourth and final experimental chapter of this thesis used three case studies to show that a higher training load and lower positive affect led to improved pacing patterns in developing

athletes. This thesis contributes to the literature on pacing by identifying the optimal changes in relative speed needed to win a medal in competitive middle distance events.

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List of Abbreviations

ASA	Amateur Swimming Association
ATP	Adenosine Triphosphate
BLa	Blood lactate concentration
CHO	Carbohydrate
CNS	Central nervous system
CV	Coefficient of variation
IAAF	International Association of Athletics Federations
iEMG	Integrated electromyography
FINA	Federation Internationale de Natation
LDH	Lactate dehydrogenase
MVC	Maximal voluntary contraction
O_2	Oxygen
PFK	Phosphofructokinase
PHV	Peak height velocity
PO	Power output
POMS	Profile of mood states
PPO	Peak power output
RER	Respiratory exchange ratio
RPE	Rate of perceived exertion
TT	Time trial
$\dot{V}E$	Volume of expired air
$\dot{V}O_2$	Volume of oxygen consumed
WAS	Worcester affect scale

Preface

Academic peer-reviewed publications arising from this thesis:

Mytton, G.J. Archer, D.T. Thompson, K.G. Renfree, A. St Clair Gibson, A. (2013) Validity and reliability of a 1500-m lap time collection method using public videos. *International Journal of Sports Physiology and Performance*, 8(6), 692-694.

Mytton, G.J. Archer, D.T. St Clair Gibson, A. Thompson, K.G. (2014) Reliability and stability of performances in 400-m swimming and 1500-m running. *International Journal of Sports Physiology and Performance*, 9(4), 674-679.

Mytton, G.J. Archer, D.T. Turner, L.T. Skorski, S. Renfree, A. Thompson, K.G. St Clair Gibson, A. (2015) Increased variability of lap speeds differentiate medallists and non-medallists in middle distance running and swimming events. *International Journal of Sports Physiology and Performance*, 10(3), 369-373.

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Mytton, G.J. Archer, D.T. Rumbold, P. St Clair Gibson, A. (2015) Differences in the pacing patterns of female medallists and non-medallists in the 400-m freestyle swimming event. *Journal of Sport Sciences*, 33(S1), S10.

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Authors Declaration

I, Graham John Mytton, declare that the body of work contained in this thesis comprises all my own work and has not been submitted for any other award. I confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by Northumbria University Ethics Committee.

Author: Graham J. Mytton

Signature:

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Chapter 1: Introduction

Pacing patterns are a well investigated topic in sports science literature with researchers using a range of methods and techniques to analyse pacing responses during exercise. For example, research has been carried out using data collected in the lab, in the field and in competition, and has covered a range of sporting performances including running, cycling, rowing, swimming, speed skating, mountain biking and triathlon (see table 2.1 for details).

Pacing can be viewed as the outward manifestation of fatigue/fatigue avoidance because it is thought that humans will vary their pace in order to distribute their effort over an exercise bout (Edwards & Polman 2012) to allow for the best possible completion time for a given activity (Mauger *et al.* 2012). Exercise participants may use a performance template to judge their pace, constantly comparing actual feedback with expected feedback from the central and peripheral body regions (Tucker 2009) and assessing the risk to themselves of continuing at the current pace (de Koning *et al.* 2011a). The increased prevalence of pacing studies have followed the widespread interest in the governance of physiological fatigue in the past two decades and in particular the development of the central governor theory (Noakes 1997) and the adoption of complex models of teleoanticipation (St Clair Gibson *et al.* 2001) and integration (St Clair Gibson & Noakes 2004) in the regulation of power output during athletic events. These models of power output regulation suggest that the body appears to stay within safe limits of exercise intensity for the duration of any athletic event (according to homeostasis based principles) and also suggest that a subconscious brain regulator determines the pace available at any

given moment in a race, based on current physiological status and distance to the finish (the principle of teleoanticipation). The study of pacing, therefore, is the study of a performance manifestation of this regulatory system and is concerned with the most effective use of the finite resources available to the body to complete a set race distance.

In sporting performances, pacing patterns have been identified as being negative, positive, all-out, even, J-shaped, reverse J-shaped and U-shaped (Abbiss & Laursen 2008), patterns which can be seen in Figure 1.1. It is likely that pacing for short events lasting less than two minutes, would benefit from a positive or all-out pacing pattern (Robertson *et al.* 2009, de Koning *et al.* 2011b, Hettinga *et al.* 2011) and that pacing in long distance events would be optimal when even-paced (Renfree & St Clair Gibson 2013) or even paced with the potential for an end-spurt (Tucker *et al.* 2006). However, in middle distance events lasting two to four minutes, the most optimal pacing pattern is less clear. Optimal pacing patterns have been reported as even (Robertson *et al.* 2009), fast start or U-shaped (Mauger *et al.* 2012) and reverse J-shaped (Skorski *et al.* 2014a) in 400 m freestyle swimming, and U–shaped (Noakes *et al.* 2009, Hanon & Thomas 2011) and evenly paced (Foster *et al.* 2014) in 1500 m running. This confusion in the literature does not provide coaches and athletes a basis on which to formulate pacing strategies that will maximise their performance. This may be because of the difficult balance athletes need to find between maintaining a high pace and ensuring they do not fatigue before the end of the race. Therefore, the first aim of this thesis is to explain optimal competitive pacing patterns in elite and developing athletes by comparing medallists to non-medallists in 1500 m running and 400 m freestyle swimming events.

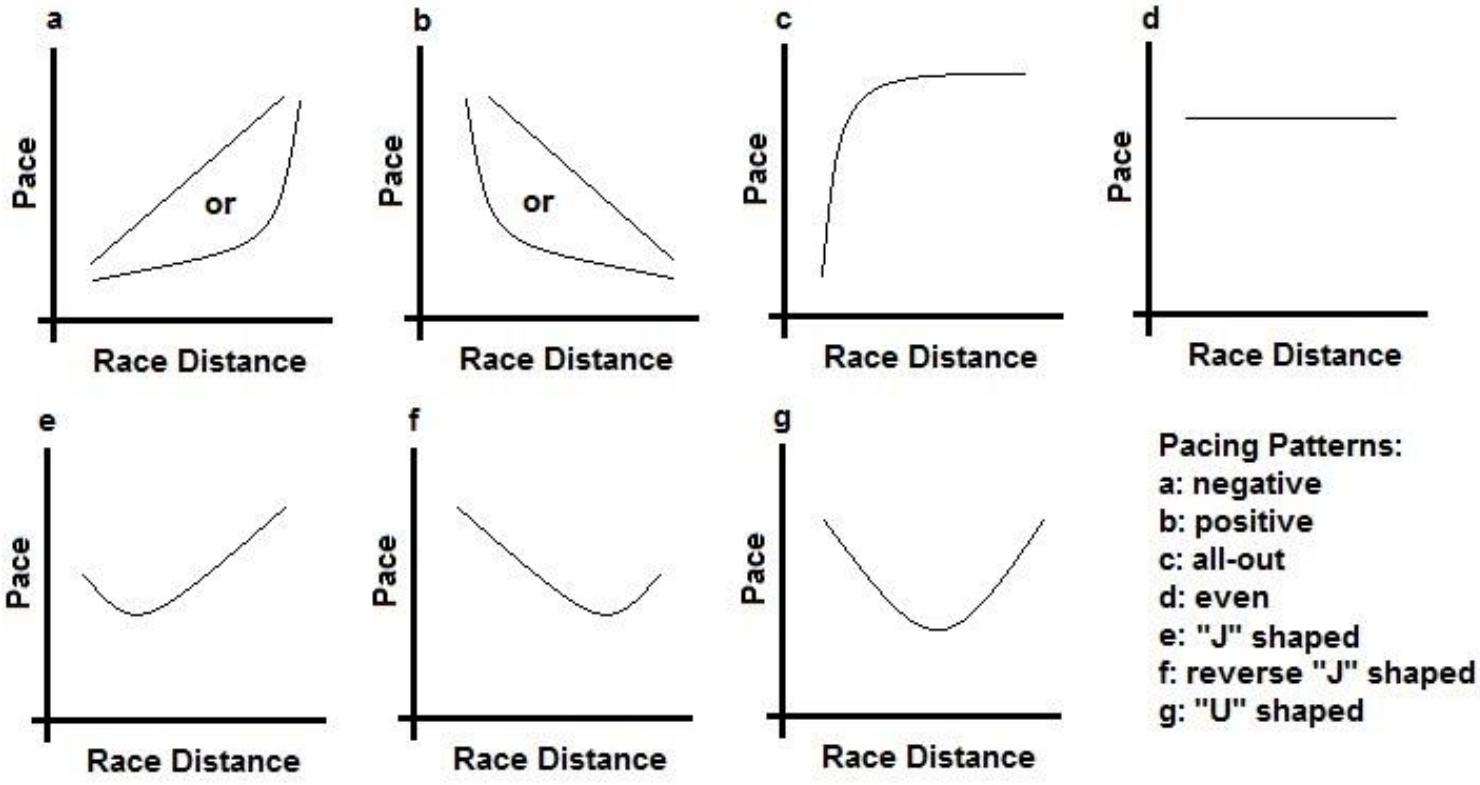


Figure 1.1: The seven pacing patterns as described by Abbis and Laursen (2008).

Sex differences in pacing is also a contradictory area in the literature. Differences in pacing patterns have been reported in middle distance events where successful male athletes showed a greater end-spurt speed (Corbett 2009), higher pacing variation throughout the event (Mauger *et al.* 2012) and lower variation in pace (Foster *et al.* 2014) compared to successful female athletes. In addition to this confusing picture, no differences in pacing patterns between sexes have been reported in middle distance events (Robertson *et al.* 2009, Brown *et al.* 2010). Given the physiological differences that exist between sexes (Tarnopolsky 2010), it would appear likely that the most optimal pacing patterns differ between men and women to maximise the resources available to that athlete. Therefore, the second aim of this thesis is to investigate sex differences in competitive middle distance pacing patterns of medallists and non-medallists in 1500 m running and 400 m swimming events.

Whilst optimal pacing patterns may be affected by an athlete's physiological make-up, there are other factors that may affect the pacing decisions taken during an event. For example, if pacing is altered to ensure fatigue levels that are too high to continue are avoided in a race, then the levels of pre-existing fatigue may affect the pacing pattern used. Athletes tend to vary their training load over a year and, in particular, taper training loads in the run-up to and event in order to minimise accumulated fatigue (Turner 2011). In addition, psychological factors such as mood may be influenced by physiological status, and therefore affect pace decisions made during a race (Renfree *et al.* 2012). Currently an analysis of training load, mood and pacing patterns does not exist in the literature and so the third aim of this thesis is to fill this knowledge gap by investigating how the fluctuations in training load and mood over a year may affect pacing during competitive performances.

1.1: The Chapters

Chapter 2: Literature Review

This is a detailed review of pacing research to date starting with laboratory and simulation based research before reviewing pacing research using competitive data. Differences between male and female athletes and elite and developing athletes are explored to support the discussion in chapters four to seven. A review of the effects of training load and mood on swimming performance follows to support the discussion in chapter eight.

Chapter 3: Validity and reliability of a new method for obtaining lap times from video in 1500 m running events

This chapter describes a novel method for collecting split time data in 1500 m elite running races to support the collection of these data in chapters four and five. The new method, which involved using published videos to capture split times of all runners, is a valid and reliable way of obtaining split times which will increase the amount of data available for use in chapters four and five.

Chapter 4: The reliability and stability of pacing profiles in elite 400 m freestyle swimming and 1500 m running events

This chapter presents an analysis of the use of retrospective performance split times in 1500 m running and 400 m freestyle swimming races. 1500 m running data was collected using the method validated in chapter three and compared to published 400 m freestyle swimming split times. Stability was measured using a "cumulative means" method described by Hughes *et al.* (2001) to show the number of samples

needed before the variation in the mean between events reached less than 1%. Reliability was measured by calculating typical error and coefficient of variation values between two performances by the same athlete in different events. This chapter concluded that it was necessary to collect data from at least three swimming and at least five running events to achieve reliability and stability.

Chapter 5: The pacing patterns of male medallists and non-medallists in the 400 m freestyle swimming and 1500 m running events

Using the validated video collection method from chapter three, and with the knowledge of the minimum number of events information from chapter four, this chapter presents an analysis of pacing patters used by male medallists and non-medallists in five Olympic, World and European finals in 1500 m running and 400 m freestyle swimming events. The pacing patterns used by athletes who medalled in these finals, compared to those that did not, showed similarities including the need to reduce pace earlier in the race in order to have enough energy to increase pace during the final stages.

Chapter 6: A comparison of pacing patterns between sexes and medallists and non-medallists in 400 m freestyle swimming

This chapter focussed solely on the 400 m freestyle swimming event reporting the pacing patterns used by elite female medallists compared to non-medallists. Unpublished data suggested that female patterns would differ from males and therefore, render practical applications from chapter five irrelevant to female swimmers. Pacing patterns of medallists and non-medallists were compared using normalised and relative speed data and found that female medallists varied their pace

more than non-medallists and showed an increase in speed towards the end of the race. This end-spurt however, was less pronounced than in males, and there were smaller differences in speeds shown in lap one, and larger differences in lap three, between medallists and non-medallists in females compared to the difference found in males at the corresponding race sections.

Chapter 7: The pacing patterns of male and female development swimmers in the 400 m freestyle event

This chapter presents a comparison of pacing patterns used by development swimmers in the 10-12, 13-14, 15-16 and 17+ y groups. Building on the findings of chapter six, male and female swimmers were separated in the analysis which used split times from the key regional Age Group Championships (10-14) and Youth Championships (15+) from all seven regions of the Amateur Swimming Association. Swimmers of different ages and at different stages of cognitive development adopt a different pacing pattern. Younger swimmers start faster, slow down more and speed up more than older swimmers who displayed a flatter parabolic pacing pattern. Once again medallists started relatively slower and finished relatively faster, mirroring the pattern found in senior swimmers. Boys had a faster relative end-spurt than girls which began in the 300 m to 350 m section of the race in both sexes.

Chapter 8: The effect of training load and affect on pacing patterns over a season in male and female development swimmers in the 200 m and 400 m freestyle event

Whilst chapter seven presented an analysis of pacing patterns used by development athletes in the most important event of the season, these athletes compete regularly

throughout their training year. Using case studies following three swimmers over a one year period, this chapter attempted to demonstrate how changes to training and mood patterns are associated to the best performances. The best performances were associated with parabolic pacing patterns and followed periods of high training load and low positive affect.

Chapter 9: General Discussion

This concluding chapter draws on the experimental data reported in chapters five to eight and compares the similarities and difference found in pacing patterns in male and female elite and developing athletes, attempts to explain the underlying psychophysiological mechanisms, and applies the findings to practical applications for athletes and coaches.

Chapter 2: Literature Review

This chapter aims to provide an overview of the body of knowledge about pacing patterns in sport and exercise. It will begin with information about the underlying physiology of middle distance sports events before outlining pacing pattern research in laboratory settings, simulated competition and real competitive situations. Subsequent sections will report the current thinking on the psychophysiological explanation of pacing and fatigue, sex differences in pacing, knowledge of pacing in developing athletes and the effects of training and mood on pacing.

2.1: The physiology of middle distance events

Middle distance events are those that last between two and ten min and are highly dependent on both the aerobic and anaerobic energy systems (Brandon 1995). Research into performance in middle distance events has included investigations into the physiological capacity and power of the aerobic energy system, for example investigating the relevance of oxygen consumption ($\dot{V}O_2max$), anaerobic threshold, critical power, economy and $\dot{V}O_2$ kinetics, as well as power and capacity in the anaerobic system. In a group of heterogeneous athletes, possession of larger aerobic and anaerobic capacities are associated with superior middle distance performance. However, in more homogenous groups such as elite athletes with similar exercise capacities, it is aerobic and anaerobic power specifically that will hold the key to performance (aerobic and anaerobic power being the rate at which adenosine triphosphate (ATP) is re-synthesised from these metabolic pathways). For example, a faster time constant (a description of the time needed to complete the primary component of $\dot{V}O_2$ uptake curve) of the $\dot{V}O_2$ response, a measure of aerobic power,

has been shown to be a key factor in 400 m freestyle swimming performance (Reis *et al.* 2010) and 1500 m running performance (Hanon *et al.* 2007), both events which last 2-3 min in duration. The efficient translation of aerobic power (e.g. $\dot{V}O_2$ uptake response leading to aerobic ATP re-synthesis) to velocity is defined as economy whereby athletes with a lower $\dot{V}O_2$ cost per given velocity will be at an advantage in middle distance races. Early work on running economy was done by Di Prampero who demonstrated that runners with a lower oxygen cost at a given velocity (higher economy) had a metabolic advantage during a race (Di Prampero 1986). Equally, possession of a superior swimming economy provides an advantage to an athlete as it enables them to cover a given distance with lower energy cost or to cover the same distance at a higher speed (Zamparo *et al.* 2011).

A method to determine energy system contributions called the accumulated oxygen deficit method (AOD method) involves the subtraction of the estimated cost of exercise on an individual basis from the actual aerobic cost of exercise as measured by $\dot{V}O_2$ consumption (Medbø *et al.* 1988). The product of this sum is assumed to be the anaerobic contribution. Using the AOD method, the aerobic contribution during middle distance running simulations have been reported as 66% and 84% for the 800-m and 1500 m respectively (Spencer & Gastin 2001) in highly trained male runners. Again using the AOD method Duffield *et al.* (2005) found similar relative mean contributions of the anaerobic system in trained men for a 1500 m simulated run (23% anaerobic; 77% aerobic) which was not significantly different from that found in trained women (14% anaerobic; 86% aerobic).

In the study by Duffield *et al.* (2005) a comparison was made between the AOD method and a method of estimating energy system contributions using an algorithmic combination of blood lactate and stored phosphocreatine concentrations to estimate anaerobic energy production (La/PCR method). This value was then divided by the total energy utilisation during an event to provide a percentage. Using this alternative method, the anaerobic contributions were again very similar in men (19% anaerobic; 81% aerobic) and women (18% anaerobic; 82% aerobic). In an earlier study a significant anaerobic component in middle distance races was reported as ranging from 14% to 24% in 1500 m and from 29% to 44% in 800-m track running events (Hill 1999) using the same LA/PCR method. Finally Busso and Chatagnon (2006) created a model based on the assumptions that the anaerobic system provides part of the energy needed for exercise above critical power and all of the exercise above total metabolic power. Applying this model to male 1500 m elite runner's performance, it predicted an anaerobic contribution of 22%.

Unlike the availability of data for middle distance track running as described above, there are limited data estimating the same aerobic/anaerobic relative contributions in swimming. One study which employed the AOD method in freestyle swimming reported a 13% anaerobic contribution for the 200 m event and a 5% contribution for the 400 m event (Reis *et al.* 2010). A limitation of this study was the mechanical constraints imposed by swimming with an aqua trainer and attached gas analyser which lowered swimming velocity seen in the study when compared to competitive performances. In addition some swimmers during the 400 m event swam at an average velocity below their peak $\dot{V}O_2$ velocity and, as such, presented without an

AOD and a negative anaerobic contribution was identified, something which is not physiologically possible.

Using a method that modelled energy requirements based on a large body of evidence from the 1970's and 1980's, Zamparo *et al.* (2011) estimated that the cost of swimming 200 m at high speed was 38.5% anaerobic and 61.5% aerobic. This was a higher anaerobic contribution than reported in a previous study using a similar method of modelled data in young swimmers (12-17y) for the 200 m of 28.3% anaerobic and 71.7% aerobic (Zamparo *et al.* 2000). The same study estimated the contributions in 400 m swimming as 13.9% anaerobic and 86.1% aerobic (Zamparo *et al.* 2000). The data from Hill (1999) for 800 m and 1500 m running and Zamparo *et al.* (2011) for 200 m swimming potentially allow for the estimation of the contributions in 400 m swimming to be made using the reported ratios between 800 and 1500 m running applied to the data for 200 m swimming. This method is only able to provide a guideline but may be appropriate because the 800 m run/200 m swim and 1500 m/400 m swim have similar durations. Using this extrapolation method, the estimated anaerobic cost of 400 m swimming is predicted to be 20%, higher than other reported values described earlier (Zamparo *et al.* 2000, Reis *et al.* 2010) but similar to the 1500 m, an event of similar duration. The study by Reis *et al.* (2010) was the only direct measure of energy contributions in middle distance swimming found in the literature, perhaps because of the complex requirements of the equipment needed and it's negative effect on swimming mechanics and velocity which would have a larger impact on the drag forces in the water than the same equipment used on a treadmill for example.

Table 2.1: Estimated anaerobic and aerobic energy contributions in males during 1500 m running and 400 m freestyle swimming.

1500 m Running		**400 m Swimming**		**Reference**
Estimated anaerobic contribution (%)	**Estimated aerobic contribution (%)**	**Estimated anaerobic contribution (%)**	**Estimated aerobic contribution (%)**	
16	84	-	-	Spencer and Gastin (2001)
19	81	-	-	Duffield *et al.* (2005)
23	77	-	-	Duffield *et al.* (2005)
22	78	-	-	Busso and Chatagnon (2006)
20	80	-	-	Hill (1999)
-	-	5	95	Reis *et al.* (2010)
-	-	14	86	Zamparo *et al.* (2000)
-	-	20	80	*Own extrapolation method*
Mean (± SD)				
20.0 (± 2.74)	80.0 (± 2.74)	13.0 (± 7.55)	87.0 (± 7.55)	
Range (minimum – maximum)				
16 – 23	77 – 84	5 – 20	80 - 95	

Despite the wide range of values reported in the literature, it is clear that anaerobic power and anaerobic capacity will significantly impact on race performance in middle distance events by making a significant contribution to overall energy production. For example, Hill (1999) described a scenario where a 15% improvement in an athlete's anaerobic capacity would lead to a 6-s decrease (equal to a 2.4% improvement) in 1500 m run time because of the reduced time spent at $\dot{V}O_2$max. Anaerobic power is limited by the rate limiting enzyme phosphofructokinase (PFK) which catalyses an early stage of glycolysis and anaerobic capacity is limited due to a finite store of phosphocreatine and glycogen in humans (Kenney *et al.* 2010, Katch *et al.* 2011). In addition to these limitations, waste products from glycolysis such as lactate and hydrogen ions and the reduction in glycogen stores may be partly responsible for peripheral fatigue mechanisms (Phillips 2015). Therefore, the use of an athlete's anaerobic power and capacity must be carefully managed and timed to avoid this potentially fatiguing mechanism to affect the remaining portions of a race.

Models of fatigue can be broadly divided into central and peripheral schools of thought. One central fatigue hypothesis suggests that a central governor (Noakes *et al.* 2005) is responsible for the collation of afferent feedback, and that the subsequent increase or decrease in neural activation of individual skeletal muscle fibres (Tucker 2009) is designed to maintain homeostasis, thereby protecting the exercising individual from a terminal metabolic crisis (Noakes & St Clair Gibson 2004). Amann and colleagues (2006, 2007) proposed that afferent feedback from skeletal muscles inhibits central neural drive to limit the development of peripheral fatigue. This negative feedback system would limit exercise intensity in order to protect the locomotor muscles from developing a level of peripheral fatigue which exceeded a critical threshold. More recent literature has suggested that the need to limit exercise intensity reduces as the race end gets nearer because the risk to the exercising individual reduces (de Koning *et al.* 2011a). This provides an explanation for the increase in pace often seen at the end of competitive events (known as an end-spurt).

The peripheral fatigue hypothesis has its roots in work done by Hill and colleagues almost a century ago (Hill *et al.* 1924). The model describes the notion that there is a maximal oxygen uptake by the human body ($\dot{V}O_2max$). Work rates that demand more oxygen than can be delivered result in a lack of oxygen, or anaerobiosis, in the working muscles which causes termination of exercise. Thus, peripheral fatigue is caused by a process or processes that are found distal to the neuromuscular junction which lead to disturbances in the exercising muscle which in turn attenuates the force that can be produced by that muscle (Phillips 2015). These processes may include the accumulation of hydrogen ions, inorganic phosphate and ammonia and

the depletion of glycogen and phosphocreatine in the exercising muscle (Shei & Mickleborough 2013).

Athletes competing in middle distance events will choose how to utilise their aerobic and anaerobic power, based on their knowledge of their own personal movement cost (economy), by choosing a pacing pattern. A pacing pattern in an individual, and collectively in a homogenous group of athletes, is therefore a manifestation of the decisions, often subconscious, made by the athlete about how to deploy their finite physiological resources by altering the aerobic and anaerobic power contributions at any particular time during the race, or as Mauger *et al.* (2011) suggested, the manipulation of power output over an exercise bout to allow for the best possible completion time in a given activity. Others have gone further by suggesting that a pacing pattern is deployed to prevent a catastrophic failure of an athlete's physiological systems prior to the end of an event (St Clair Gibson *et al.* 2013).

2.2: The history of pacing research

Pacing patterns, as shown in Figure 1.1 and evident in real and simulated competition, can be negative, positive, all-out, even or parabolic J-, reverse J- and U-shaped (Abbiss & Laursen 2008) and have become a popular topic of research in sport science literature (Hopkins *et al.* 2011). Table 2.2 lists studies investigating pacing patterns found using a comprehensive search database and identifies key facts about the participants, data collection and analysis methods.

Table 2.2: Investigations of pacing patterns in the literature including the ability of participants used and the data collection and analysis methods relating to competition and performance.

Author	Sport(s)	Participants	Setting	Data collected during competition?	Data analysed separating performance level?
Foster *et al.* (1993)	Cycling	Trained	Laboratory	No	No
Foster *et al.* (2003)	Cycling	Elite & Trained	Laboratory	Simulated	No
Ansley et al. (2004b)	Cycling	Trained	Laboratory	Simulated	No
Ansley *et al.* (2004a)	Cycling	Untrained	Laboratory	No	No
Atkinson *et al.* (2004)	Cycling	Untrained	Laboratory	No	No
Albertus *et al.* (2005)	Cycling	Trained	Laboratory	No	No
Garland (2005)	Rowing	Elite	Lake & indoor	Yes	Yes (top half *vs.* bottom half)
Tucker *et al.* (2006)	Running	Elite	Track	Yes	No
Berg *et al.* (2008)	Cycling	Trained	Laboratory	Simulated	No
Vleck *et al.* (2008)	Triathlon	Elite	Open Water & Road	Yes	Yes (finishing position)
Chen *et al.* (2007)	Swimming	Elite	Pool	Yes	No
Corbett (2009)	Cycling	Elite	Track	Yes	Yes (top half *vs.* bottom half)
Dugas *et al.* (2009)	Cycling	Trained	Laboratory	No	No
Foster *et al.* (2009)	Cycling & rowing	Untrained	Laboratory	No	No
Mauger *et al.* (2009)	Cycling	Trained	Laboratory	No	No
Morton (2009)	Cycling	Trained	Laboratory	No	No
Noakes *et al.* (2009)	Running	Elite	Track	Yes	No
Robertson *et al.* (2009)	Swimming	Elite	Pool	Yes	No
Brown *et al.* (2010)	Rowing	Elite & Sub-elite	Lake	Yes	No
Green *et al.* (2010)	Running	Trained	Track	No	No
Hausswirth *et al.* (2010)	Running	Trained	Track	No	No
Lee *et al.* (2010)	Running	Trained	Road	Yes	No
Muehlbauer *et al.* (2010c)	Rowing	Elite	Lake	Yes	Yes (winner *vs.* others)
Muehlbauer *et al.* (2010b)	Speed Skating	Elite	Ice Rink	Yes	Yes (top half *vs.* bottom half)

Angus and Waterhouse (2011)	Running	Elite	Road	Yes	No
Faulkner *et al.* (2011)	Running	Untrained	Laboratory	Simulated	No
Hanon and Thomas (2011)	Running	Elite	Track	Yes	No
Hettinga *et al.* (2011)	Speed Skating	Elite	Ice Rink	Yes	No
Le Meur *et al.* (2011)	Triathlon	Elite	Lake & Road	Yes	No
Mauger *et al.* (2011)	Cycling	Trained	Laboratory	Simulated	No
Peiffer and Abbiss (2011)	Cycling	Trained	Laboratory	Simulated	No
Corbett *et al.* (2012)	Cycling	Untrained	Laboratory	Simulated	No
Stone *et al.* (2011)	Cycling	Trained	Laboratory	No	No
Le Meur *et al.* (2012)	Pentathlon	Elite	Track	Yes	No
Mauger *et al.* (2012)	Swimming	Elite	Pool	Yes	Yes (comparison to WR)
Micklewright *et al.* (2012)	Running	Untrained	Track	No	No
Renfree *et al.* (2012)	Cycling	Trained	Laboratory	No	No
Stone *et al.* (2012)	Cycling	Trained	Laboratory	Simulated	No
Abbiss *et al.* (2013)	Mountain Biking	Elite	Track	Yes	Yes (top, middle and bottom 20%)
Cohen *et al.* (2013)	Cycling	Trained	Laboratory	No	No
de Morree and Marcora (2013)	Cycling	Untrained	Laboratory	No	No
Gee *et al.* (2013)	Rowing	Trained	Laboratory	No	No
Renfree and St Clair Gibson (2013)	Running	Elite	Road	Yes	Yes (quartile groups)
Foster *et al.* (2014)	Running	Elite	Track	Yes	No
Hanley (2014)	Running	Elite	Cross Country	Yes	Yes (medallists and non-medallists)
Skorski *et al.* (2014a)	Swimming	Junior trained	Pool	Simulated	No
Thomas *et al.* (2015)	Cycling	Trained	Laboratory	No	No
Skorski *et al.* (2015)	Cycling	Trained	Laboratory	No	No
Dormehl and Osborough (2015)	Swimming	Junior elite	Pool	Yes	No
Micklewright *et al.* (2015)	Running & Cycling	Trained & Untrained	Road & Laboratory	Yes & No	No
Veiga and Roig (2016)	Swimming	Elite	Pool	Yes	No

An early study by Foster *et al.* (1993) demonstrated that an even pacing pattern produced the best performance during a 2 km laboratory cycling time trial (TT) compared to either negatively or positively paced starts. However, there were no significant differences found for $\dot{V}O_2$ uptake, O_2 deficit or post-exercise blood lactate concentration (BLa) in this study, although the authors did suggest that the positive start trials may have been compromised by rapid muscle lactate accumulation during the trials. Interestingly, this early study did not display any evidence of an end-spurt, even in the negative start patterns.

Foster and colleagues followed up this early laboratory study with a review of pacing in athletic performance which included data from real race performances as well as from other laboratory studies they had previously performed (Foster *et al.* 1994). They reported that shorter sprint events appeared to benefit from positive starts whilst middle distance events tended to benefit from even pacing with successful performances in the velodrome, ice skating rink and running track characterised by the least reduction in speed as the race progressed. They further stated that pacing is particularly important when 'the medium resisting the motion of the athlete could produce a large decrease in velocity with the loss of power output' (Foster *et al.* 1994 p.80), for example swimming compared to air-resisted activities such as running, cycling and speed skating.

More recent research has identified parabolic pacing patterns during athletic activity, including J-, reverse J- and U-shape which add another level of complexity to our understanding of pacing selection by athletes, and suggests that alterations between slow and fast pace occur throughout the race. Berg *et al.* (2008) reported a reverse J-

shaped pattern when experienced cyclists were instructed to cycle as fast as they could for five min. Participants self-selected a fast start before slowing in the middle portion and increasing pace mildly towards the end of the time limit. Given the constancy of oxygen consumption ($\dot{V}O_2$), respiratory exchange ratio (RER) and heart rate (HR) from the second minute despite the steady increase in the rate of perceived exertion (RPE) throughout, it would appear that participants slowed after their fast start in a pre-emptive manner in order to save themselves from a potential catastrophic physiological failure which may have occurred if they had carried on at their initial fast pace. However they then found that they had some reserves left that allowed them to increase pace in the final minute (Berg *et al.* 2008). Using 2 km rowing performances taken from international championships, Brown *et al.* (2010) also report reverse J-shaped pacing patterns. In addition, they reported that pacing patterns changed as the level of competition dropped through elite and sub-elite races of the same distance where-by the highest competitive level had a flatter parabolic pacing pattern and the lowest level had a more extreme reverse J-shaped pattern. They concluded that the higher level athletes were able to adopt a more aggressive strategy in the middle of the race due to a higher level of energy production during the race and a stable and efficient rowing technique and/or they were wiser about their own capabilities due to greater experience allowing for a less conservative strategy (Brown *et al.* 2010). Examining a longer event, Lee *et al.* (2010) reported a reverse J-shaped pacing pattern in a half marathon event. Through the use of ingestible telemetric temperature sensors the researchers were able to show that increases in core temperature were not related to subsequent changes in pace, which is one of the hypothesised components of the teleoanticipatory model of pacing that suggests athletes will change their pace in response to immediate physiological

changes in the body and previously created pacing templates (Tucker 2009). This study was potentially limited however, by a low resolution of the pacing data available for such a long event.

The J-shaped pattern is similar to this but with a faster final portion than the initial portion of the athletic event, suggesting that participants compete more conservatively at the start of the race, and therefore, have additional spare physiological capacity that could be employed at the end of the race. For example, this was seen in 2 km rowing TTs (Foster *et al.* 2009). In this study, participants PO was highest during the final 100 m of all three of their 2 km TTs and interestingly this was despite the PO during the initial part of the trial increasing with each TT as participants developed their optimal performance template (Foster *et al.* 2009). A J-shaped pacing pattern was also seen in 38% of world record mile run performances between 1886 and 1999 which was slightly less than the reverse J-shaped pattern which was seen in 44% of these world record runs (Noakes *et al.* 2009). Finally, a J-shaped pacing pattern was seen in a 20 km cycling TT when participants were given both accurate and inaccurate feedback during the TT but was not seen when participants received no feedback and demonstrated a slow finish (Micklewright *et al.* 2010).

There is also evidence of U-shaped pacing patterns in the literature. In contrast to the Brown *et al.* (2010) data reported above, pacing patterns during a 2 km rowing race at the 2008 Olympics shows a U-shaped parabolic pattern with the beginning and end portions of the race equally faster than the middle portion (Muehlbauer *et al.* 2010c). This pattern was consistent when variables such as heat *vs.* final and men *vs.*

women were compared in this study. There are psychological advantages to a fast start in rowing so that rowers can see their competitors (as rowers have their back to the finish line as they race it means they can see those behind them, unlike all other head to head type races) and so this may be a tactical, rather than a physiological, pacing strategy. In the longer event of marathon running, Angus and Waterhouse (2011) reported the use of a U-shaped pacing pattern by Haile Gabreselassie during a world record performance in the 2008 Berlin marathon using a method that accounted for gradient changes and their effect on pace. Interestingly they report that the U-shaped pattern existed to a "near-perfect" symmetry whilst at the same time reporting high variation on a kilometre by kilometre basis suggesting that Gabreselassie was able to control his macro-race pace using a number of micro variations in his running speed.

2.3: Laboratory and simulation pacing research

Laboratory studies based on deception have shown that cyclists can both extend their time to exhaustion (Morton 2009) and increase their overall pace (Stone *et al.* 2012) when deceived about elapsed time and previous performances, respectively. In the latter experiment, cyclists received feedback of their performance via an avatar of a baseline performance set in the first 4 km TT. The feedback was either an accurate presentation of previous performance or was an avatar cycling at 2% greater PO but presented as an accurate presentation of the previous performance (deception). In the deception trial, the contribution to PO by the anaerobic system over 90% of the total distance was the significant difference in performance and led to a significant reduction in time to completion of 1.7%. In other words, the cyclists still had an

energy reserve to call on in the final stages of the TT even though they were deceived into working harder. This resulted in a higher post trial RPE in the deception trial compared to the base line and accurate feedback trials. In contrast, Ansley *et al.* (2004a) showed that deception in supramaximal exercise lasting around 30 s served to lower PO, and Mauger *et al.* (2011) showed that cyclists provided with incorrect feedback about their performance also slowed during a 4 km TT. These studies would suggest that athletes can be deceived into altering their self-selected pace in medium duration exercise trials, although there is a possibility that excessive deception will prove de-motivating and negatively affect performance, or that the athletes will realise they are being deceived and will thereafter disengage from the study protocol. Previously it has been reported that deception in distance feedback did not alter speed (and therefore overall time), rate of perceived exertion (RPE) or heart rate (HR) during a 20 km cycle TT where incorrect distance feedback (including both faster and slower km split times) was given every 1 km (Albertus *et al.* 2005). In addition, inaccurate feedback which deceived cyclists into thinking they were 5% faster than they actually were, led to unsustainably high pace during a 20 km TT when correct feedback was given in a subsequent trial shown by the fact that pace in the latter stages of the trial dropped and no improvement in time to completion was seen (Micklewright *et al.* 2010). These two studies suggest that deception that is either of too great a magnitude or that varies between fast and slow deception, may not improve performance. Therefore, it is probable that participants use a pacing template at the onset of an event which can be confounded by deception based methodology trials only when the deception is small and potentially only during middle distance events.

Other laboratory based cycling time trials have shown that pacing patterns can be altered by external factors. For example, in the presence of trance music played to participants during a TT, speed was higher in the first 3 km of the 10 km TT which allowed for a quicker finishing time (Atkinson *et al.* 2004) compared to a control ride. This initial higher speed during the TT, which took 1030 ± 39 s to complete, meant that a U-shaped pacing pattern was displayed during the playing of trance music compared to an even start without music. Both TT performances indicated an end-spurt, however the presence of trance music resulted in a 2% improvement in TT performance. The authors noted that a faster start can sometimes be detrimental to performance because athletes may become excessively fatigued later in the race, however their results suggested that a U-shaped pacing pattern is optimal for this distance (Atkinson *et al.* 2004). Furthermore, Peiffer and Abbiss (2011) found that a warmer environmental temperature led to greater pacing variation but slower finishing times during a 40 km TT. They reported a U-shaped pacing pattern in 17, 22, 27 and 32 degrees centigrade, however the drop in power output mid-race was greater in the highest temperature. Power output continued to drop to a significantly greater degree in 32 degrees than all other temperatures in the second half of the race, subsequent to which all conditions showed a similar end-spurt increase in PO (although similar in magnitude, the end-spurt in higher temperatures had a lower starting point). The authors suggested that it was possible that an anticipatory reduction in PO occurred in the higher temperatures to ensure heat production decreased and the local environment was tolerable for exercise (Peiffer & Abbiss 2011). In contrast, no difference in pacing patterns were found in a 15-minute TT (no distance was reported but this is a similar time to completion trial as Atkinson *et al.* (2004) reported for a 10 km TT) following pre-trial fatiguing period of 100 drop

jumps (de Morree & Marcora 2013), or in an 80 km TT with varying fluid ingestion (Dugas *et al.* 2009). In both of these studies, however, a PO difference in the order of 5-8% was seen between experimental and control conditions and all bar one of the TT splits were lower in the fatigued and dehydrated condition, showing that whilst pacing patterns were not significantly different, TT performance was affected (Dugas *et al.* 2009, de Morree & Marcora 2013). Finally, a sham competitive environment was created by Corbett *et al.* (2012) who reported that the additional motivating factors that form part of a head-to-head competitive race were potentially responsible for an increase pace seen in the trial participants during the second half of a 2 km TT compared to a non-competitive TT that had been completed previously. The authors suggested that the rate of anaerobic energy yield was the contributor to the increase in pace that they found. They also reported that a significantly higher PO occurred during the first 1 km in the head-to-head competitive trial compared to the non-competitive TT after which the pacing pattern was the same in both (Corbett *et al.* 2012). In these examples, there is no obvious distance effect on pacing which suggests that different external influences will each have a different effect on pacing in cycling, perhaps due to differing effects of their distance on the teleoanticipation regulatory mechanism and its assessment of the event requirements and/or conditions (Ulmer 1996, St Clair Gibson *et al.* 2001, St Clair Gibson & Noakes 2004).

Le Meur *et al.* (2012) reported an increase in minute ventilation ($\dot{V}_E$) and a decrease in HR following a positive pacing pattern in modern pentathlon, but in agreement with the study of Foster *et al.* (1993), there were no changes to blood lactate concentration or the volume of oxygen consumed ($\dot{V}O_2$) compared to an alternative

pacing pattern. In terms of performance, Le Meur *et al.* (2012) reported that a positive pacing pattern with a 105% starting pace imposed for the first two of three 1 km run elements, did not improve overall performance compared to a free paced run which started faster (110%) but quickly reduced pace (98% after 170 m). Because $\dot{V}O_2$ did not change they hypothesised that early anaerobic contributions led to a slowing of pace later on and that this may highlight the importance of "saving" anaerobic contributions to pace until later in a race, which was also found to be beneficial in Stone *et al.* (2012). Cohen *et al.* (2013) use the phrase "a price to pay" when reporting the results of an investigation into pacing following a short high intensity breakaway phase in a cycle trial. They reported that although RPE and HR returned to a pre-ascertained trial template (one collected in a self-paced TT completed before the experimental TT) following a 1 km maximal burst halfway through a 10 km TT, PO was reduced and BLa were increased during the remainder of the trial. These studies suggest that the physiological disturbances that occur when pace is increased from a normal (self-paced) template will negatively impact pacing for the rest of the event.

Most of these laboratory studies have used cycle ergometers due to the easy self-selection of pace and the additional parameters that can be easily measured during cycling relative to running and swimming protocols, such as PO and electromyographical (EMG) signals. There has been very little laboratory work using exercise modalities other than cycling. There has been some work using computer models to investigate the best pacing strategy for a range of athletic events based on assumptions about physiological processes and biomechanical factors such as drag and power output - for example cycling (van Ingen Schenau *et al.* 1992), speed

skating (van Ingen Schenau *et al.* 1990) and running (Ward-Smith 1985). The over-riding consensus of these articles was that sprint athletes require an all-out strategy whereas “middle distance” athletes are advised to try to run at an even pace. This hypothesis was also modelled by de Koning *et al.* (2011b) in events lasting approximately 100 seconds. They reported that faster starts appeared to be beneficial in 1500 m speed skating and 800 m running, whereas 200 m swimmers should pace themselves more evenly. The main reason for this difference in swimming, despite a similar length of event and therefore energy cost, was suggested to be due to the very high drag forces and low velocities associated with this modality, which results in the risk of a high homeostatic disturbance arising from a fast start with the potential to have a catastrophic knock on effect in the latter part of the race (de Koning *et al.* 2011b).

The fatigue that manifests itself when power output drops during an athletic event may be central or peripheral in nature (see section 2.1). Recently Thomas *et al.* (2015) have shown that peripheral fatigue was the major contributing factor to fatigue during a short, fast 4 km laboratory cycle ride compared to longer, lower intensity 20 km and 40 km rides where central fatigue was the major contributor. The 4 km ride in these time trials averaged a little under 6 min (Thomas *et al.* 2015) or around 40% longer than an elite 1500 m run or 400 m swim suggesting that these latter events would be associated with peripheral fatigue. It is therefore, possible to suggest that pacing during middle distance events such as the 400 m swim or 1500 m run is necessary to avoid specifically peripheral fatigue early in the race which could have detrimental consequences later on.

2.4: Competitive pacing research

There are many examples of fast starts and end spurts in the literature when presenting analysis of competition pacing, some of which are included in figure 2.2. Pacing patterns have been shown to have faster initial and final lap pace in 1-mile running world record events with 30 of the 32 world record times showing an 'end spurt' (Noakes *et al.* 2009) resulting in a U-shaped pacing pattern. An analysis of 1500 m world records over the past century by Tucker *et al.* (2006) again reported an end-spurt in the majority of these performances, and suggested that athletes maintain an energy reserve in the middle part of the race. Hanon and Thomas (2011) reported that 1500 m runners had a fast start and again showed an end-spurt between 1200-1300 m of the race. In fact, the end spurt phenomenon has been shown repeatedly to be part of a normal pacing strategy in triathletes (Vleck *et al.* 2008), cyclists (Foster *et al.* 2009, Mauger *et al.* 2011) and rowers (Foster *et al.* 2009) (see figure 2.2).

Running races of 800 m or shorter distance have shown a positive pacing strategy with a steady decline in pace throughout the race and no end-spurt, though these findings are limited by solely reporting 400 m split times (Tucker *et al.* 2006). Hettinga *et al.* (2011) demonstrated that in speed skating over 1500 m the fastest section is between 300-m and 700-m of the race resulting in an inverted U-shaped pacing pattern. The authors suggest that a fast pace early on could negatively affect the athlete's ability to maintain an optimal body position due to fatigue and that this would have a large impact on speed skating due to the high impact of aerodynamics on the athlete as they travel at high speeds.

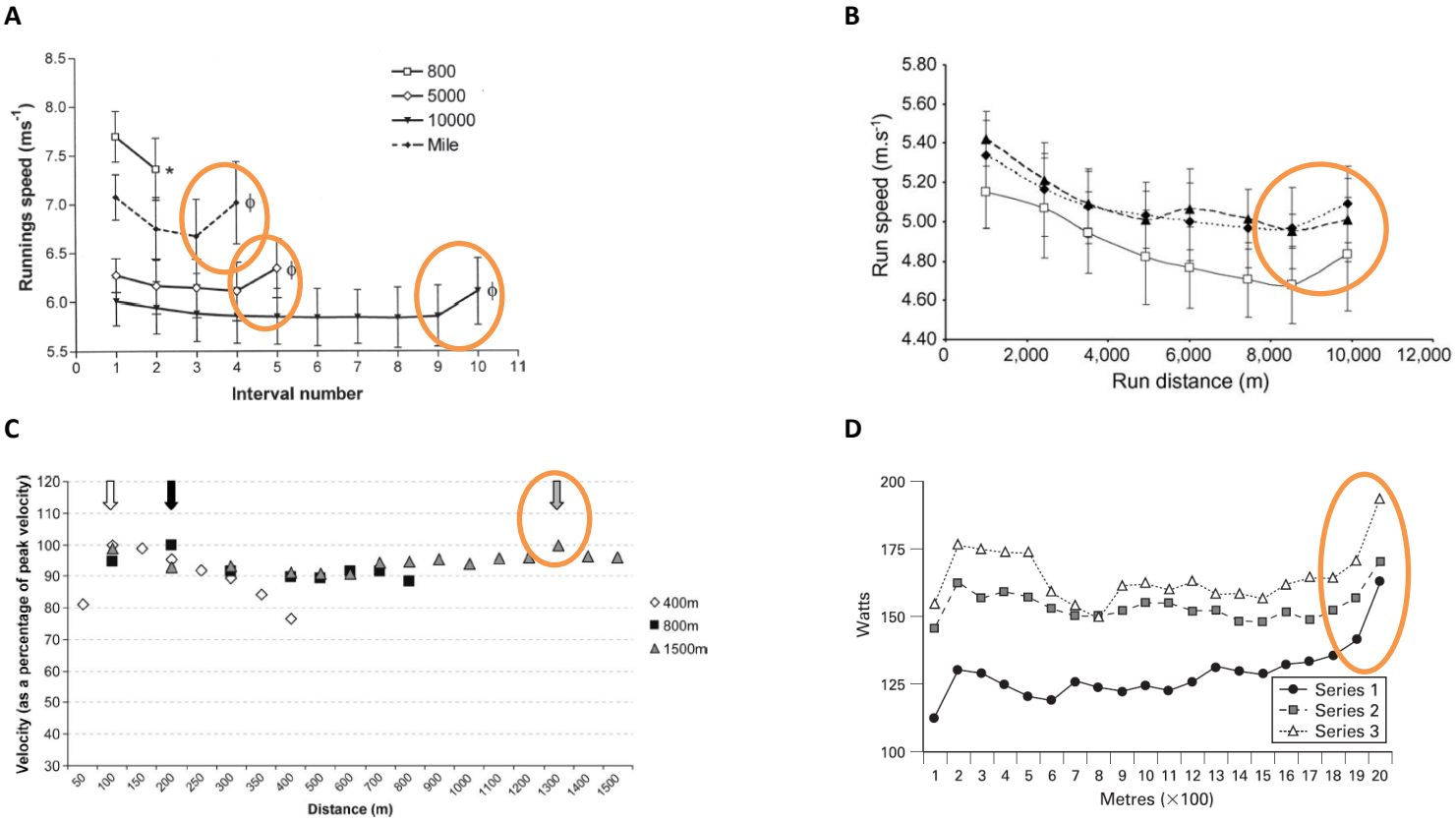


Figure 2.2: Examples of end-spurts seen in the literature. A: Various running distances from Tucker *et al.* (2006). B: 10 km run phase of a triathlon form Vleck *et al.* (2008). C: various running distances from Hanon and Thomas (2011). D: 2 km rowing races from Foster *et al.* (2009).

In order to try and model optimal pacing in swimming events, Robertson *et al.* (2009) collected data retrospectively for a range of distances and strokes for semi-finalists and finalists. They reported all-out, positive and U-shaped pacing strategies in 100 m, 200 m and 400 m freestyle respectively and suggested that athletes should work to improve their pace in the final lap of sprint events and the middle laps of medium distance events in order to meaningfully improve their time (and therefore position), because these laps had the highest correlation with final time. Swimmers were also advised to maintain a parabolic pacing pattern in the 400 m event with a faster start and faster finish that was shown to be successful in this and previous literature. Robertson *et al.* (2009) showed that pacing patterns were broadly similar in heats compared to finals, but that there were differences in pacing patterns between strokes. For example, in 200 m butterfly swimming, where local fatigue in the arms will be disproportionately higher compared to other strokes due to its less economical modality, a balance between increasing PO and body position in the water was suggested to be needed to best improve performance.

Brown *et al.* (2010) reported that pacing patterns in elite middle distance rowing are of a flatter parabolic nature than national level and sub-elite rowers, but found that all groups had a faster initial pace followed by a reduced middle section pace and an end spurt. This was based on the competitive 500-m split times (four laps) taken from World and Olympic championships (elite) and French championships national and sub-elite races. Analysis of the normalised lap data (lap velocity relative to average velocity) identified a relatively slower first lap and final lap in elite compared to national and sub-elite rowers. In addition the elite rowers were relatively faster than national rowers in lap two and faster than both national and sub-elite in lap three.

The authors concluded that elite rowers may be able to maintain a higher anaerobic contribution throughout the race (as opposed to just the start and end in sub-elite and national rowers) and had a more efficient technique, highlighting the contribution of physiological and technical factors in establishing pacing patterns. The parabolic pacing pattern reported by Brown *et al.* (2010) confirms the findings of an earlier study by Garland (2005), where this parabolic pattern was consistent between sexes and winning and losing finalists.

A study into the pacing patterns found in cross-country mountain biking competitions has shown that in national standard athletes, less variability in split speed was associated with increased success in male riders (Abbiss *et al.* 2013). Differences were, for the most part, found in the variation of speed (measured by lap-by-lap standard deviation) between the top 20% and the bottom 20% of finishers. This study employed the notion of using competitive data to compare successful athletes with their unsuccessful colleagues by splitting the finishing field into the top, middle and bottom 20%, and discarding the rest to provide three distinct groups. The distinction between successful and unsuccessful athletes has been used when analysing pacing in marathon running by splitting finishers into quartile groups (Renfree & St Clair Gibson 2013), in rowers by separating the top and bottom half of finishers (Garland 2005) and in swimming by comparing finalists with semi-finalists (Robertson *et al.* 2009). A study of pacing patterns at the rowing regatta of the 2008 Olympic Games compared the winning boat's pacing pattern with non-winners in the same race and concluded that pacing patterns were not different (Muehlbauer *et al.* 2010c). Once again a U-shaped pacing pattern was identified which was consistent through different race types (heat *vs.* final), boat rank (winner *vs.* others), boat type

(single *vs.* team) and sex. As stated earlier, rowing is unique compared to other sports in that athletes look backwards as they race meaning that a fast start could by psychologically beneficial to keep opponents in sight. The authors suggested that a fast finish is preferable in most head to head competitions as to win only requires an athlete or team's race time to be marginally lower than their opponent, compared to a time trial event where athletes race the clock and not their opponent directly. Muehlbauer *et al.* (2010c) suggested that this makes end of race acceleration "mandatory to increase the chance of winning" in head-to-head competitions, presumably to either catch-up or stay ahead of other opponents.

Pacing patterns in marathon running have been shown to differ between the top 25% of finishers and the remaining athletes, where the best athletes maintain an even pace throughout the race, with no significant differences in speed found between 5 km sections of the race in the best finishing runners (Renfree & St Clair Gibson 2013). The remaining athletes, separated into 3 equal groups of 25% of the finishers, showed greater variation than the top group with a marked slowdown in speed at 35 km in group two and from 5 km in groups three and four. All groups demonstrated an end-spurt from either 35 km or 40 km although the authors did not state if this increase in speed was significant from the previous segment of the race. Interestingly, in this analysis the pacing pattern was compared to the pattern in each individual's personal best performance and it was found that the best performers making up the top 25% of finishers were those that began the race below personal best pace. In contrast, groups three and four began at 102.5 and 103.5% of their personal best pace respectively. The authors suggested that the choice of an unsustainable early pace, which could have been due to factors such as distraction by

the crowd or personal motivation, led to physiological disturbances later on that meant that individuals had to slow down to avoid a catastrophic physiological failure (Renfree & St Clair Gibson 2013).

The research above has shown that the majority of middle and long distance events are likely to display a parabolic pacing pattern which may be due to psychological or physiological contributory factors. Some research has attempted to separate winning performances from the rest of the field in rowing, marathon running and mountain biking with the suggestion in the former that there were no difference in pacing pattern (Muehlbauer *et al.* 2010c) and in the latter two that less variation in pace was associated with success (Abbiss *et al.* 2013, Renfree & St Clair Gibson 2013) when times were grouped into three or four performance groups. Whilst a study by Hanley (2014) distinguished between medallist and non-medallist performances, their data is only presented relative to the gold medallists and as such a pacing pattern for each individual cannot be identified. This is the only study found in the literature that uses the distinction of medallist or non-medallist to represent success or failure in elite competitions, which is surprising given athletes and their funding bodies usually target the winning of a medal as a key indicator of success (UKSport 2015). The comparison of medallists and non-medallists will become a key theme of this thesis.

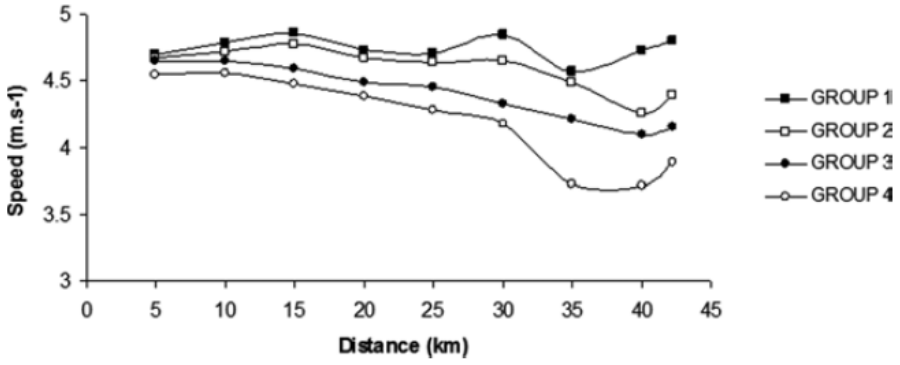
2.5 Pacing data presentation

The pacing literature describes a range of units of measurement when pacing patterns are reported, including the use of absolute speeds, split times or power outputs, speed relative to initial pace, speed relative to the previous lap, speed relative to an

individual athlete (for example the race winner), and normalised speed. The use of absolute speed or absolute PO are the most common units found in pacing literature. Speed values are typically reported as $m.s^{-1}$ (Vleck *et al.* 2008, Mauger *et al.* 2011) or $km.h^{-1}$ (Faulkner *et al.* 2011) and PO is reported in Watts (Foster *et al.* 2009, Gee *et al.* 2013). Absolute split times (s) have also been used by researchers previously (Noakes *et al.* 2009, Foster *et al.* 2014).

Speed that is reported relative to the initial speed can be useful to show the impact of early pace on the rest of the race. For example Renfree and St Clair Gibson (2013) were able to report that only the top 25% of marathon finishers' demonstrated faster 5 km segments in every segment following the first 5 km. The use of relative speed in this example allowed the authors to report that different magnitudes of change of pace in the different finishing groups categorised finishing groups (separated into 4 equal groups based on finishing time), findings which augmented the analysis of the absolute speeds at each stage of the race between groups. Figure 2.3 describes how the pacing differences between these groups are made clear when relative pace is used (B) compared to absolute pace (A). Other authors have reported speed changes relative to the previous lap. For example Veiga and Roig (2016) analysed the change in velocity from one lap to the next in 200 m swimming strokes. The use of a change in velocity was useful to simplify the comparisons between a large number of data sets (four strokes and two sexes). When speed for each section of the race is presented relative to the overall race speed this is termed normalised speed. This measure is useful as it shows the difference between current speed in any given section to overall race speed and is accepted in the literature as a method of

A



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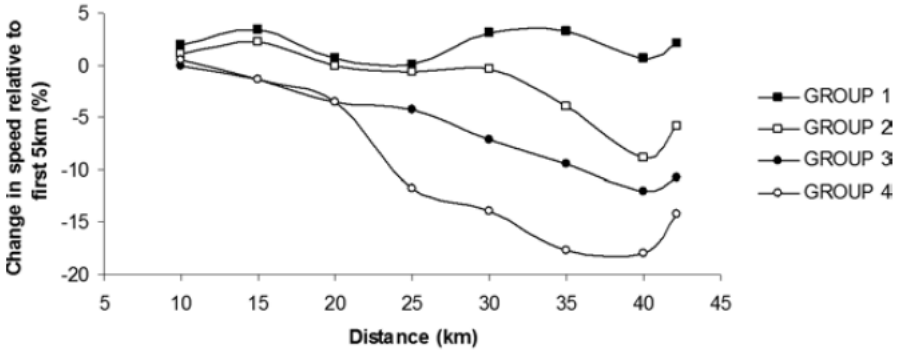


Figure 2.3: Absolute speed of marathon finishing groups (A); speed relative to the first 5 km of the same groups (B) from Renfree and St Clair Gibson (2013).

describing pacing pattern changes (Mauger *et al.* 2012, Skorski *et al.* 2014b). Normalising lap speeds to overall speed allows researchers to investigate the pattern of change in speed over the course of the race across the whole range of finishing times (Garland 2005) and across different events (Brown *et al.* 2010), and essentially individualises pacing profiles to each athlete. In a similar technique, normalised speed was presented by Micklewright *et al.* (2012) and Micklewright *et al.* (2015) as

deviations from the mean speed to compare a large number of different groups. Pacing data presented in this thesis will use the normalised speed technique to allow for comparisons across different modalities and across a range of finishing times expected when investigating developing athletes.

2.6: Psychophysiological explanations of pacing

Pacing patterns seen during exercise performances are thought to be a result of both complex interaction of afferent inputs to the central nervous system (Amann 2011) and the individual's anticipation of the remaining physiological requirements of the event based on previous performances (Paterson & Marino 2004). Group III/IV muscle afferents relay biochemical perturbations in the peripheral muscle, including for example, the concentration of hydrogen ions and inorganic phosphates, to the central nervous system (CNS) which in turn reduces central motor drive (Amann 2011). However to add to the complexity, Amann (2011) also confirmed the possibility of an exercise reserve which could be deployed towards the end of an event producing an increase in power output despite local muscle level fatigue markers being high. In other words, the researchers suggest that an interaction between physiological state and anticipation of the remainder of the event will help to inform the decisions made about central motor drive (St Clair Gibson *et al.* 2001).

Rating of perceived exertion has been suggested as the likely major independent factor for differences in the selection of pace during an activity. Tucker (2009) proposed a model for this regulation where the maximal tolerable RPE and the rate of RPE change interact to provide an athlete with a reason to modify their work rate,

and therefore, adopt a particular pacing strategy (figure 2.4). Tucker's model suggests that athletes exercise to an RPE template that is created by knowledge of the rate of change in RPE from previous exercise performances. If the current RPE matches the template and therefore is at an acceptable level, performance can continue as planned. However, if the rate of change in RPE does not match the template because of changes in local muscle conditions, environmental conditions, tactical decisions to increase speed, and/or other factors, work rate will be adjusted to ensure that the individual can reach the exercise endpoint without a potentially harmful homeostatic disturbance (Tucker 2009). The uncertainty of the anticipatory RPE in an athlete's mind during a race could then explain the end-spurt phenomenon. As this uncertainty reduces as the event nears its finish the CNS could allow for increases in work rate that would increase RPE but not above what was pre-determined as an acceptable level and rate of change. To examine this theory, Mauger *et al.* (2009) designed a study to compare RPE, BLa, peak oxygen consumption ($\dot{V}O_2$peak), integrated electromyography (iEMG) and PO during four consecutive 4 km TT between a control group (CON) who knew the details of the planned exercise and an experimental group (EXP) who did not. They hypothesised that the EXP group would develop and fine tune a pacing pattern during the subsequent TTs using RPE and afferent feedback (e.g. BLa) which would be evidenced by changes to $\dot{V}O_2$, PO and iEMG activity. Their results demonstrated that the EXP group were able to develop an effective pacing pattern that matched the CON group by the fourth TT where the time to complete was 0.5% different between groups. In the first TT the EXP group, with no fixed-point to anchor their efforts, took a conservative approach with a slow speed, low PO, low $\dot{V}O_2$ and low RPE during the TT. These variables then consistently increased as knowledge of the

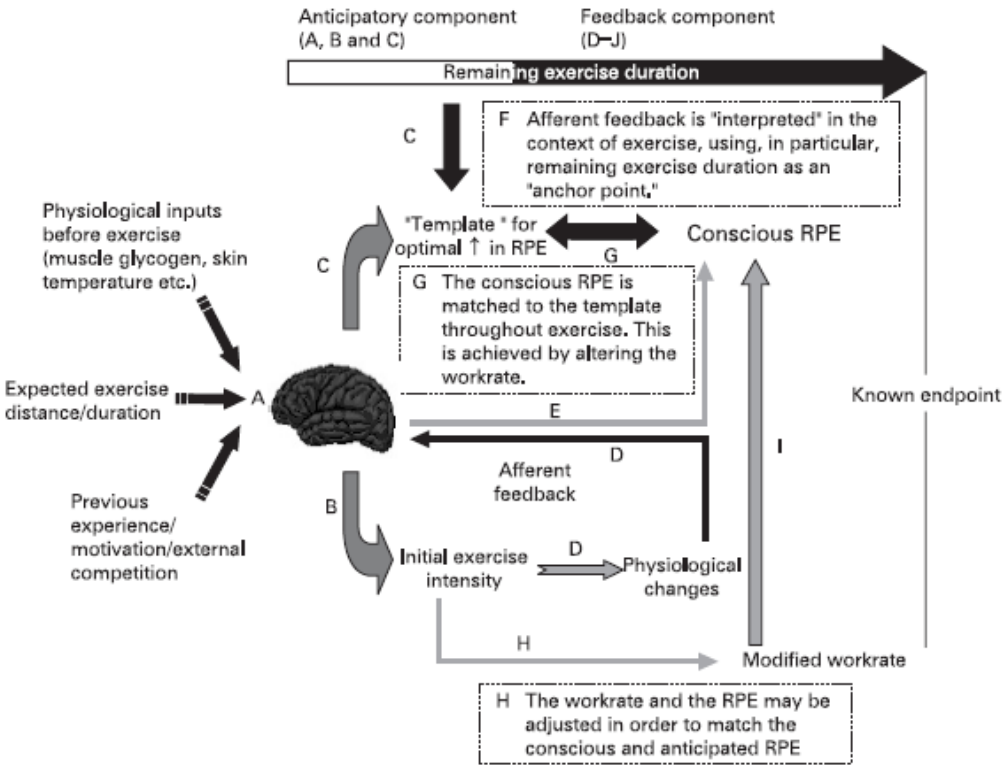


Figure 2.4: Tucker's proposed model for the anticipatory regulation of exercise during self-paced exercise (Tucker 2009).

exercise was developed over the three subsequent trials. The control group recorded their lowest RPE in TT1 which suggests they had used their knowledge of the upcoming three additional TTs to pace themselves over not just the first 4 km trial but all four trials. In the EXP group, PO and iEMG did not track each other as consistently as it did in the CON group and, in fact, there was a negative correlation between iEMG and PO and further research is needed to investigate this phenomenon (Mauger *et al.* 2009). This study may have provided support for the role of an RPE template to adopt an effective pacing pattern that ensures energy reserves are utilised fully during a race (Tucker 2009), although this does not rule out an alternative performance template such as one based on power output.

Whilst the arguments above for RPE playing a major role in pacing are strong, it has been suggested that the regulation of power output is more complicated than using RPE alone (Cohen *et al.* 2013). In their novel study, participants completed a self-paced 10 km bike ride and a second ride of the same distance that included a burst of speed enforced at 4 km. RPE during the burst of speed was increased and returned to its normal growth pattern as seen in the control trial, however PO was lower in the 5 km following the burst. The authors suggested that the higher BLa seen following the burst of speed may play a part in fine tuning the momentary PO although another marker of physiological disturbance, HR, did revert back to its normal pattern. It is therefore possible, that pace is set at macro level by RPE but then fine-tuned by other factors such as BLa or free hydrogen ions. This fine tuning could be due to the effect of local muscle perturbations on the rate of RPE change not matching the template RPE (Tucker 2009). Recently, Skorski *et al.* (2015) showed that RPE is consistent between TTs regardless of the level of accumulated fatigue but that physiological variables such as HR, BLa and RER were lower in the fatigued state. This reinforces the notion that central drive may adapt motor unit recruitment to fit the body's current condition to ensure that RPE follows a consistent template during repeated exercise bouts or that RPE is loosely correlated with underlying physiological variables and is not the paramount 'driver' of events.

Marcora (2008b) argues against a subconscious "governor", suggesting instead that RPE data from exercise studies can be equally interpreted on the basis that perceived exertion consciously affects voluntary control of movement and muscle recruitment. A psychobiological model based on the proposal that five factors may control motor recruitment has been suggested, the five factors being perception of effort, potential

motivation, knowledge of the distance/duration to cover, knowledge of the distance/duration covered, and previous experience/memory of perceived exertion during exercise of varying intensity and duration (de Morree & Marcora 2013). In addition, the concept that perception of effort is a result of corollary discharge rather than afferent feedback is suggested (de Morree *et al.* 2012). The authors promote the view that fatigue based on this model is a form a "task disengagement" rather than task failure, a position which is supported by investigations that show high levels of PO generated during a 7 s test of maximal cycling power immediately following an exercise to exhaustion cycle protocol (Marcora & Staiano 2010).

It is possible that $\dot{V}O_2$ kinetics play a role in pacing patterns used in middle distance events. Bailey *et al.* (2011) were able to show that during a 3-minute cycling exercise, a fast start pacing pattern enhanced performance compared to a slow or even start. In the fast starting 3-minute trial, the end-spurt was 16% higher than in the slow start and even paced trials, which was used to support the notion that faster $\dot{V}O_2$ kinetics at the start had led to increased aerobic energy re-synthesis, saving the anaerobic pathway's resources to be used for the end-spurt (Bailey *et al.* 2011). In a 4-minute running race Hanon *et al.* (2007) showed that during a simulated 1500 m race, and despite a fast start pattern, increasing $\dot{V}O_2$ to maximum levels in a short time does not appear to optimise race performance. These two studies showed that fast starts may be beneficial in generating a faster $\dot{V}O_2$ response in exercise lasting up to 3-min, and despite providing invaluable mechanistic information, neither study used a genuinely competitive race or showed performance enhancement. Further, the breathing equipment used as a requirement of the trials (and carried in the case of the running event) may have detrimentally affected performance.

In normal conditions therefore, it seems that previous experience (or exercise templates) play a key role in exercise regulation and that these may be based on RPE, PO or some other measure. Studies of pacing in the heat and during pharmacological manipulation may help to further explain the mechanisms involved (Roelands *et al.* 2013). Power output is reduced when exercising in hot conditions even at the start of exercise when core temperatures are not raised (Tucker *et al.* 2004, Abbiss *et al.* 2010). Studies on pacing in the heat have tended to show drastic and rapid reductions in PO in the early stages of exercise as participants adjust to the conditions. However, initial pace is often fast following the normal parabolic template of prolonged exercise (Abbiss *et al.* 2009, Ely *et al.* 2010, Levels *et al.* 2012). It is possible that the template is so engrained that participants begin with their normal pacing pattern response which, either consciously or sub-consciously, is then found not to be suitable for the hot conditions. There is evidence that RPE is fixed at the onset of fixed intensity exercise and rises linearly in relation to exercise duration regardless of hot or cold conditions, and further, the rate of RPE increase predicts exercise duration (Crewe *et al.* 2008). This evidence together adds weight to the existence of a pre-existing performance template for an exercise bout which, as exercise progresses, is adjusted depending on the conditions to allow for the best possible performance but also attenuating the possibility of a catastrophic failure occurring.

Another area of psychophysiological pacing research has been the effect of pharmacological manipulations. The brain neurotransmitters dopamine (Watson *et al.* 2005, Roelands *et al.* 2008a, Swart *et al.* 2009, Roelands *et al.* 2012) and noradrenaline (Piacentini *et al.* 2002, Roelands *et al.* 2008b) have been manipulated

during exercise, and in addition the afferent nerve blocker fentanyl has been used to attenuate the central inhibitory affect (Amann *et al.* 2009).

In data from trials following the administration of the dopamine reuptake inhibitor bupropion, participants showed a smaller initial PO reduction which led to a faster 30-min TT during cycling in 30 degree heat with no difference in RPE (Watson *et al.* 2005, Roelands *et al.* 2012).The same effect was not seen in 18 degree conditions (Watson *et al.* 2005). Using an alternative drug called methylphenidate which also increases the amount of circulating dopamine in the brain, similar results were found with a lower reduction in PO in the first 5 min of a cycling TT in 30 degree heat in the experimental group (Roelands *et al.* 2008a). As with bupropion, the same effect was not seen in 18 degree heat and the increase in RPE throughout the trials (both the placebo and methylphenidate groups in 18 and 30 degree heat) were the same. Swart *et al.* (2009) used methylphenidate in a fixed RPE trial in ambient temperatures. They found that PO took longer to fall and that exercise duration was longer in the experimental group versus a placebo group indicating that the drug allowed participants to access additional energy reserves (Swart *et al.* 2009). It is clear that increasing the circulating dopamine in the brain can therefore be responsible for enhanced exercise performance, particularly during the first 5-10 min during exercise in the heat when pace is self-selected, and in ambient temperatures when the RPE is fixed.

Manipulation of noradrenaline levels is possible with the administration of reboxetine which increases the levels of the neurotransmitter, which in turn is associated with increased arousal and motivation. With a low dose of 4mg, neither

cycling performance nor psychophysiological measures (RPE, HR, BLa) were affected by reboxetine (Piacentini *et al.* 2002). With a higher dose of 8mg however, reboxetine administration did have the effect of reducing exercise performance through a reduction in PO in both ambient and hot conditions (Roelands *et al.* 2008b), which was surprising given the known effects of noradrenaline on increasing motivation and arousal. However, this finding could perhaps be explained because noradrenaline is thought to increase levels of serotonin which has a central fatiguing affect.

In the Roelands *et al.* (2008b) study PO was not described over time, which means that the pacing response to noradrenaline manipulation is still unknown. The evidence above does, however, allow conclusions to be drawn about the positive effect of dopamine increases on the early stages of exercise in highly stressful conditions such as exercising in hot conditions. Throughout these trials similar RPE was reported despite the changes in PO suggesting that the pacing alterations seen early in the exercise bout were made to allow the participants to stick to their pre-planned RPE template, and would suggest that central mechanisms play a large role in pacing.

A further pharmacological fatigue study used the nerve blocker fentanyl which reduces afferent feedback from nociceptors, metaboreceptors and c fibres to determine whether alterations in exercise output were originated centrally (Amann *et al.* 2009). In this study, participants cycling with the nerve block demonstrated higher iEMG, PO and BLa and lower arterial oxygen saturation in the first half of a 5 km TT as compared to placebo or control TTs. It was suggested that as the peripheral

muscle fatigue was “unseen” by the brain due to the block, participants were able to cycle at higher power outputs. In addition, the second half of the blocked and placebo TTs produced very similar results and a post TT quadriceps stimulated twitch force was significantly lower in the blocked group. The evidence from this study would appear to support the theory that afferent nerve pathways from local muscles can exert inhibitory influences on the CNS (Amann *et al.* 2009). The central drive may combine with stored exercise templates to distribute pace over an event in order to finish in the best position whilst maintaining whole body homeostasis.

Other researchers have concentrated on the potential psychophysiological effects on pacing of exercising in groups. For example there is a physiologically beneficial effect in the use of drafting during running and cycling performances. When cycling for 20 km continuously behind another cyclist, Hausswirth *et al.* (2001) reported significant reductions in $\dot{V}O_2$ (reduced by 16.5%), $\dot{V}E$ (10.6%), HR (11.4%) and BLa (44%) compared to cycling for 20 km alternating between leading and drafting every 500-m. Similarly large reductions in the physiological cost of cycling when drafting behind another cyclist have been reported (McCole *et al.* 1990, Hausswirth *et al.* 1999). Drafting benefits are reduced for running compared to cycling as running is less mechanically efficient than cycling and wind resistance is reduced due to lower movement speeds. Despite this, there are suggestions that drafting may be able to improve middle distance running performances by one second per 400 m lap (Pugh 1970). Recently, Zouhal *et al.* (2015) reported that following another runner for 2000-m of a 3000-m race reduced peak BLa following the race, reduced RPE during the race and improved performance, but without affecting the cardiorespiratory parameters ($\dot{V}O_2$, $\dot{V}E$ and HR). The authors use this data to suggest that drafting

benefits can be psychological as well as physiological. However, another conclusion could be that participants were able to run faster without an increased aerobic cost suggesting that drafting did have a clear physiological benefit. In swimming and rowing, drafting behind a competitor can also be beneficial as the leading athlete or boat disturbs the water, and so the relative velocity of the fluid passing the trailing athlete is much lower which results in reduced drag forces (McGinnis 2013). However swimmers may feel the benefit less due to the wide spread use of anti-turbulence lane ropes in pool competitions. Along the same lines but with different reasoning, Renfree *et al.* (2015) have reported the benefits of collective behaviour on group exercise in terms of both physiological and mental fatigue. In this interesting second aspect, they suggest that following a competitor may result in reduced decision making, and therefore a reduced cognitive load.

2.7: Sex Differences

This thesis explores sex difference in pacing, and therefore, an understanding of the physiology of fatigue between sex differences is needed. Research has demonstrated that men and women fatigue through different mechanisms in some circumstances. Women are reported to have generally greater fatigue resistance during isometric muscle contractions (Avin *et al.* 2010) although the picture is complicated by task specific differences (Hunter 2009). After 10 short duration maximal isometric voluntary contractions (MVCs) and a 100-s fatiguing isometric contraction of the lower leg, women demonstrated less of a reduction in voluntary force and iEMG activity compared to men (Martin & Rattey 2007). The methodology allowed the authors to conclude that their male participants demonstrated greater central fatigue,

which was also the case when the non-dominant leg was used in the 100-s fatiguing contraction and comparative reductions in force and iEMG occurred in the contralateral leg. During maximal isometric contractions of the elbow flexor both men and women appear to have strength reserves as shown by similar increases in muscle twitches that were superimposed through transcranial magnetic stimulation (Hunter *et al.* 2006), which would suggest that there are no significant differences between sexes in central fatigue. Men appear to fatigue both centrally and peripherally as described by Glace *et al.* (2013) with decreases in voluntary and stimulated isometric strength following a 2 h cycling protocol at ventilatory threshold. However, whilst female participants in the same study fatigued centrally, as shown by a reduction in force during isometric contractions which occurred after the same 2 h cycling protocol, there were no reductions in stimulated muscle force which was a significant difference from the male participants (Glace *et al.* 2013) and suggests reduced peripheral fatigue. An earlier study by the same research group showed that total fatigue in female participants was lower than in males following a similar 2 hr running protocol (Glace *et al.* 1998).

Russ and Kent-Braun (2003) hypothesised that women have an "oxidative advantage" over men during fatiguing exercise which may be due to a larger muscle mass in males producing greater mechanical compression of the muscle bed (and thus reducing oxygen availability), greater metabolic demand by larger muscles which will increase the reliance on anaerobic pathways or an increased reliance on glycolytic metabolism to meet the energy demands of exercise. The authors designed a study to compare fatigue in normal and ischaemic (occluded) conditions during voluntary and involuntary contractions in males and females. They found that during

repeated isometric contractions of the dorsiflexor muscle in ischemic conditions, the advantage that women were found to have compared to men in the non-ischaemic condition disappeared, and was attributed to a higher central activation ratio immediately following fatiguing exercise in females in normal conditions. However, this effect was not found in a similar study by Wust *et al.* (2008) where sex differences in force production during 2 min fatigue tests were present in both normal and occluded conditions. In this study, isometric quadriceps contractions were repeatedly electrically stimulated with men showing a greater reduction in torque in both normal and occluded conditions. The authors concluded that there was a difference in the peripheral fatigue levels of male skeletal muscle which could not be attributed to motivation, muscle size, oxidative capacity and/or blood flow (Wust *et al.* 2008). When men and women were matched for performance on a repeated sprint cycle, sex differences in the reduction of mechanical work and iEMG activity were the same (Billaut & Bishop 2012). In this study, 35 participants completed 20 x 5 s sprints interspersed with 25 s rest, and the results confirmed that women's mechanical work and iEMG activity of three lower leg muscles was reduced to a lesser degree than in men, suggesting that women showed lower levels of central fatigue. However, when seven males and females were matched for workload during the first sprint, the differences in both workload and iEMG were not present. Billaut and Bishop (2012) suggested that differences in fatigue may be due to the higher initial workloads often demonstrated by men (and the increased physiological responses and fatigue in the working muscle that this would cause) rather than a difference in fatigue mechanisms.

Whilst the picture is not completely clear it does appear that there may be sex differences in the central response to fatiguing isometric contractions. Investigations of sex differences during dynamic contractions appear less frequently in the literature. A comprehensive review by Tarnopolsky (2008) reported that women use more fat and less carbohydrate (CHO) and protein substrates during endurance exercise compared to men. The increase in fat utilisation in women has been attributed to the higher levels of 17-β-estradiol, an oestrogen hormone, whilst the reduction in CHO and protein utilisation is thought to follow due to reduced metabolic demand rather than physiological differences or lower levels of glycogen storage (Tarnopolsky 2008). The role of oestrogen appears more certain with the observation that women in the luteal phase of the menstrual cycle, a phase associated with higher levels of oestrogen, demonstrate reduced levels of glucose appearance, disappearance and total glycogen utilisation than women in the follicular phase (Devries *et al.* 2006). The rate limiting anaerobic enzymes PFK and lactate dehydrogenase (LDH) could play a role in the reduced utilisation of glycogen as levels have been shown to be 25.5% and 27.6% lower in women than men (Jaworowski *et al.* 2002), although this could be an effect rather than a cause. In the same study they found no sex differences in the levels of the rate limiting aerobic enzymes β-hydroxacyl-coenzyme A, succinct dehydrogenase and citrate synthase when biopsies were taken at rest (Jaworowski *et al.* 2002). When applied to exercise performance, a reduced anaerobic rate of ATP production could explain how, during exercise performance of 4-5 min, it has been shown that women fatigue earlier than men when cycling at 100% of their VO_2 peak (Lambert *et al.* 2013). Conversely, when men and women were compared for fatigue induced during repeated isotonic contractions at 50% of maximal strength there was no difference in fatigue between

sexes. This could be due to the suggestion that women were able use their greater fat utilisation and aerobic enzyme levels to overcome reduction in anaerobic metabolism and also that women tend to have greater type 1 muscle fibre ratios (Hunter 2009).

Pacing patterns are both the regulatory outcome and the physical manifestations of the fatigue process, therefore if the mechanisms for fatigue are different in males and females it would be logical to suggest that pacing patterns may differ as well. Abbiss *et al.* (2013) reported similarities in pacing patterns between males and females in cross country mountain biking, characterised by riders significantly speeding up in lap two (of seven) followed by a consistently reducing speed in each of the next laps. The faster lap two compared to lap one could be explained by the mass start in this event causing congestion early in the race. There were sex differences described in this study when comparing the top and bottom 20% of finishers. The top 20% of male finishers had significantly less variation in lap speed than the bottom 20%, however this same distinction was not found in elite female riders. This lower variation of speed is also found in successful athletes when comparing male age group riders (U23 and junior riders with a mean age of 18) with their non-successful colleagues, and in female junior riders but not in female U23 riders. This final anomaly aside, it would seem that success in cross-country mountain bike racing is associated with a more even pace in males and junior female competitions but not in races with older female riders for reasons that are not currently clear.

Other researchers have also reported sex differences in pacing of middle and long distance events. In the triathlon, final positioning in the men's field was attributed to a fast start in the initial swim section, while in females the mid-race bike section was

the more influential factor on finishing position (Vleck *et al.* 2008). Sex differences in pacing patterns have also been reported in 400 m freestyle swimming events. Normalising swim speeds to that of the current sex-specific world record, Mauger *et al.* (2012) reported that fast-start-even and parabolic pacing patterns were used most frequently by males and females. However, in males the performances that were closest to the world record performance were conducted using a positive pacing pattern, whereas female best performances were conducted using a fast-start-even pacing pattern (Mauger *et al.* 2012).

Pacing patterns in 1-mile running world record performances are historically similar between sexes with both males and females showing a reverse J-shaped fastest-slower-slowest-faster pacing pattern (Foster *et al.* 2014). However, data from the men's event suggested a progressive shift with time to a more even pace, with the coefficient of variation (CV) between split times moving from 6% in the early 20th century to around 2% in recent performances. The authors could not identify the same evolutionary changes in the women's split times and concluded that this may be a result of less depth of competition in the women's field, potentially resulting in a change in approach to world record attempts (Foster *et al.* 2014). Corbett (2009) found similarities and differences between pacing patterns in the women's 3 km and the men's 4 km pursuit performance using data from the 2006, 2007 and 2008 cycling world championships, where one lap equals 250 m. Both sexes displayed a slow first lap (due to the inertia needed to overcome a standing start), lap two being the fastest, followed by a progressively declining absolute velocity for the remaining 10 or 14 laps (depending on the 3 km or 4 km distance). When 1 km split times were expressed as normalised data and the field separated into fast and slow performances,

success in both sexes was related to a relatively slower first 1 km in the women's 3 km and the men's 4 km races. In addition, success in the men's race was also associated with a relatively faster final 1 km whereas this increase in pace towards the end of the race was not seen in the women's event (Corbett 2009).

In contrast, some studies of pacing that have used male and female participants have reported no differences in pacing patterns between sexes. Brown *et al.* (2010) used a repeated measures ANOVA to look for differences between males and females in pacing patterns during competitive 2 km rowing races. No differences were found either in elite or sub-elite level rowers both on water and on indoor ergometers when normalised velocity was measured every 500-m. Rowers of both sexes used a reverse J-shaped pacing pattern following the fastest-slower-slowest-faster model. Finally, Robertson *et al.* (2009) did not find difference between sexes when analysing split times from 50-, 100- and 200 m elite swimming events covering all four strokes. The use of observations of pacing plots were used to come to this conclusion, rather than through statistical methods, which might explain the lack of differences found between sexes despite a very large sample size.

The previous sections reflect the conflicting evidence regarding sex differences in the literature, although it is interesting to note that in both pacing studies where no differences were found (Robertson *et al.* 2009, Brown *et al.* 2010), the data sets included large participant numbers but no separation of successful and unsuccessful performances, and at least one but possibly both studies, included data from heats/semi-finals as well as finals. Where success has been a factor in the data analysis, and despite this being defined differently, men and women have shown

differences in pacing patterns. However, there does not appear to be a consistent pattern of pacing for successful performances, with men having success with a greater end spurt (Corbett 2009), a faster start (Vleck *et al.* 2008), less variation (Abbiss *et al.* 2013, Foster *et al.* 2014) and more variation in pace (Mauger *et al.* 2012) compared to women. This could be due to the variation in exercise distances, modalities and the definition of success. This thesis will build on this body of literature and investigate sex differences of successful and unsuccessful finalists in middle distance events as defined by the recognised indicator of a championship medal winning performance.

2.8: Developing Athletes

Children and young people display changing physiological and psychological characteristics as they develop into adults. Piaget described the final stage of cognitive development occurring in children aged 13-18 y old (Piaget 2008) and although it is difficult to define, it is widely accepted that physical peak capacity will occur after this age in both men and women. Other common measures of development such as peak height velocity (PHV), skeletal maturation and sexual maturation show that girls begin their key adolescent maturation process around two years earlier than boys, but that there are considerable individual differences in both the timing and tempo of these events (Beunen & Malina 2008, Malina 2014). Performance indicators from Buhl *et al.* (2013) suggest that peak swim performance is achieved at 18.6 ± 1.5 y in women and almost 2 years later at 20.3 ± 1.0 y in men in the 400 m freestyle. This is similar to the findings of Zingg *et al.* (2014) who also found that females displayed their peak swim speed earlier than males, although at

slightly later ages of 20-21 and 22-23 y old respectively in the 200 m freestyle. Therefore, it is possible that the psychophysiological explanations of pacing provided in section 2.6 above cannot entirely be applied to young people who have not fully developed physically and mentally.

2.8.1: Physical Development

An increase in fat mass in girls, which tends to occur in late puberty (Wheeler 1991), has been reported as being detrimental to swimming performance by Zuniga *et al.* (2011), who suggested that the 3% higher average body fat scores they found in female swimmers compared to male swimmers aged 8-13 y old may partially explain why boys have faster swim times. However, fat mass is just one physical variable that may affect athletic performances during a child's development. The skeleton develops in a predictable manner in most children and more rapidly in girls than boys, so that by age 12 girls have attained 94% of their adult height, whereas boys have only reached 84% (Boyd & Bee 2010). The skeleton continues to grow until 16 y on average in females but adult height is not reached until the 20s for the average male. In addition, joint development in boys also lags behind girls until around 18 y reducing boy's coordination and motor control compared to teenage girls (Boyd & Bee 2010). In terms of the respiratory system, puberty is associated with a large growth spurt in the lungs which continues until 18 y in women and 24-30 y in men (Chamley *et al.* 2005). The muscular system also goes through a growth spurt in puberty with muscle fibres becoming thicker and denser in both sexes, however the increase in strength is greater in boys than girls (Boyd & Bee 2010). For example, boys aged 16 y+ had stronger leg muscles than girls of the same age and were

stronger than younger boys, however there was not a difference in strength between girls aged 11-13 y and 15-17 y, suggesting that the muscular development of boys is both greater and continues for longer than in girls (Buchanan & Vardaxis 2003, Buchanan & Vardaxis 2009). These physical developments result in the progression of the body's physiological processes, for example resting cardiac output develops rapidly between 10 and 15 y increasing by 50% to the adult average of 6 $l.min^{-1}$ as a result of large increases in stroke volume, which more than counteract a slowing of the resting heart rate (Chamley *et al.* 2005). In addition to the physical developments outlined above, improvements in the body's control systems are aided by brain development spurts. For example, fine motor skills are developed between 6-8 y followed by frontal lobe development to support logic and planning between 10-12 y, perception and motor functions between 13-15 y and finally further frontal lobe development from 17 y onwards (Chamley *et al.* 2005).

There is an on-going debate about the metabolic changes associated with maturation. For example a lower anaerobic and higher aerobic utilisation generally seen in children and young people is evidenced by lower glycolytic enzyme activity (PFK, LDH, aldolase and pyruvate kinase) and higher oxidative enzyme activity (fumarase, isocitrate dehydrogenase, malate dehydrogenase, succinate dehydrogenase) during exercise in children compared to adults (Ratel *et al.* 2010). According to Dotan (2010), children are more limited in their capacity to utilise type II muscle fibres which can explain why they are less fatigable and recover more quickly from exercise and why they appear to have an "oxidative superiority". During puberty, adolescents tend to experience a deconditioning of the aerobic system combined with an increase in muscle mass (Beneke 2010) and a natural tendency for motor unit

utilisation to change from type I to type II during maturation (Dotan 2010). Interestingly, this change in motor unit utilisation is probably not due to a change in muscle phenotype with the percentage of type I, IIa and IIb fibres seemingly unchanged before and after puberty (Riddell 2008) and so presumably are due to changes in the neural pathways that activate different fibre types. When applied to treadmill running these differences similarly occur, with boys displaying faster and higher $\dot{V}O_2$ kinetics at the onset of exercise (probably due to an enhanced aerobic pathway contribution) and a greatly reduced slow component (estimation of anaerobic contribution) following moderate and heavy exercise (Williams *et al.* 2001) compared to men. It was later suggested that this response was due to the coupling between muscle oxidative systems and muscle phosphocreatine responses, which in adults can buffer decreases in ATP at the onset of exercise far more effectively than in children (Barker *et al.* 2008). Investigations into children's physiological differences however, are complicated and may be affected by experimental methods such as the choice of exercise intensity (Barker 2010), reporting differences when using data relative to mass or muscle mass (Beneke 2010) and biomechanical inefficiencies such as smaller moment arms in children (Berthoin 2010).

In addition to the natural changes outlined above, developing athletes will show signs of physiological adaptation to training. Vaccaro *et al.* (1980) measured a range of physiological characteristics of twelve male swimmers aged 14-16 y old who had been part of a training group for at least six years. They reported that these swimmers had a lower than average body fat percentage (10.8 ± 4.5%) although their body mass was not different to non-swimmers of the same age. Unpublished data has

suggested that developing swimmers who train 7-10 times a week have a lower than average body fat percentage. Mean body fat percentages measured using the three or four site skinfold method were of 8.8% in five males aged 16-18 y and 20.2% in seven females aged 16-19 y (unpublished data). This compares to an average value of 15.9% for males and 22.1% for females in this age group (ACSM 2010). In addition, Vaccaro *et al.* (1980) also reported higher than average $\dot{V}O_2$max (56.8 ± 9.7 ml.kg-1.min-1), total lung capacity (5.47 ± 0.12 l), forced vital capacity (4.28 ± 0.79 l) and forced expiratory volume (3.81 ± 0.70 l in 1 s) compared to non-swimmers of the same age and suggested that the swim training undertaken by these participants had a positive effect on lung dimensions. It is not possible to be sure that the physiological changes described by Vaccaro *et al.* (1980) were the result of swim training or the result of young people with enhanced physiological characteristics such as these being selected (or selecting themselves) for swim training groups.

2.8.2 Cognitive Development

Knowledge about the cognitive development of young people is largely based around Piaget's work in the 1970s in which four phases of development were identified (Figure 2.5). The first two stages, the sensory-motor period and the pre-operational period, are concerned with the interpretation and assimilation of new sensory-motor inputs and the development of knowledge of the properties and relations of concrete objects (Goswami 2008). These stages are both egocentric in that interpretations of the world are made in relation to the self only and include the development of the concepts of transivity, conservation and class inclusion. These terms denote the ability to make correct comparisons across different objects and contexts and to

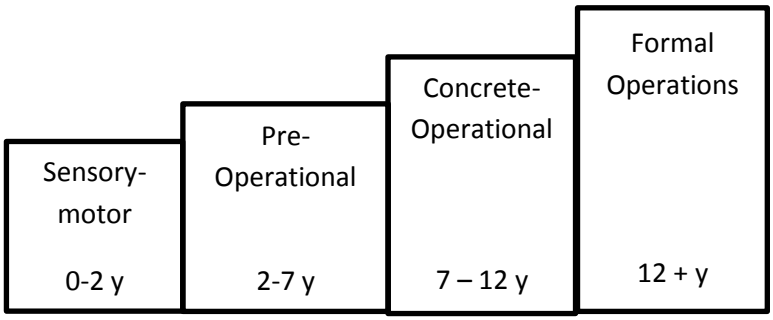


Figure 2.5: Piaget's four stages of development

categorise objects, all of which appear to be present by the age of seven years (Goswami 2008). In the concrete operational stage, children start to take the perspectives of others and create a series of classifications of objects, but as the name suggests, cognition can only occur in concrete objects, in other words those that are immediately present (Smith *et al.* 2011). Therefore, children in the first three stages of development would find it difficult to plan ahead which would impair their ability to plan a pacing pattern for use in a race. However, the logical ability to place objects into an ordinal series may allow children in the concrete operations stage to adapt their pace during the race based on the feedback they are receiving from their body as it happens because they can understand feelings of higher and lower fatigue. Concrete operational children would be expected to start the race at full speed, followed by a slowing as physiological processes in both central and peripheral systems show signs of fatigue, until either the end of the race or a lowering of the fatigue signal occurred.

Formal operational children are able to generate hypotheses and develop reasoning and deductive capacity (Goswami 2008). In this stage therefore, it would appear to be possible to deduce the physiological requirements of an event pre-emptively and

so begin to plan a pacing pattern that would lead to the successful completion of that event before it begins. Piaget's work is not without criticism due to the context of some of the tasks used, the expected consistency of cognition once a child enters a new stage, the underestimation of cognition in very young children and the lack of importance placed on the influences of other people in the child's environment (Siegler *et al.* 2011). In addition, the reliance of Piaget's work on informal observation and interview methods are hard to re-create (Smith *et al.* 2011). Nevertheless, the clear boundaries between different developmental stages and the capacity to apply these to pacing from the context that the formal operation group are the only group likely to foresee the need for pacing, make it a useful basis from which to study pacing in developing adolescent athletes.

2.8.3 Pacing in developing athletes

Using Piagetian theory, Micklewright *et al.* (2012) analysed pacing patterns displayed by children in the concrete operational and formal operational stages using a 4-minute running task around an adapted track. As expected, they found that children in the pre-operational and early concrete operational stages did not display evidence of a pacing template and started fast and continually slowed during the 4-minute task. The authors hypothesised that the illogical reasoning and egocentricity that characterises these stages make 'forming an appropriate pacing strategy unlikely' (Micklewright *et al.* 2012 p.367). In contrast, the late concrete operational and formal operational groups displayed a parabolic pacing pattern with a faster start and finish and slower mid-section, and this pattern was more developed in those in the highest cognitive group, in particular with a faster end-spurt. Micklewright *et al.*

(2012) suggested that mechanisms in the brain that develop with intelligence are able to 'learn' the performance template in these children but it was unclear if these children were relying on RPE to set and then adapt their pacing pattern as was suggested previously (Tucker 2009) or some other mechanism. A parabolic U-shaped pacing pattern was also seen when children aged 9-11 y ran an 800-m TT that was unfamiliar to them (Lambrick *et al.* 2013). The young participants in this study ran three TTs in a row and although their performance improved, their pacing pattern was not different suggesting that they were able to pace optimally without learning a performance template. When a competitive element was added to the running of the 800-m for the fourth time, the time to completion increased by over 7% and an end-spurt was not present as was seen in the three TT runs. The lack of change in pacing pattern in the three TTs was surprising because it would be expected that participants would learn from each previous trial to improve the performance template that they were following (Foster *et al.* 2009), especially as this was a novel task to these participants. In this study, both HR and RPE did not differ between trials when compared at the same section of the TT or competitive run (Lambrick *et al.* 2013) which may explain the fact that the same pacing pattern was used for all three TTs because the runners were getting similar feedback throughout the TT and so adjusted pace in a similar way.

The validity of the use of RPE scales for perceiving effort in children has been reported in most cases by correlating the data to exercising heart rate (HR) or performance measures such as force and speed. Lower correlations have been reported using the Borg 6-20 RPE scale in children (r=0.45-0.79) compared to adults (r=0.89-0.95) although these correlations were higher in children when an adapted

RPE scale was used such as the OMNI or CERT scales (r=0.87-0.94) and not different to the correlations observed in adults when these adapted scales were used (Groslambert & Mahon 2006). In a study of 8-12 y olds using the OMNI scale, participants showed high correlations between RPE and both HR (r=0.93) and $\dot{V}O_2$ (r=0.94) measures (Robertson *et al.* 2000). Using a 30-minute cycling test and RPE in the participant's legs, chest and as an overall sensation, the authors were also able to show that children use the feeling of exertion in their legs as the dominant perceptual input into overall RPE (Robertson *et al.* 2000). In the formal operational stage where adolescents can understand different mathematical concepts, hypothesise and deduce meanings, it would be expected that they could use RPE scale effectively, but in a similar pattern to younger children, correlations between RPE and physiological markers were still lower than in adults (r = 0.74-0.87) using the standard 6-10 point Borg scale but higher using adapted scales (r = 0.86-0.89) (Groslambert & Mahon 2006). There is a difference however, in adolescents who seem to rely more on cardiovascular symptoms of fatigue (e.g. HR) to perceive exertion levels compared to younger children (Pfeiffer *et al.* 2002, Yelling *et al.* 2002). Whilst adolescents can reproduce consistent pacing patterns in repeated performances (Skorski *et al.* 2014b), there is some evidence to suggest that RPE is not consistent across different exercise tests (Marinov *et al.* 2003) and by extension, different exercise modalities. Therefore, children in the concrete operational stage appear to be able to provide accurate RPE when measures are adapted for their use and therefore, can be expected to use this information to adapt their pace during exercise to ensure they can reach the end of the event. In the formal operational stage, children should be able to use their performance templates from previous relevant experiences (i.e. the same exercise) to pre-select a pacing pattern and then

go on to utilise it, adapting it throughout the activity using RPE or other regulatory processes.

Using a biomechanical approach to study pacing in adolescents, Dormehl and Osborough (2015) attributed changes in swimming velocity during the 100 m and 200 m freestyle event to changes in stroke rate, stroke length and stroke index (velocity / stroke length). They report that similar to adults, adolescents competing in these two events use an all-out pacing pattern with velocities dropping throughout the event. The reduction in velocity was attributed to a lower stroke rate being utilised during the race (compared to elite athletes in the same events) due to inexperience and/or "swimming specific power", and/or to a reduced stroke length over the course of the race. These mechanical explanations of pacing are useful in order to identify suitable training methods for developing athletes. For example, the authors suggested using hand paddles to develop power only when stroke rate can be maintained and developing stroke length only when not at the expense of stroke rate (Dormehl & Osborough 2015).

2.9 Effects of training load on swimming performance

The periodisation of training cycles is a wide spread practice in athletic preparation whereby the type, duration and intensity of training is manipulated throughout the cycle. The principles of periodisation are built on centuries of knowledge about athlete preparation dating from the second century AD with contemporary methods largely based on the writings of Lev Matveyev in the 1960s and Tudor Bompa in the 1980s (Issurin 2010). Periodisation involves altering the training type, intensity and

load so that maximal adaptation to training and minimal accumulated fatigue occur at the time of a planned competitive event, in order to maximise performance. A training macro-cycle can be divided into smaller training blocks called mesocycles which can be months in duration, although this has developed with block periodisation methods to 2-6 weeks in length (Issurin 2010). It has become normal for individual athletes such as swimmers to engage in mono-, bi- or tri-cyclic training programmes within a year as they aim to 'peak' for acute phases of competition (Turner 2011).

In an attempt to measure the impact of different training regimes on performance, Stewart and Hopkins (2000) correlated elements of the typical training programmes (for example length of mesocycle, weekly training distance, number of session per week, pace as a percentage of seasons best) of 25 registered New Zealand swimming coaches with typical performance times for their middle distance and sprint swimmers. The training cycle was separated into build up, speciality, taper and post-competition mesocycles which in total made up a 24-week training programme. The authors reported that performance in middle distance swimmers was positively correlated with weekly and session swim distance in the build-up, speciality and taper periods. They also reported negative correlations between swim performance and interval training distances in the taper and post-competition periods and the duration of rest intervals in interval training during the build-up and speciality periods. This study was limited by substantial differences in training load measures between the coaches' self-reported values and those obtained during validation observation visits. Whilst the authors observed that this may be a result of an anomaly on the particular day of the visit compared to the coaches usual training

regime, this does highlight a limitation in using self-reported typical values for training loads rather than a method where training loads are more fully measured on a session by session basis. Using a study design that allowed for greater prescription of training and theoretically better comparison between training methods, Faude *et al.* (2008) compared the impact of four weeks of high volume, low intensity training with four weeks of high intensity, low volume swim training in 10 regional or national level swimmers. They found that there was no difference in competitive performance times in the three months following the two training periods or in the performance of an incremental swimming test, or in maximal 100 m and 400 m time trials.

A taper is a training block that occurs immediately before a competition and has received a lot of attention in the literature in swimming. It has repeatedly been described as a graduated 3-week reduction in training volume (Houmard & Johns 1994, Mujika *et al.* 2002, Trinity *et al.* 2008, Hellard *et al.* 2013) although this description is not universal and for instance, taper periods of 11 days (Papoti *et al.* 2007) and four weeks (Mujika *et al.* 2007) have been investigated. Thomas *et al.* (2008) suggest that the optimal taper is 22.4 days in length. A preparatory competitive event was used by Mujika *et al.* (2002) to investigate the effect of a 3-week taper block between this event and the 2000 Sydney Olympic Games in all individual swimming events from 50 m to 400 m including all four strokes and two medley formats. This allowed the researchers to plot changes in performance by individual swimmers at the two competitive events and they reported that male swimmers improved swim time in all 13 events included in the analysis and female swimmers improved in 12 of the same 13 events. They reported that all of these

performance improvements were of the magnitude to have a meaningful effect on finishing position and that 11 of the 25 events had a statistically significant improvement. This research did not measure or control the training loads used during the taper period and in fact these are only described in general terms rather than on an individual basis.

In a similarly descriptive research design, Hellard *et al.* (2013) compared performances by individual swimmers in international competitions to those recorded in preparatory competitions that took place three weeks prior and thus are a measure of the three week taper effect. In this study training load was measured, which allowed the researchers to cluster programmes into four different types in both the three weeks leading up to the preparatory event (overload period) and the three weeks leading up to the international event (taper period). They report that the most effective training programme design is one where total training load reduces marginally from 84%, to 81, to 80% of maximum individual training load in the overload period and then continues to progressively decrease from 57%, to 45% to 38% in the taper period. This led to an improvement in swim time on average of 2.4% compared to a previous performance, and 2.8% compared to the preparatory race, in the overload and taper periods respectively.

A limitation to both the Mujika *et al.* (2002) and Hellard *et al.* (2013) studies was the lack of control over the training regime used by the participants in their 3-week taper period and the lack of a control group for statistical comparison. This is a common theme when using elite athletes as participants, because these individuals may not be prepared to use experimental methods, or be part of a control group of athletes,

where training methods may negatively affect their performance in an important event. In an attempt to partly overcome this limitation, Trinity *et al.* (2008) compared the 3-week taper period in a group of seven female college swimmers across two consecutive years where the design of the taper was substantially changed from one year to the next. In the lead up to the national championships of 2004, in a period labelled the low intensity taper, training was characterised by low time spent in high intensity training (15-20%) and low weekly training mileage in all three weeks. In comparison, the taper period in the lead up to the 2005 national championships, labelled the high intensity taper, contained a greater proportion of time spent in high intensity training (30-32%), a higher weekly training distance in week one and a higher high intensity training distance in weeks one and two, compared to the low intensity taper of the previous year. Performance at competitive events at the start of the three week taper as well as at the national championships was available for both years. There was a significant decrease in swim velocity following a low intensity taper compared to the maintenance of swim velocity following a high intensity taper suggesting that the latter was more beneficial for swim performance (Trinity *et al.* 2008).

Whilst these investigations provide coaches with useful information regarding appropriate training loads, particularly during taper periods in the three weeks leading up to a competitive race, they do not allow for a discussion about the effects of training load on the pacing of successful and unsuccessful performances. No study was found in the literature that attempted to measure the effect of training load prior to competition on pacing patterns during competitive performances which would be

expected given the body of knowledge referred to above that shows a training load effect on overall performance.

2.9.1: Measuring training loads

The training impulse (TRIMP) has been in use since the 1970's after its development by Banister *et al.* (1975) to ensure that training intensity plays a part in the calculation of training load. Early TRIMPs used HR x session time to quantify training however, the method then developed into a TRIMP based on the product of session RPE and training time. This method was validated against HR in continuous training (Robinson *et al.* 1991), interval training (Foster *et al.* 2001) and against comparable aerobic exercise in resistance training (Sweet *et al.* 2004). Impellizzeri *et al.* (2004) reported that session RPE correlated well to a variety of HR based calculations during intermittent exercise. This method has the advantage of using a single global session figure and includes periods of rest and work, something which is difficult to measure accurately. Both HR TRIMPS and session RPE TRIMPS are in regular use (Earnest *et al.* 2009, Manzi *et al.* 2009, Haddad *et al.* 2011, Wrigley *et al.* 2012). The session RPE TRIMPS can be used effectively in any training situation including continuous, interval and resistance training sessions. There has been some criticism of both the session RPE based methods and of the use of HR methods to validate them with (Borresen & Lambert 2009), based on the subjective nature of RPE values.

A new bioenergetics approach was proposed by Hayes and Quinn (2009) that incorporates an individual's relative training velocity as well as rest periods into the

equation. This is a good addition to improve the measurement of training however, the method requires the collection of eight different pieces of information about each repetition in a training session making it complex and time consuming. It requires a minimum of two test sessions (recommended three to five sessions) to measure critical power, which may be difficult to obtain in athletes undertaking a heavy training schedule, and the assessment of critical power itself has limitations. In addition, the method will only work for training modalities where velocity can be measured so, for example, it could not be used for land training in swimmers.

Given that swimmers participate in land training to augment their continuous and interval training sessions, the effectiveness of both HR based and bioenergetics methods in recording the full training impulse is reduced. The session RPE TRIMP was employed in this thesis using the CR-10 RPE scale (Wallace *et al.* 2008).

2.10: Effects of mood on pacing patterns

In the previous section, training loads during the taper period were shown to affect performance. There is also evidence that mood is not only affected by training load but also that mood may affect performance. O'Connor *et al.* (1991) subjected 40 swimmers to three days of increased training where swim distances were increased by 10-20% compared to the normal loads and swimming intensity was maintained. They reported an increase in mood disturbance with a significant reduction in the feelings of vigour and significant increases in the feeling of fatigue and in overall mood (overall mood was a summation of the five negative variables minus the one positive variable and so an overall increase indicates a negative change) over the

three days. This was in agreement with previous research carried out by the same group which increased training distance in a similar group of swimmers by a greater amount (50% distance) and for longer (10 days) and found significant increases in the scales for depression, anger, fatigue and overall mood (Morgan *et al.* 1988). In addition to the short term studies showing mood fluctuating with training distances in swimmers, Raglin *et al.* (1991) used POMS to asses mood changes over four seasons. They reported that the sub-scales of depression, anger, fatigue, confusion and vigour fluctuated correspondingly with training distance in 186 male and female swimmers. Only the sub-scale of tension reacted differently in response to training distance (it remained elevated after a reduction in distance) and differently between sexes (it was higher in females than males in each of the four seasons). In more recent studies the link between training load and mood has not been evidenced in swimmers (Faude *et al.* 2008), or other athletes (Filaire *et al.* 2004, Hernández *et al.* 2009), which could be the result of the complex nature of mood. For example, Faude *et al.* (2008) found no differences in mood state during high intensity low volume swim training when compared to low intensity high volume swim training over a four week period.

All of these studies used the profile of mood states (POMS) questionnaire to measure mood which consists of six sub-scales. One of these scales is of a positive dimension (vigour) and five are of a negative dimension (anxiety, depression, anger, fatigue and confusion) (Weinberg & Gould 2011). Sport psychologists have usually looked for an iceberg profile of above average vigour and below average for all five negative sub-scales to mark out potentially successful athletes (Morgan 1980). The iceberg profile theory of a successful athlete is not fully accepted in the literature because of

a lack of consistency found in the profiles of elite athletes and a lack of performance impact identified (Lane 2008). Recently, Rhoden and West (2010) have developed a simpler tool for assessing mood called the Worcester Affect Scale (WAS) with affect being described as the person by situation interactions which influence psychological state. Affect can be negative, for example fear, anger or sadness, and positive, for example joy and love, and variations in positive and negative affect are related but are largely independent of each other (Watson & Clark 1997). The WAS is a set of two simple 10-point scales asking participants "how positive do you feel right now" and "how negative do you feel right now" from "not at all positive" /"not at all negative" (score of 1) to "extremely positive"/"extremely negative" (score of 10). The WAS was validated against its parent scale (the Positive and Negative Affect Scale) where similarity between the measures was observed. However, it has the added benefit of being simpler and quicker (Rhoden & West 2010) than the full scale. Affect measured using the WAS has been shown to be a key factor in the pacing of a 20 km cycling performance (Renfree *et al.* 2012). In this study, eight well trained cyclists completed two 20 km self-paced cycle TTs with a range of measures including PO, iEMG, affect, RPE and HR measured every 0.5km. Data between the participant's fast and slow TT were compared and it was found that whilst RPE and HR were not different between trials, positive affect was significantly higher during the fast TT and negative affect was significantly higher during the slow TT. Positive and negative affect was significantly different between fast and slow performances throughout the whole of the 20 km trials, PO was significantly higher during the fast trial for kilometres 1 to 18 compared to the slow trial and iEMG was significantly higher throughout the slow trial compared to the fast trial. Based on these results it was proposed that during the slow (low PO) trial, negative affective feelings

resulting from some unseen peripheral fatigue was forcing increased central muscle activation to reach expected RPE levels. In the fast trial, positive affective feelings, possibly as a result of lower peripheral fatigue, may have led to lower central activation in order to reach a similar RPE and a higher PO. These findings led the researchers to suggest that affect is a key regulator of exercise (Renfree *et al.* 2012), and therefore pacing. Previously, high levels of positive affect prior to competition was associated with an improved performance in elite climbers (Sanchez *et al.* 2010) and with improved self-efficacy which, in turn, was able to predict better performances in wrestlers (Treasure *et al.* 1996).

If positive and negative affect prior to and during performance may affect the regulation of exercise and be associated with the outcome of competitive performances, and furthermore, training load can affect mood, it would appear to be interesting to investigate the relationship between affect, training and the pacing of performance. The final experimental chapter of this thesis will take an exploratory approach to the measurement of training load and affect prior to competitive performances and pacing in swimmers.

2.11: Literature review conclusions

Middle distance events are predominantly aerobic in nature but with an important role in the timing of the deployment of the finite anaerobic component during the event to maximise performance. Pacing studies in simulated and competitive environments have shown that middle distance events are often parabolically paced, designed to ensure that athletes use up all available physiological resources with limited negative side effects, specifically peripheral fatigue, associated with anaerobic energy production. It is possible that these pacing patterns are based on pre-determined RPE or power output responses mapped out by an athlete before they compete based on their previous experiences and implemented through changes in central motor drive. Whilst many examples of pacing pattern analysis exist in competitive running, there is less evidence for swimming, rowing and cycling middle distance events. Furthermore, there is very little research that separates the pacing patterns of successful performances from those seen in less successful performances during elite competitions, which may mask the most effective patterns that have been employed to win medals. In addition, the effect of sex and age, which from a psychophysiological viewpoint could be alter optimal pacing pattern selection, has received very limited attention and is mostly generated from data obtained during running events.

Therefore, this thesis will attempt to systematically investigate these gaps in the literature, specifically in middle distance running and swimming. Firstly, there is a need to design and test a data collection method to provide pacing information from elite competitive events in running, to match the plethora of lap times freely

available in competitive swimming. Then an examination of the number of samples needed in studies employing retrospective data collection in order obtain a reliable sample would be useful. Following this, each chapter will analyse successful pacing patterns in men, women and children using data collected exclusively from competitive environments and consistently separated into successful and unsuccessful performances in order to better understand optimal pacing pattern selection related to successful competitive sport performance.

Chapter 3: Validity and reliability of a new method for obtaining lap times from video in 1500 m running events

3.1: Introduction

Timing and results data from competitive sporting events is sometimes made publicly available to view with different governing bodies taking different stances on the level of detail and competition results they make public. In international swimming events licensed by the Federation Internationale de Natation (FINA), classified results and 50 m split time data for each competitor are published by the timing company Omega on a dedicated website which contains results from the year 2000 onwards. For events in this country, British Swimming publishes the same type of information for all national events for the last ten years on their website which includes 50 m split time information and classified results. For regional events, the eight regional governing bodies also do the same and the majority of clubs provide the same level of information for local events that they host. The collection of this data is made possible by the use of electronic touch pads placed at the end of each swimming lane, equipment that is used at all levels of swimming in this country.

The same plethora of data is not available for all sporting events. For running competitions held under international, national or regional governance, finishing times are often published and in some instances, split times of the leading athletes on each lap are also included. However, because track running does not have an equivalent to the touch pad in swimming, split time data for all competitors are rarely included. New methods have been developed using transponders in the bib numbers

of competing athletes that emit signals which are picked up by radio antennae placed around the track. The first data made available from this method was collected at the Beijing Olympics in 2008 and published by the International Association of Athletics Federations (IAAF 2009) and consisted of 100 m split times for most middle and long distance races that took place on the track during the championships. This method alone however, does not allow researchers to use large amounts of information from races pre-2008 and is reliant on the subsequent publication of the data which is not yet common practice following athletics events.

Therefore, in order to capture split time data from track running, alternative data collection methods must be identified. Video playback is widely used in sport and exercise research in a variety of contexts including joint range of movement analysis, impact analysis, player and ball tracking as well as pacing. Le Meur *et al.* (2012) used video capture and playback to record the pacing strategies of modern pentathletes every 170-m during a competitive event around a 340-m indoor track and Brown (2005) used a video capture and hand notational method to collect 800-m and 1500 m split times around a running track. In the second example, the location of each athlete on the track was collected once the leading athlete passed each 100 m mark and from this, running speeds were calculated for each athlete. These methods have the advantage of gathering competitive data and thus avoid the need for simulated races to be run in the laboratory. However, these studies required a high level of access to international events and used a complex set up of three cameras positioned around the track.

Video footage of major events is available in the public domain and provides an extensive opportunity to obtain split time data of elite athletes during competitive events but without the expensive travel and set up costs of the methods described above, or being limited to a small number of events. A search on the You Tube website revealed start to finish race footage was available for a large majority of the major track meetings over the past ten years. An ability to use this freely available footage would be beneficial if a valid and reliable method were available to measure lap times of all competing athletes. Therefore, the aims of this chapter were to calculate the validity and intra-rater reliability of obtaining lap time data using publicly available video footage.

3.2: Methods

3.2.1: Data Collection

Data were collected from five major international competitions between 2005 and 2011 in 1500 m running events. Videos were only used when a static camera view of the start/finish line existed as athletes crossed the line on every lap. Videos were included from the 23rd and 24th Olympiads (Athens 2004 and Beijing 2008), the IAAF World Championships in 2009 and 2005, and the European Athletics Championships in 2010. Of the 60 individual performances available, 55 athletes were in shot at the start/finish line for every lap and were included in the analysis. All videos were captured using *Screenr* screen capture software and had a frame rate of 25 fps and had a frame height and width of either 320 x 240 or 640 x 360 pixels. The videos were uploaded into Dartfish Team Pro (version 4.5.2.0) and each

athlete's lap timed using the frame by frame playback facility. Each frame advance was equal to 0.04 s.

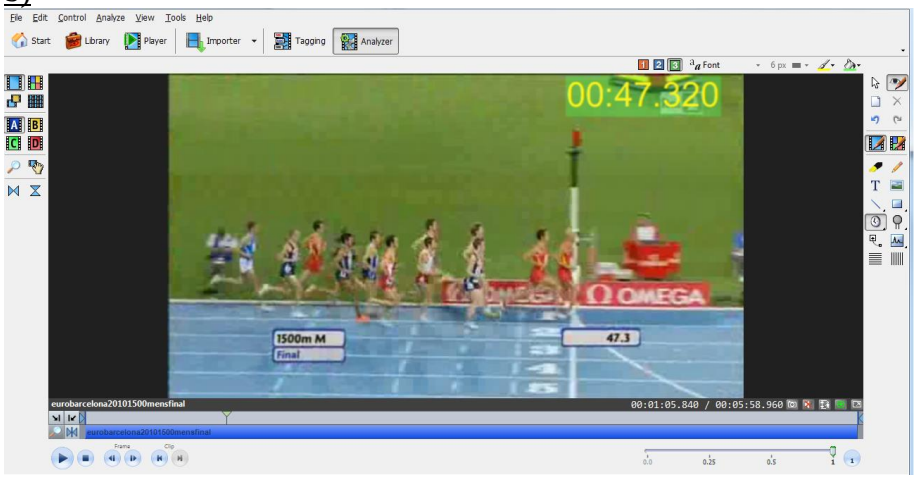
This method resulted in a low video resolution, however athletes were clearly visible in both video sizes as seen in figure 3.1. Because only the start/finish line was used as the track marker, athletes were always closest to the camera at this point reducing the need for higher resolution images. Recording height varied between videos and was not measurable. Where an athlete was completely hidden behind a competitor, he was given the same split time as the athlete nearer the camera which occurred on 11 occasions (figure 3.1c). A static camera view of the start/finish line was not available for the 2011 or 2007 World Championships or the European Athletics Championships in 2006.

3.2.2: Validity of the timing data

Firstly, measured split times at 300, 700, 1100, and 1500 m for the 12 finalists in the Beijing 2008 final were compared to transponder chip times collected by ST Sport Service and published by the IAAF (2009). Secondly, measured finish times from all 55 performances were compared to the official results obtained from www.iaaf.org or www.european-athletics.org for the respective 1500 m running events. This would show any combined aggregated error from all four laps. An Excel spreadsheet (Hopkins 2006) was used to calculate a correction factor using linear regression. Validity was assessed using typical error (TE) with 90% confidence limits (CL), coefficient of variation (CV) and a validity correlation coefficient (Hopkins 2006).

a)

b)



c)

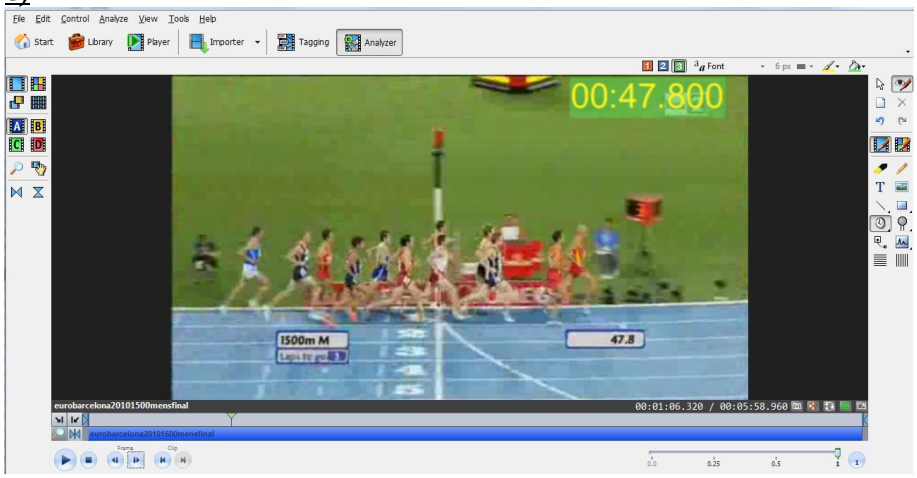


Figure 3.1: Screenshot of the view provided by (a) 320 x 240 pixel sized videos, and (b) 640 x 360 pixel sized videos, and (c) an example of athletes recording the same split time.

3.2.3: Intra-rater reliability when collecting lap times from video

The 2008 Beijing event was chosen at random from the five events by a dice roll. The finishing times for each athlete were collected on two occasions separated by 8 months by the same researcher. Hopkins' reliability spreadsheet (Hopkins 2010) was used to calculate the TE and CV.

3.2.4: Ethical approval

The data used in chapter three to seven were obtained from publicly available websites and ethical approval to collect secondary data was given by the Northumbria University Health & Life Sciences ethics committee. All data were anonymised upon addition to the database and it was ensured that no individuals could be identified from the reporting of the results.

3.3: Results

3.3.1: Validity of the timing data

Table 3.1 shows the TE (±90% CL) and CV of each split time from Beijing 2008 (12 athletes) and between official and measured finishing times (55 athletes). The correlation coefficient between the official and measured finishing times was r=0.99 (figure 3.2) and a linear regression using all 55 samples collected for the 1500 m run

Table 3.1: Typical error (±90% CL) and CV between the video split times and IAAF published split and finishing times.

Split	Chip Time to Video Time TE ± 90% CL (s)	Chip Time to Video Time CV (%)	Official Time to Video Time TE ± 90% CL (s)	Official Time to Video Time CV (%)
n	12	12	55	55
300 m	0.03 ± 0.04	0.08	-	-
700 m	0.11 ± 0.16	0.11	-	-
1100 m	0.02 ± 0.03	0.01	-	-
1500 m	0.03 ± 0.05	0.02	0.04 ± 0.05	0.02

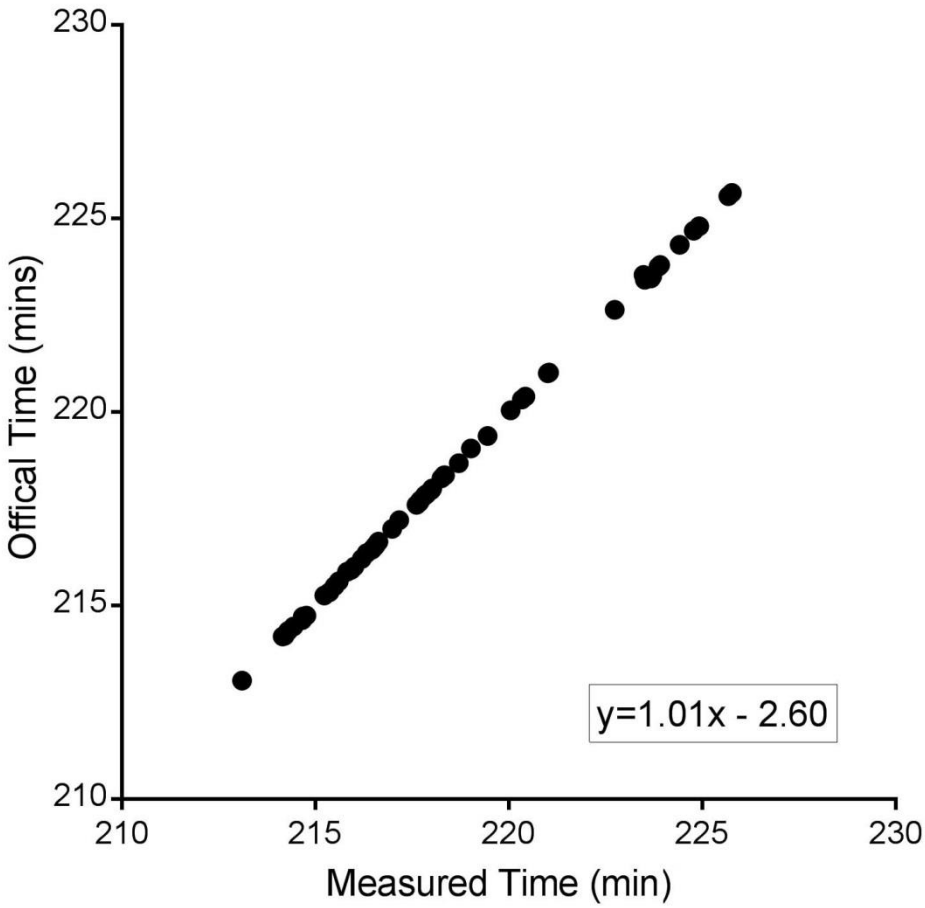


Figure 3.2: Linear regression of measured and official 1500 m run times.

calculated a correction equation of y = 1.012x -2.60 where y is the corrected value and x is the measured value obtained from the Dartfish software.

3.3.2: Intra-rater reliability when collecting lap times from video

The TE (±90% CL) between the finish times of the 2008 1500 m Olympic final collected on two separate occasions was 0.02 s (± 0.02 s) and the CV was 0.01%. This is less than the 0.04 s frame-by-frame time present in this method and demonstrates that the method for collecting lap times using frame by frame video playback is highly reproducible.

3.4: Discussion

The analysis of running data shows a high agreement between the video method and the official split and finishing times. It would be possible to correct all race times using the regression equation formulated. However, the TE and CV values are so low as to make this correction negligible. Measured times were accepted on this basis as a valid representation of the official times. In addition, the method's reliability was very good as shown by low TE and CV values of the intra-rater reliability analysis.

Using a similar method but from video analysis collected from three trackside cameras, Brown (2005) reported absolute intra-operator error in 100 m split times of between 0.10 and 0.88 seconds per 100 m split times in the 1500 m race when the same observer carried out the method on the same video footage. The new method

validated in this chapter compares well with a maximum intra-operator absolute error of 0.08 seconds over the entire 1500 m race and may be superior to Brown (2005) because of the better positioned camera and perpendicular view to the start/finish line.

The method validated in this chapter is somewhat limited by a lack of control of the video resolution, frame rate and recording height due to its reliance on publicly available video footage. In addition, a small number of videos that do not provide a view of the start/finish line for every athlete on every lap, lose some potential split time data. Whilst the resolution of videos is relatively low, athletes are clearly visible using this method as can be seen in figure 3.1. Using a capture rate of 25 frames per second, and with athletes travelling at an average of 6.87 $m.s^{-1}$ in the 1500 m running event, this method can capture an athlete's track position to within 0.28 m or 0.07% of lap distance, indicating that the method has good sensitivity.

The usage of transponder chip timing systems may increase in the future but currently results published from competitive running track events are very limited. Given that the systems record the passing of a passive chip through a magnetic field, it can be assumed that the timing is very accurate as long as the magnetic field is correctly positioned. However, confusion exists in the IAAF rule (rule 165.24.e of the competition rulebook) that states that times from transponder chips will be rounded up to the next whole second (IAAF 2013) which would appear to make this method reliable to within 0.99 seconds. Despite this rule, the split times made available by the IAAF (2009), and used in this chapter to validate the video split times, were published to the nearest tenth of a second.

This chapter has shown that use of freely available videos can dramatically increase the number of competitive events that can be analysed in pacing studies, including in this thesis, in an inexpensive way compared to studies that utilised similar methods but obtained the video in situ or via a transponder chip. Despite the simplicity of the methods, it retains validity and reliability as shown here.

This new method was used in chapters four and five to collect split time data from all athletes competing in the finals of 1500 m international running events providing comparative pacing pattern information between these runners and swimmers where split times are publicly available. This comparison would not have been possible without the validation of this new method. This method opened up the possibility of obtaining split time data for 1500 m runners wherever suitable video footage was available going back a number of years. As already discussed, swimming data is available for over ten years and so further work was needed to assess the number of competitive events needed for this type of pacing pattern comparison in running and swimming to be stable and reliable.

Chapter 4: The reliability and stability of pacing profiles in 400 m freestyle swimming and 1500 m running events

4.1: Introduction

In the previous chapter a novel method for obtaining retrospective split times during high level 1500 m running competitions was validated. This method opened up new opportunities for the analysis of middle distance pacing patterns which have previously been determined using a range of methods including laboratory trials (Foster *et al.* 2003, Stone *et al.* 2011, Edwards & Lander 2012), the collection of real time data (Chen *et al.* 2007) as well as the use of retrospective data collected from automatic timing systems (Tucker *et al.* 2006, Corbett 2009, Robertson *et al.* 2009).

As well as being relatively cheap and easy to obtain, the use of retrospective data is preferable to other data collection methods in two ways. Firstly, it is data collected in real competitive events where athletes race without interference from the research process. This was highlighted by de Koning *et al.* (2011b) who stated that the evaluation of data from high level competitions can provide a real-world view of pacing differences between athletes and sports. Secondly, using retrospective data is more widely obtainable than collecting the data in real-time which would involve researchers travelling to world-wide locations with expensive tracking equipment and devising complex notational methods. All of these barriers can be overcome by using retrospective data allowing larger datasets to be incorporated into pacing research. This raised the question of how many events should be included before a

comprehensive assessment of pacing patterns in middle distance running and swimming could occur.

Data used in retrospective studies in pacing varies widely in scope from lap times collected at a single event (Brown 2005) to lap times collected over 85 years (Tucker *et al.* 2006) and a number of studies have used multiple events to provide their data (Corbett 2009, Robertson *et al.* 2009). Whilst Tucker *et al.* (2006) used all available world record data from the 1920's onwards, others have selected performance to use resulting in a range of between 17 (Brown 2005) and 3,057 (Robertson *et al.* 2009) participants to be included in the analysis. However, none of these studies have justified their choice of data collection period or demonstrated that they have collected data from enough participants to ensure that the full range of sporting performances have been taken in to account when analysing different pacing patterns.

A stable profile is found when performances become consistent between events and as such the term stability denotes that the addition of more data to a database will not alter the mean values. Thus, stability ensures that the full range of likely outcomes are represented in the mean (and variation from the mean) values. A number of methods have been used to estimate a required sample size including the use of coefficient of variation and limits of agreement (Skorski *et al.* 2013), t-tests between data from one event compared to a number of previous events (Hughes *et al.* 2001) and 90% confidence limits (Robertson *et al.* 2009). An alternative method of identifying sample size has been developed by Hughes *et al.* (2001) which uses a cumulative mean calculation in the context of match play in a variety of racket and team sports. This method would appear suitable for use in other contexts such as measuring

pacing profile stability because it is able to produce the minimum number of events needed before data stabilises starting with the most current available data and working backwards through the available retrospective data.

Whilst the stability calculation by cumulative mean uses data from all competitors from the selected events, it is also important to ensure within-subject reliability where an athlete performs at two separate events within the time period. Hopkins *et al.* (2009) clearly state that reliability over time is a key measure to check for habituation, practice, learning, and potentiation. Athletes competing in international finals will almost certainly be in the final/maintenance stage of their career (Stambulova *et al.* 2009) having developed their physical and technical abilities over time to be one of the best eight (swimmers) or best twelve (running) athletes in the world at their event. However, within this final/maintenance stage, athletes could continue to develop through practice and training or could notice a decline in performance due to a number of reasons including physical decline, injury or loss of form amongst others. Therefore, assessing within-subjects reliability from one final appearance to the next is important to ensure robust data sets are used in this thesis.

Based on the middle distance events of 400 m freestyle swimming and 1500 m running, the current chapter aims to a) establish the reliability of swimming and track athletics lap data of international-standard competitors, and b) to determine the number of races required to be analysed before a stable pacing profile can be established within an acceptable error margin for the investigation of pacing and the and planning of training and race strategies.

4.2: Methods

4.2.1: Data collection

Data were collected from five major international competitions between 2005 and 2011 in both 400 m swimming and 1500 m running events. In total 40 performances were analysed from five international 400 m freestyle swimming final competitions. Split times from the final in each championship were included from the Ligue Européenne de Natation (LEN) European Championships in 2008 and 2010 and the FINA World Championships in 2007, 2009 and 2011. Data were freely available in the public domain from the Omega Timing results service (www.omegatiming.com) and were anonymised before use. For 1500 m running, video recordings were obtained from public websites of five athletics final events. Videos were included from the 23rd and 24th Olympiads (Athens 2004 and Beijing 2008), the IAAF World Championships in 2005 and 2009, and the European Athletics Championships in 2010. Videos were only used when a static camera view of the start/finish line existed as athletes crossed the line on every lap during the final of the 1500 m event. In total 55 performances were analysed from these five events. The videos were uploaded into Dartfish TeamPro v5 (Dartfish, Switzerland) and each athlete's lap times measured using the frame by frame playback method validated in chapter 3.

4.2.2: Within-subject pacing profile reliability

Hopkins *et al.* (2009) suggested reporting TE to demonstrate within-subject reliability. Data from each athlete's first recorded event was used as trial one and from their second as trial two. Eleven swimmers had competed in more than one championship final (with a mean time between finals of 20.5 ± 13.3 months). Twelve runners had competed in more than one championship final (24.9 ± 18.9 months between finals). Trial one to trial two data were then compared using Hopkins' reliability spreadsheet (Hopkins 2010) and the TE ± 90% CL and coefficient of variation (CV) reported. A two-way ANOVA with repeated measures on lap was used to analyse changes in the coefficient of variation between the laps and sports with post hoc t-tests used to isolate the differences found. Statistical significance was set at $p<0.05$ and Cohens *d* effect size was calculated for all significant differences using the pooled standard deviation as the denominator and the difference between group means as the numerator (Thalheimer & Cook 2002). Effect size was classified as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2) and large (>1.2-2.0) (Batterham & Hopkins 2006).

4.2.3: Stability of the pacing profile

The stability of the pacing profile was analysed using the cumulative mean method (Hughes *et al.* 2001) to calculate the number of races needed before the cumulative mean stabilises itself to within set error margins (N_E). Lap times for each finalist were added in reverse chronological order and added to a cumulative mean. The point at which the cumulative mean entered and remained within a set % error range was

identified. Error percentages of 10%, 5% and 1% were calculated for each lap. The N_E needed for each lap to remain within a 1% range was identified.

4.3: Results

4.3.1: Within-subject pacing profile reliability

The mean total times were 216.08 ± 2.30 s and 217.67 ± 3.03 s for the 1500 m run and 225.86 ± 2.33 s and 225.48 ± 2.54 s for the 400 m swim in trials one and two respectively. The TE values for within-subject reliability for each lap were low and can be seen in table 4.1.

Table 4.1: Typical error (±90% CL) for within-subject reliability in each lap and in total time.

Event	**Lap 1**	**Lap 2**	**Lap 3**	**Lap 4**	**Total Time**
400 m swim typical error (s)	0.47	0.56	0.76	0.70	2.00
± 90% confidence limits (s)	±0.34	±0.43	±0.59	±0.58	±1.55
1500 m run typical error (s)	2.43	1.70	1.01	1.03	3.18
± 90% confidence limits (s)	±1.78	±1.25	±0.74	±0.76	±2.33

The reliability of swimming times, both individual laps and total time, is greater than running times. Figure 4.1 shows the CV between two performances from the same athlete at different events. There was a significant interaction between lap number and sport (F = 6.04, df = 4, p = 0.001). Post hoc t-tests between sports showed that variation was greater in running than in swimming in laps one (p = 0.001, *d* = 1.21 large effect size), two (p = 0.007, *d* = 1.06 moderate effect size) and four (p = 0.014,

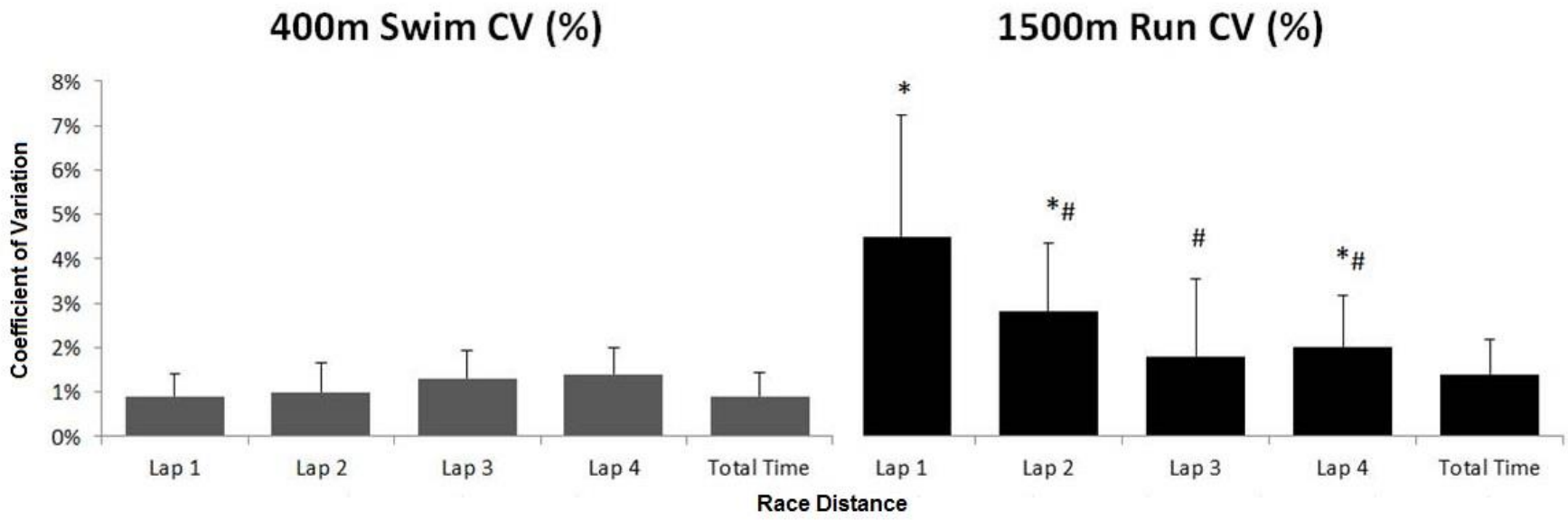


Figure 4.1: Within-subject coefficient of variation for within-subject reliability in each lap and in total time. Error bars show standard deviation.

**Significantly greater variation than the corresponding swimming lap.#Significantly reduced variation than running lap one.*

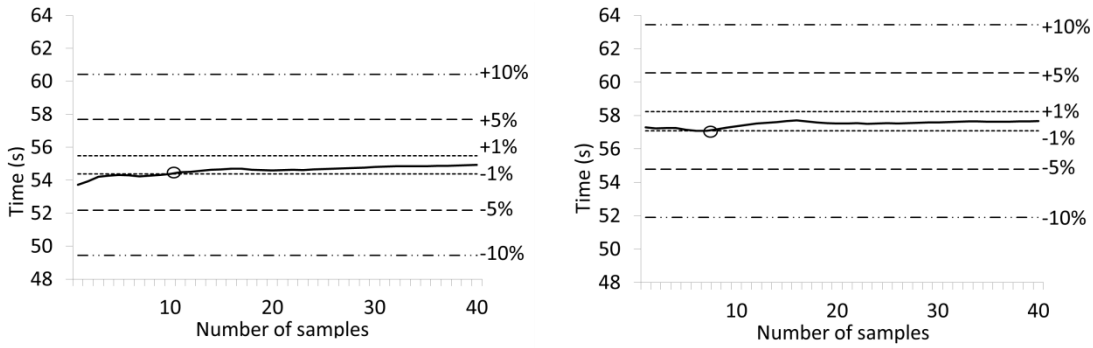
d = 0.98 moderate effect size) but not different in lap three or total time. Post hoc tests within sports showed that swimming laps tended to become more variable during the race (p=0.060), however lap one in running was significantly more variable than laps two (p = 0.012, *d* = 0.62 moderate effect size), three (p =0.022, *d* = 0.99 moderate effect size) and four (p = 0.040, *d* = 0.92 moderate effect size).

4.3.2: Stability results for 400 m swimming

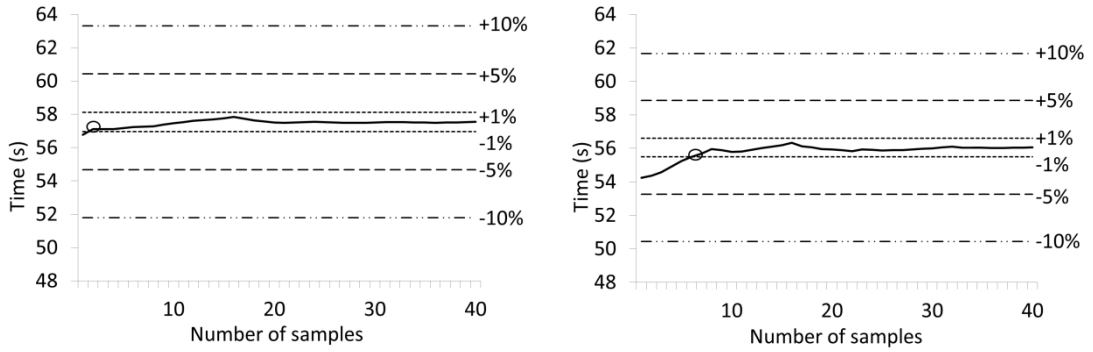
Analysis of figure 4.2 (a-d) shows that it is necessary to collect data from at least ten individuals to stabilise the cumulative mean to within 1% in lap one in 400 m swimming and that less data is needed to stabilise laps two to four (table 4.2). The cumulative mean stays within 1% of variation if more individual performances are added. Eight athletes compete in swimming finals and so an appropriate sample size to ensure stability in 400 m swimming split times would be two events or more.

4.3.3: Stability Results for 1500 m running

The 1500 m running stability analysis demonstrates that it is necessary to collect data from at least 44 individuals to stabilise all four laps in this event (figure 4.3a-d). The cumulative mean stays within 1% of variation if more individual performances are added. Twelve athletes compete in swimming finals and so an appropriate sample size to ensure stability in 1500 m running split times would be four events or more. Table 4.2 summarises the $N_{(E)}$ for the individual laps in 1500 m running.



a: 400 m swimming lap 1 cumulative mean b: 400 m swimming lap 2 cumulative mean

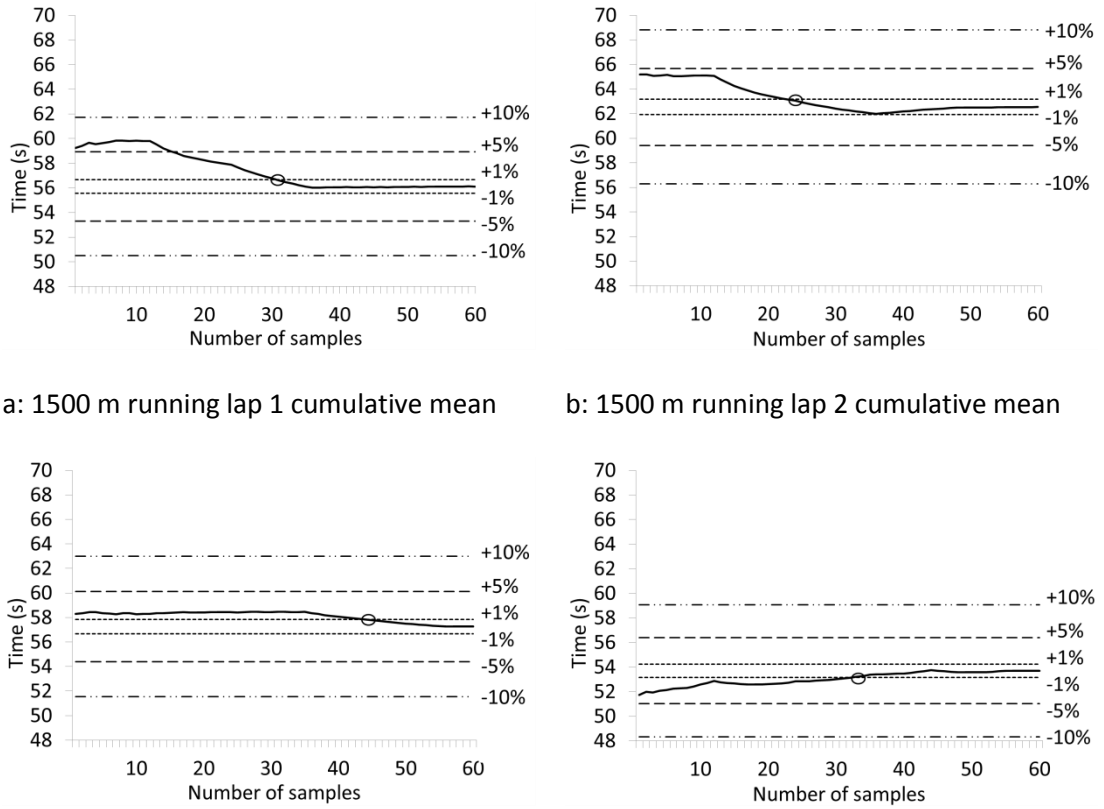


c: 400 m swimming lap 3 cumulative mean d: 400 m swimming lap 4 cumulative mean

Figure 4.2(a-d): 400 m swimming laps one to four cumulative means by number of individual performances collected (Long dashes and dots = 10% limits; long dashes = 5% limits; short dashes = 1% limits. Circle indicates stabilized data to a 1% limit).

Table 4.2: Summary of the number of performances needed to stabilise data for each lap in 400 m swimming and 1500 m running

Event	Lap	10% Limits of Error	5% Limits of Error	1% Limits of Error
400 m swimming	1	2	2	10
	2	2	2	8
	3	2	2	2
	4	2	2	6
1500 m running	1	2	16	31
	2	2	2	23
	3	2	2	44
	4	2	2	33



a: 1500 m running lap 1 cumulative mean

b: 1500 m running lap 2 cumulative mean

c: 1500 m running lap 3 cumulative mean

d: 1500 m running lap 4 cumulative mean

Figure 4.3(a-d): 1500 m running laps one to four cumulative means by number of individual performances collected (Long dashes and dots = 10% limits; long dashes = 5% limits; short dashes = 1% limits. Circle indicates stabilized data to a 1% limit).

4.4: Discussion

The findings of this study suggest that in international standard competitors, within-subject reliability for 400 m swimming times is greater than 1500 m running for individual lap times despite both events being of similar duration. Laps one, two and four in the 1500 m running events were found to demonstrate greater variation than the corresponding laps in the swimming events. These differences between exercise modalities might be due to a number of factors such as a higher degree of tactical racing in the first lap in track athletics when the athletes will jostle for position, the

manner of the start being different to swimming (i.e. dive start in swimming) and differences in kinetic energy production and mechanical efficiency between running and swimming (de Koning *et al.* 2011a). It would appear that elite swimmers vary their pace less than elite runners at the beginning of a race. The differences in variability measured between exercise modalities reduced as the races progressed, which may be due to pacing becoming more tightly controlled as competitors in either sport attempt to protect their remaining metabolic resources to achieve their best performance by the end of the race. This shows that swimmers and their coaches are more able to predict the potential strategies of their opponents than runners and therefore, incorporate this knowledge when planning race strategies and training interventions. This could take some uncertainty out of an athlete's mind at the start of an event.

The direction of change in within-subject variation in velocity as the race progressed seemed to be the opposite in running and swimming. Swimmers became less consistent and runners became more consistent in their lap times from one race to the next with each subsequent lap. Swimmers in the 400 m event demonstrated a high degree of consistency from their first to their second race in the first 100 m of the race with the coefficient of variation of each lap time tending to increase as the race progressed. A similar pattern in elite swimmers was reported when analysing between-subjects mean and standard deviation times for the 400 m freestyle event (Robertson *et al.* 2009). The coefficient of variation calculated from their data results in values of 1.54%, 1.29%, 1.60% and 2.12% for the four 100 m race segments respectively when using data collected from nine international events. This is very similar to the pattern of change shown in figure 4.1 and in both cases CV rose by

about one-third from lap one to lap four. This is likely to be an indication of fatigue and deterioration in mechanical efficiency as the race progresses. This contrasting pattern to runners, who's lap times became more consistent as the race progressed from one event to the next, might also be due to swimmers not having to compete for space in their lane at the start of the race, which will mean they are able to self-select a more optimal pace for the entire event earlier in the race than track and field runners can. In middle distance running, athletes are more influenced by external factors and their pace may be dictated by the pace of the running pack to maintain a tactically advantageous position by reducing drag (Brownlie *et al.* 1987). This confirms that 400 m swimming is more predictable, and therefore, better projections can be made when planning training interventions in order to race specific opponents which should help athletes avoid the negative reactions likely to exist in enforced pacing regimes (Lander *et al.* 2009).

The cumulative mean method shows that 400 m swimming lap times stabilise sooner than 1500 m running with 10 and 44 samples needed in the two sports respectively. This may be due to a number of reasons, some of which have been mentioned previously, which affect the variability of speed during the races. For example, the environmental conditions the race is performed in, the number of competitors that compete in international finals (eight in swimming and twelve in running), running lanes that are shared for the majority of the race, lane changes and drafting that occur in running, the start being different with swimming rapidly attaining racing speed, and marked differences in mechanical efficiency and drag forces experienced between the sports. Another point to note is that while lap one in 400 m swimming took the longest to stabilise compared to the other laps, it was also the most reliable

lap within subjects. This may indicate that the swimmer's time to complete the first lap was consistent between events, but varied between performers to the greatest extent, possibly indicating that factors such as the range of pacing strategies adopted, reaction times and starting ability affected lap one to a greater extent than subsequent laps.

The data for within-subject reliability suggest that lap one should not be used as the relative marker for 1500 m runners or lap four for 400 m swimmers as they were the least reliable laps from one race to the next in the individuals pacing patterns. Total race time has been shown here to be a more consistent variable across both disciplines and validates the use of this variable to normalise lap times as has been previously used but not explained (Marcora 2008a, Corbett 2009, Muehlbauer *et al.* 2010c, de Koning *et al.* 2011a).

Individual lap times were separately analysed to allow later comparisons between the four lap times to be made. In using this method the most conservative error range of ± 1% has been used. This shows that stable data can be obtained by collecting 400 m swimming data from at least two events and 1500 m running data from at least four events. This provides a statistical framework for ensuring that lap times are collected from enough samples in subsequent chapters.

Unlike in previous research, outliers were not identified and excluded from the data set (Robertson *et al.* 2009) in order to ensure that all possible pacing patterns were included, which may mean that the number of events required to establish the stability of race profile in the present study is a conservative estimate. In contrast,

several performances from the same participants were used to establish the stability of split and overall times in both running and swimming events, which would be expected to overestimate race stability. However, Hughes *et al*. (2001) have also used repeated measures on the same individual in their analyses to establish normative performance profiles.

In conclusion, the lap times of international competitors in 1500 m running and 400 m swimming are both reliable, however swimming lap times show greater reliability than running lap times. There was a contrasting trend found in terms of variations in speed across laps in running and swimming, with runners demonstrating a reduced variation in speed as races progressed, while the opposite occurred in swimming albeit to a lesser extent. An appropriate sample size for retrospective data collection has been shown to be at least four events in running and at least two events in swimming to ensure that the data has stabilised to within 1% margins for overall time.

Chapter 5: The pacing patterns of male medallists and non-medallists in the 400 m freestyle swimming and 1500 m running events

5.1: Introduction

In the previous two chapters, methods for collecting reliable and stable data from competitive running and swimming performances were reported which allow for a thorough investigation of the optimal pacing patterns used by successful medal winning athletes in 1500 m running and 400 m swimming. Whilst pacing patterns in these events have been investigated elsewhere (see section 2.4), differentiation between athletes who win a medal and those that do not have not been made.

Pacing patterns have been shown to have faster initial and final lap pace in one mile running world record events with 30 of the 32 world record times showing an 'end spurt' (Noakes *et al.* 2009) which has been identified as being between 1200 - 1300 m of the race (Hanon & Thomas 2011). Compared to 1500 m running, a milder end-spurt has been reported in 400 m swimming (Robertson *et al.* 2009) with a fast start that may be accounted for by the dive and 15-m underwater stroke (Mauger *et al.* 2012, Skorski *et al.* 2014b). Comparisons between 1500 m running and 400 m swimming do not exist in the literature but may be useful to contrast pacing patterns of middle distance events with similar net energetics. The current 400 m men's freestyle swimming world record is 220.07s (FINA 2011) and the current 1500 m men's running world record is 206.0s (IAAF 2011) suggesting that the energetics of

both events are similar and derived primarily from the aerobic energy system (see section 2.1).

Recently modelled performances of 800-m runners, 200 m swimmers and 1500 m speed skaters demonstrated that pacing patterns are different for these events despite very similar net energetic requirements (de Koning *et al.* 2011b). A key aspect of this research was the development of models that include the forces of drag and friction which differ between skating, running and swimming. The study recommended that 200 m swimmers, who experience the highest drag, keep to an even pace whereas 800-m runners should start faster. There is some evidence to suggest that in running, although the ability to achieve a fast overall time is important, so is tactical positioning throughout the race (Renfree & St Clair Gibson 2013). Similarly, tactical positioning at intermediate stages of middle distance races was a found to be a significant factor in finishing position at the London Olympic Games (Renfree *et al.* 2014). In swimming, athletes are not in close physical proximity so pacing patterns should focus on an optimal individual performance (Roelands *et al.* 2013) although there could be some tactical advantages in drafting behind a competitor (Maglischo 1993) whilst avoiding waves created by them (Stager & Tanner 2005).

There have been calls for high level competition data to be used to investigate pacing in the real world and outside of laboratory conditions (de Koning *et al.* 2011a, Renfree *et al.* 2014). An investigation into pacing differences in world class middle distance swimming and running competitions would add to the theoretical basis developed by others for shorter events (de Koning *et al.* 2011b). In addition to the differing physical environment, middle-distance running and swimming also differ in

the degree of interaction between athletes. Pool swimming races are performed in separate lanes for the entire race, whereas runners will come into closer contact, resulting in a greater tactical component, increasing the potential for variability in pacing within- and between events. So, despite 400 m freestyle swimming and 1500 m running events being of similar duration, it would be interesting to contrast the two sports.

In a recent review article (Roelands *et al.* 2013) many examples of parabolic pacing patterns in longer duration events were reported, however the difference between medallists and non-medallists was not investigated. Whilst some literature has identified differences in pacing profiles based on finishing position by splitting finishers into quartiles (Renfree & St Clair Gibson 2013) or by comparing groups of finalists and semi-finalists (Robertson *et al.* 2009), there is a need to define pacing patterns that are successful enough to win a medal which is often the target for elite athletes and their funding agency. This information could be used by coaches and athletes in these events when preparing training strategies and racing plans.

The aim of this chapter was to analyse the pacing patterns displayed by medallists and non-medallists in international competitive 400 m swimming and 1500 m running finals.

5.2: Methods

5.2.1: Data collection

Running split times were collected from the finals of the 1500 m event between 2004 and 2010 from the Olympic Games (2004 and 2008), World Championships (2005 and 2009) and the European Championships (2010). The split times were collected using the video method described in chapter three. Swimming split times were collected from the Omega timing results service (www.omegatiming.com) from the 400 m freestyle men's final event between 2006 and 2011 from the World Championships (2007, 2009 and 2011) and the European Championships (2006, 2008 and 2010). Sample sizes for both events exceeded the minimum sample size required to meet the rules of stability and validity set out in chapter four.

Due to effects of polyurethane swim suits on speed (Tomikawa *et al.* 2008) a preliminary assessment of data from events in 2008 and 2009 when polyurethane suits were legal was carried out in order to assess if the inclusion of this data was likely to affect pacing patterns now that these suits have been banned from use in competition.

5.2.2: Data analysis

Lap distances for both running and swimming events were divided by the lap time to provide lap speed ($m.s^{-1}$). Overall race speed was calculated so that each lap speed could be expressed as a percentage of the overall race speed, also known as

normalised speed (Skorski *et al.* 2014b). The use of normalised speed allows for the analysis of the distribution of speed during a race relative to each individual athlete (see section 2.5). Lap speeds for 100 m portions of the 400 m swimming race are presented to allow for easy comparison to 1500 m running. Normalised speed for each running or swimming lap in medallists and non-medallists were compared using an independent t-test. Lap times relative to the gold medallist were compared for each finishing position for each sport using a series of one-way ANOVAs for each lap followed up with a post hoc LSD test. In addition, absolute speeds for each finishing position were compared in the same way. Statistical significance was set at $p<0.05$ and Cohens *d* effect size was calculated as per the method and interpretation given previously (section 4.2.2).

5.3: Results

5.3.1: Effect of swim suit

There was a significantly faster third lap in the 400 m swimming events during the 2008 and 2009 years (absolute mean time 57.24 ± 0.75 with a polyurethane suit vs. 57.75 ± 0.59 s with a standard suit; $t = -2.395$, $df = 38$, $p = 0.022$). This difference can be seen in figure 5.1 which shows the normalised lap speeds and the altered lap three, and therefore lap four, pacing pattern with and without the suits. Therefore, data from the 2008 and 2009 events were excluded as a precaution.

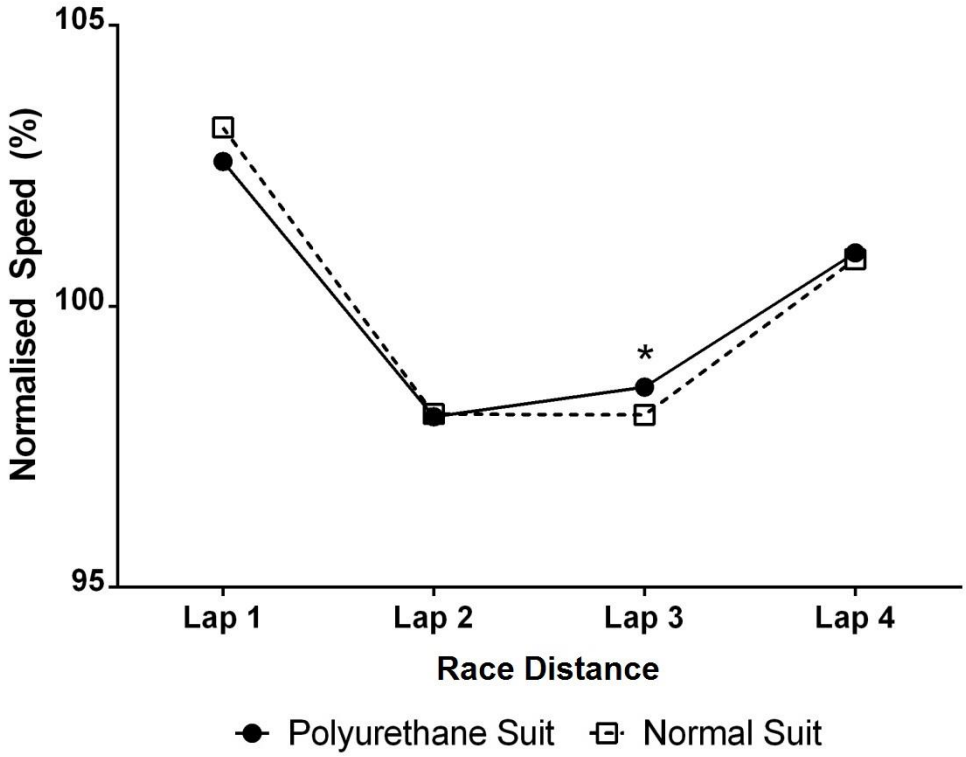


Figure 5.1: Pacing patterns with and without a polyurethane suit.

5.3.2. Normalised speed

The normalised speeds for medallist and non-medallist groups in each lap and sport are shown in figure 5.2. Medallists in 1500 m running had greater variation in speed than non-medallists with a significantly faster lap four (110.2 ± 2.8% vs. 107.9 ± 3.5%;, t = 2.273, df = 53, p = 0.027, *d* = 0.70 moderate). In absolute terms medallists were 0.22 $m.s^{-1}$ faster in lap four. In laps one, two and three, the normalised speed of the medallist and non-medallist groups did not differ from each other (lap one 96.9 ± 3.1% vs. 98.1 ± 3.5%; t = -1.249, df = 58, p = 0.217; lap two (92.7 ± 1.8% vs. 93.8 ± 2.1%;, t = -1.790, df = 58, p = 0.079); lap three 101.3 ± 3.4% vs. 102.0 ± 3.2%; t = -0.753, df = 54, p = 0.455) and absolute speeds were 0.01 $m.s^{-1}$, 0.01 $m.s^{-1}$ and 0.02 $m.s^{-1}$ faster in the medallists in these laps respectively.

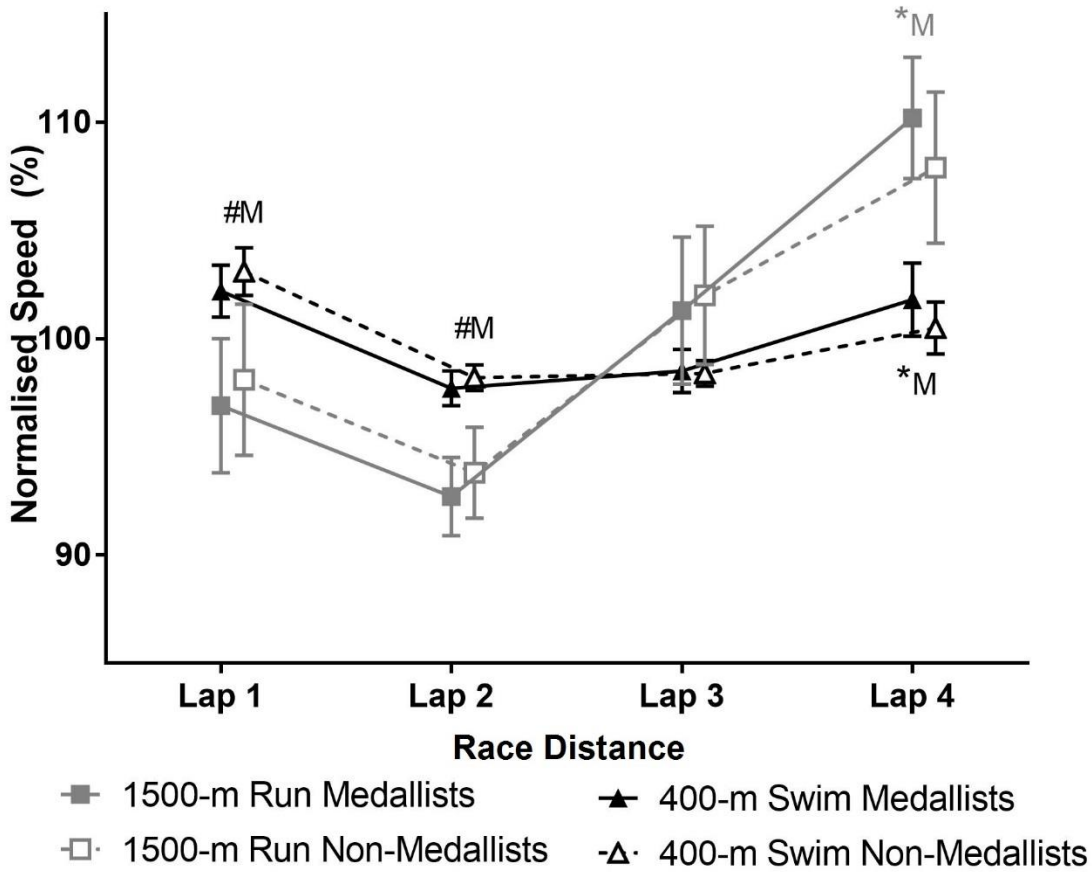


Figure 5.2: Differences between sports in normalised speed for medallists and non-medallists in 1500 m running and 400 m swimming.

* Medallists significantly faster than non-medallists; # Non-medallists significantly faster than medallists. S = small effect size, M = moderate effect size. Data points offset for clarity.

In 400 m swimming the medallist group also had greater variation in speed than the non-medallists group. The medallists in swimming had a faster normalised speed in lap four (101.8 ± 1.7% compared to 100.5 ± 1.2%; t = 3.053, df = 46, p = 0.010, d = 0.93 moderate) than non-medallists and relatively slower speeds in laps one (102.2 ± 1.2% compared to 103.1 ± 1.1%; t = -2.474, df = 46, p = 0.017, *d* = 0.75 moderate) and two (97.7 ± 0.8% compared to 98.2 ± 0.6%; t = -2.545, df = 46, p = 0.014, *d* = 0.78 moderate). Normalised speed in swimming was not different between the medallist and non-medallist groups in lap three (98.5 ± 1.0% vs. 98.4 ± 0.6%; t = 0.480, df = 46, p = 0.633). Comparison of the absolute speeds in these laps show that medallists were 0.01 $m.s^{-1}$, 0.01 $m.s^{-1}$, 0.02 $m.s^{-1}$ and 0.05 $m.s^{-1}$ faster during laps 1, 2, 3 and 4 respectively. Lap speed varied to a greater extent in running medallists (with a range of 91- 115% of overall pace) compared to swimming medallists (a range of 97-105% of overall pace).

5.3.3: Relative to gold medal lap time

In 1500 m running there were significant differences in speed in lap four between finishing positions when calculated relative to the gold medallist (F = 14.917, df = 11, p < 0.001), but no differences were observed in laps one (F = 0.709, df = 11, p = 0.724), two (F = 0.353, df = 11, p = 0.968) or three (F = 1.054, df = 11, p = 0.418) (see figure 5.3). Post hoc analysis on lap 4 identified that gold medallists were significantly faster than runners finishing 5th place or lower (see table 5.1 for significance and effect size values). In swimmers there were no differences in speed relative to the gold medallist in lap one (F = 0.892, df = 7, p = 0.522), however there were differences in laps two (F = 2.766,df = 7 , p = 0.019), three (F = 4.490,

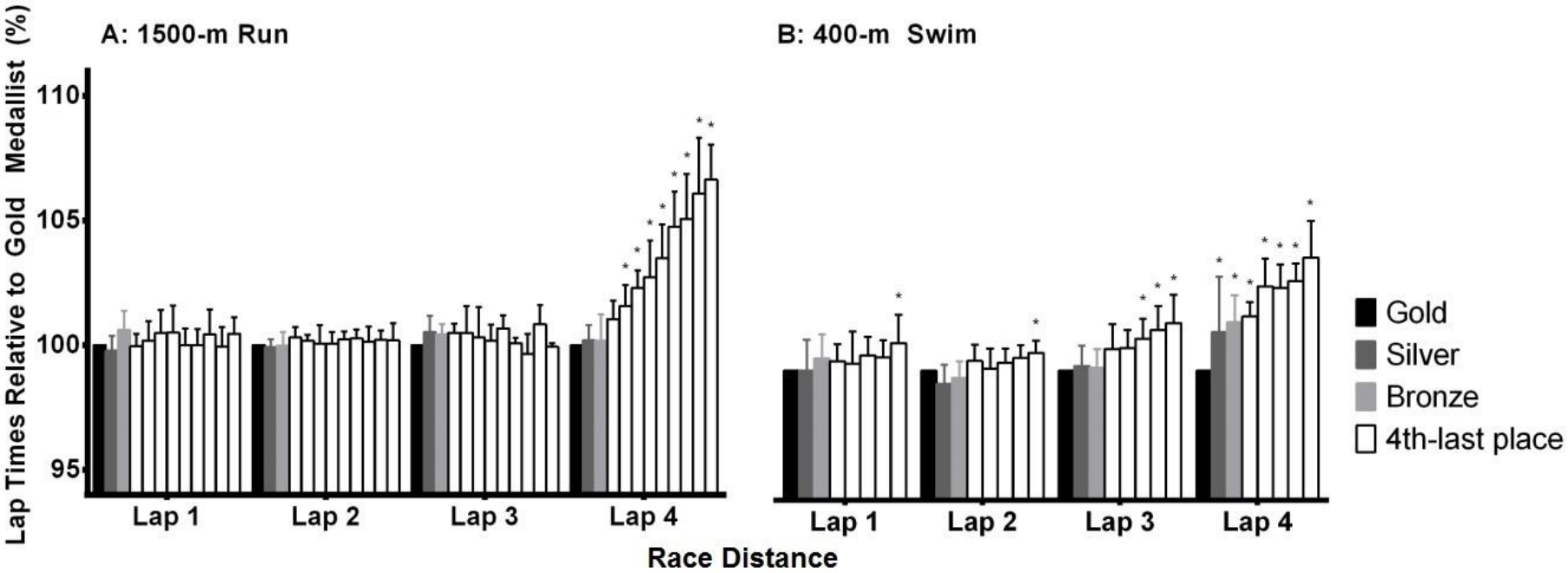


Figure 5.3: Lap times relative to the gold medallist for each lap in the 1500 m run and 400 m swim.

*Significantly slower than the gold medallist; # significantly faster than the gold medallist.

df = 7, p = 0.001) and four (F = 8.770, df = 7, p < 0.001) (see figure 5.3). Post hoc LSD tests showed that the gold medallists were significantly faster than a number of their competitors at different points throughout the race, these differences are shown in figure 5.3 and detailed statistical results provided in table 5.1. Amongst the differences shown in table 5.1 is the finding that relative pace during the last lap in 400 m swimming differentiates gold medallists from the other medallists, a finding not found in 1500 m running.

5.3.4: Absolute pace

Absolute pace for each finishing position compared to the gold medallists in 1500 m running showed no differences in laps one (F = 0.016, df = 11, p = 1.000), two (F = 0.007, df = 11, p = 1.000) or three (F = 0.120, df = 11, p = 1.000) but did report a significant difference in lap four (F = 2.860, df = 11, p = 0.007). There were, however, fewer post hoc differences in pace found (see table 5.2 for full post hoc results) using absolute pace compared with pace relative to gold medallists. The absolute pace data for 400 m swimmers showed that there were no differences in absolute pace in laps one (F = 0.368, df = 7, p = 0.916) or two (F = 0.814, df = 7, p = 0.581), but that there were differences in laps three (F = 2.663, df = 7, p = 0.023) and four (F = 4.939, df = 7, p < 0.001) (see table 5.2 for full post hoc results). As with pace relative to gold, absolute pace during the final lap was able to differentiate between the gold medallist and other medallists.

Table 5.1: Post-hoc analysis of the significant differences (plus effect size where significant) in pace of 1500 m runners and 400 m swimmers relative to the gold medallist (bold denotes significant difference)

	1500 m runners			
Finishing Position	Lap 1	Lap 2	Lap 3	Lap 4
2nd	0.648	0.752	0.237	0.802
3rd	0.206	0.957	0.322	0.834
4th	0.913	0.311	0.263	0.184
5th	0.709	0.563	0.268	**0.049 (0.655 Moderate)**
6th	0.319	0.872	0.492	**0.005 (0.960 Moderate)**
7th	0.299	0.877	0.678	**0.001 (1.144 Moderate)**
8th	0.993	0.448	0.133	**<0.001 (1.467 Large)**
9th	1.000	0.372	0.862	**<0.001 (1.990 Large)**
10th	0.376	0.662	0.443	**<0.001 (2.129 Large)**
11th	0.893	0.497	0.064	**<0.001 (2.554 Large)**
12th	0.341	0.523	0.904	**<0.001 (2.785 Large)**

	400 m swimmers			
Finishing Position	p value Lap 1	p value Lap 2	p value Lap 3	p value Lap 4
2nd	0.998	0.147	0.692	**0.028 (0.894 Moderate)**
3rd	0.360	0.435	0.809	**0.007 (1.121 Moderate)**
4th	0.482	0.273	0.081	**0.003 (1.944 Large)**
5th	0.606	0.821	0.067	**<0.001 (1.916 Large)**
6th	0.262	0.371	**0.011 (1.256 Large)**	**<0.001 (2.072 Large)**
7th	0.331	0.150	**0.002 (1.585 Large)**	**<0.001 (2.608 Large)**
8th	**0.046 (1.200 Large)**	**0.049 (1.042 Moderate)**	**<0.001 (1.868 Large)**	**<0.001 (1.476 Large)**

Table 5.2: Post hoc analysis of significant differences (plus effect size where significant) between the gold medallists and the rest of the field in absolute pace (significant differences in bold)

1500 m runners				
Finishing Position	Lap 1	Lap 2	Lap 3	Lap 4
2nd	0.930	0.954	0.785	0.887
3rd	0.854	0.989	0.829	0.929
4th	0.985	0.897	0.796	0.489
5th	0.969	0.954	0.796	0.297
6th	0.892	0.989	0.874	0.132
7th	0.884	0.977	0.920	0.081
8th	0.992	0.920	0.741	**0.027 (1.232 Large)**
9th	0.992	0.908	0.966	**0.003 (1.666 Large)**
10th	0.907	0.954	0.794	**0.012 1.507 Large)**
11th	0.969	0.920	0.666	**0.003 (1.832 Large)**
12th	0.900	0.943	0.315	**0.016 (1.796 Large)**
400 m swimmers				
Finishing Position	p value Lap 1	p value Lap 2	p value Lap 3	p value Lap 4
2nd	0.922	0.446	0.784	0.128
3rd	0.559	0.703	1.000	0.062
4th	0.559	0.446	0.175	**0.022 (1.091 Moderate)**
5th	0.697	0.799	0.136	**0.001 (1.678 Large)**
6th	0.437	0.611	0.060	**0.001 (1.678 Large)**
7th	0.496	0.375	**0.017 (1.287 Large)**	**<0.001 (1.804 Large)**
8th	0.177	0.311	**0.004 (1.573 Large)**	**<0.001 (2.223 Large)**

5.4: Discussion

The main finding of this chapter was that performance in the final lap in 1500 m running and 400 m swimming can differentiate between medallists and non-medallists which has not been previously discussed in the literature. The last lap showed the largest differences in absolute, normalised and relative speed between the medallists and non-medallists. The success associated with a more pronounced end-spurt in both disciplines suggests that medallists were able to call on reserves of energy not available to non-medallists three-quarters of the way through the race. This may have been possible due to a lower physiological disturbance in the medallists at this stage of the race which in turn may be due to their faster $\dot{V}O_2$ kinetics, a greater critical speed and possibly a greater aerobic capacity, meaning they produce a slower rise in the slow component and take longer to attain their $\dot{V}O_2$max (Burnley & Jones 2007).

In addition to the final lap differentiating medallists from non-medallists in both sports, an interesting finding was that relative pace in the final lap differentiated the gold medallists from the silver and bronze medallists in 400 m swimming but not in 1500 m running. This was the case when comparing data relative to the gold medallists but did not reach statistical significance for absolute pace data. This novel finding highlights the importance of the last lap for 400 m swimmers with gold medal aspirations, and may be different from 1500 m running because of the high energy cost of increasing pace when traveling through water (de Koning *et al.* 2011b) meaning that only the very best swimmers are able to achieve the large pace increases required at this stage of the race.

The findings show that the pacing pattern which characterises a winning race performance is different to that which characterises a world record performance as improvements in the one mile male running world record have been attributed to a relatively more even pacing pattern (Foster *et al.* 2014). This may be an effect of the use of pace-makers who are often deployed in world record attempts. In swimming, the end-spurt seen in this chapter was pronounced and saw gold medallists on average swim a faster final 100 m than the first 100 m including the dive start whilst all other finishing positions averaged a slower final 100 m than their first 100 m. Gold medal swimmers were significantly faster than all other swimmers during the final lap. In separating swimmers by finishing position, the current chapter has added to previous work (Robertson *et al.* 2009) finding a greater 'end-spurt' in medallists and showing that this differentiates them from non-medallists (the lap four speed of the medallists increased from the previous lap by 1.2% more than the speed increase in non-medallists at the same point in the race). In both events, a more conservative initial speed that allowed for increases later on appeared to be associated with success, however athletes will need mental confidence and physical talent in order to put these strategies into practice.

International 400 m swimmers demonstrated a U-shaped pacing pattern (Abbiss & Laursen 2008). The fast start can be accounted for by the dive start and underwater component where speeds of over $3.5 m.s^{-1}$ can be achieved from a grab dive start (Elipot *et al.* 2009), twice the average race speed seen in the data used here. In international competition, medallists, and in particular gold medallists, seem to exhibit a different pacing pattern during finals than non-medallists which disagrees

with others who report similar patterns for 400 m swimming finalists albeit with small individual differences (Chen *et al.* 2007, Robertson *et al.* 2009). Medallists in this chapter were swimming below their mean velocity in the first half of their race whereas non-medallists were swimming above it, indicating the importance of having the ability to increase speed at the end of the race. The first half of the race may be the time when more successful swimmers conserve energy and spare their anaerobic capacity for use later on and by doing so may help them achieve better finishing positions (Hausswirth *et al.* 2010, Bailey *et al.* 2011, Le Meur *et al.* 2012, Cohen *et al.* 2013). Conversely, those swimmers who swim faster over the initial stages seem unable to sustain the necessary speed to compete for medal positions in the latter race stages.

The 1500 m runners demonstrated a J-shaped pacing pattern (Abbiss & Laursen 2008), speeding up in laps three and four after slowing in lap two which shows similarities to previous literature for the same race distances (Noakes *et al.* 2009, Hanon & Thomas 2011). Absolute and relative speeds in lap four were higher than all other laps for each finishing position emphasising the importance of final lap speed for every finisher in the 1500 m run. Running performances showed greater variation in lap speed during a race compared to swimmers as was found in chapter four. All runners had a greater relative speed in the second half of the race compared to swimmers. The swimmers had a greater relative speed in the first half than runners and overall produced a more evenly paced pattern during races. Runners share the same lane, and therefore, are more concerned with tactical considerations (Renfree *et al.* 2014), drafting benefits (Brownlie *et al.* 1987) and their opponents' pace, whereas swimmers are able to adopt a more consistent self-selected race pattern (see chapter

four), are less spatially affected by their opponents and are exposed to greater drag forces as speeds in the water increase (Pendergast *et al.* 2005).

The current chapter employed independent statistical tests even though some individual athletes appear in more than one finishing position in different races. Athletes with more than one appearance (14 runners and 13 swimmers) had their oldest performance(s) removed from the data set to see if this would affect the findings, however normalised lap speeds changed by a maximum of 0.36% in swimmers and 0.20% in runners and no changes to statistical results were found. It was thought that it was more ecologically valid to include all athletes to ensure that the lap speeds for each finishing position were as complete as possible. Independent statistics are also less likely to produce a type I error than dependent statistics and as such are a more conservative option. This study included data from one race per calendar year from the Olympic, World or European championships to try and ensure that the pacing patterns described were indicative of those at the highest level of performance. It is acknowledged therefore, that competitive elite level performances in other competitions were not included for comparison from the 2004-2012 period and may show alternative pacing patterns.

In conclusion, previous research has used international competitive data to show pacing profiles adopted by international finalists, information which is useful for aspiring athletes. This chapter extended this approach by showing how pacing patterns can differentiate between successful and unsuccessful finalists in terms of medal success. To win a medal in both 400 m swimming and 1500 m running it appears necessary to vary pace during the race by adopting a more conservative pace

in the early stages to allow for a relatively greater increase in speed at the end of the race. As long as athletes stay in touch with their opponents, adopting a conservative speed in the early stage of 400 m swimming and 1500 m running finals might result in a more successful race performance because absolute speed can be increased by a greater margin in the final lap.

The need to increase speed in the final lap was demonstrated to good effect here by male elite athletes which raised the question of the transferability of this knowledge to female elite athletes. Because of the differences in male and female physiology and in particular the possibility that different fatigue mechanisms exist between the sexes as suggested in section 2.7, it was not clear that optimal pacing patterns would be the same in females as they have been shown to be in males.

Chapter 6: A comparison of pacing patterns between sexes and medallists and non-medallists in 400 m freestyle swimming

6.1: Introduction

Chapter five suggested that middle distance athletes need to vary their pace to be successful and, in particular, to produce an end-spurt in the final stages of the race which differentiates medallists from non-medallists. This was seen in both 400 m swimming and 1500 m running performances in male athletes (see chapter five). Studies on pacing have demonstrated that physiological differences are apparent when different pacing patterns are used (Lander *et al.* 2009, Le Meur *et al.* 2012) and these differences suggest that the choice of pacing pattern impacts upon the physiological systems of the body. Because there are physiological sex differences (see section 2.7), it cannot be assumed that pacing patters in male and female elite athletes will be the same and, therefore, the pacing pattern needed to be successful may differ in females compared to males. The knowledge of what may differentiate a medal and non-medal winning performance is beneficial for male athletes and their coaches and so this chapter attempts to determine if these patterns are the same in female athletes to extend the same benefit to this population.

Sex differences in pacing patterns have been looked at previously (Vleck *et al.* 2008, Robertson *et al.* 2009, Foster *et al.* 2014). Vleck *et al.* (2008) found significant sex differences in pacing patterns with a fast swim start most important for male performance compared to a fast bike start being the most important for female

performance in a single elite triathlon event. In the one mile run, Foster *et al.* (2014) showed how male and female pacing patterns in world record runs were similar over time using the fastest-slower-slowest-faster lap pattern, however more recent male world record performances appeared to be moving towards a more even pace. They suggested that sociodemographic reasons including lower participation rates, and therefore a lack of depth in competition, could explain this sex difference indicating that physiology may not be the only factor when analysing differences in male and female competitive sport. In a large study, Robertson *et al.* (2009) collected data from over 1,500 male and female swimmers in a range of strokes and distances and reported that whilst there were small differences in the 100 m freestyle, pacing patterns in the 200 m, 400 m or 800-m events in any stroke or in the 100 m backstroke, butterfly and breaststroke were 'largely similar'.

Mauger *et al.* (2012) reported sex differences in elite 400 m swimming competitions when normalised to the sex specific world record. Fast-start-even and parabolic pacing patterns were used most frequently by males and females (Mauger *et al.* 2012) but to different effect. Males produced a performance closer to the world record using a positive pacing pattern compared to a parabolic or fast-start-even pattern. In female performances, positive pacing produced a worse performance (further away from the world record) than fast-start even or parabolic pacing. Mauger's research is useful because it uses normalised velocity to compare different pacing patterns, however success was measured as being close to the world record performance rather than the more tangible outcome of winning a medal. Vleck et al. (2008) reported that females were more likely to select a fast-start pattern than males and that the biggest performance difference was seen when pacing followed a

positive pattern. However, these were non-significant differences, the performance difference was very minimal, and in addition, chapter five showed a parabolic pattern to be the one most associated with success in males. Some authors have opted simply to use data from male athletes (Chen *et al.* 2007) or female athletes (Renfree & St Clair Gibson 2013) rather than from both sexes and some have not reported male to female differences despite collecting and reporting them separately (Corbett 2009).

Unpublished data from our research group suggested that males and females show a trend for different pacing patterns during a 400 m freestyle swimming race depending on their ability level, in particular the elite males were relatively faster on lap four than elite females, where as regional level males and females show very similar patterns (unpublished data). This chapter will test the hypothesis that pacing patterns found to be successful in males will also be found in females and build on the unpublished work above to focus on elite female swimmers.

This chapter focuses on 400 m swimming for three reasons. Firstly, chapters four and five have shown that split times in swimming are more consistent with smaller between subject variance and therefore, pacing pattern analysis may be clearer if the element of trying to compare two different middle distance events is removed. Secondly, tactical differences between these two events complicates the comparison of pacing patterns. For example, track athletes need to decide how to position themselves within the running pack (Brown 2005) but competing in lanes means this is not a consideration for swimmers. And thirdly, lap time data were not available in enough competitions in female 1500 m running event to satisfy the demands of chapter four that at least four races are needed for a stable and reliable sample,

without using races from more than ten years ago, potentially reducing the comparability between these and more recent swimming events. This was because videos of female 1500 m events were either not obtainable in the same public way that men's videos were, or had been edited or with incorrect viewing angle at the point in which athletes completed each lap, a key requirement of the chapter three method. Therefore, the aim of this chapter was to compare pacing patterns between male and female 400 m freestyle swimming competitors during elite performances.

6.2: Methods

6.2.1: Data collection

Lap times were collected from all female swimmers in the 400 m freestyle finals from 2006 and 2011 from the World Championships (2007, 2009 and 2011) and the European Championships (2006, 2008 and 2010). Lap times were obtained from the Omega timing results service (www.omegatiming,com). Forty-eight performances were analysed from the six international events which ensures a big enough sample to satisfy the rules of validity and stability found in chapter four. Data were omitted from the 2008 and 2009 events due to alterations in the pacing pattern with polyurethane swimsuits reported in chapter five. Data from male swimmers is the same as that used in chapter five (see section 5.2.1).

6.2.2: Data Analysis

Data analysis methods used were the same as in chapter five (see section 5.2.3) employing independent t-tests to test for differences between medallists and non-medallists within each lap and a series of one-way ANOVAs followed up with LSD post hoc tests to look for differences between finishing positions in the lap times relative to the gold medallist data. Two methods were used to compare male and female pacing patterns. Firstly, 4 x one-way ANOVAs for each lap looked for differences in normalised speed between the four independent groups (male/female x medallist/non-medallist). Secondly, the change in speed from the previous lap for male and female medallists and non-medallists were calculated and analysed for differences using a similar set of one-way ANOVAs and LSD post hoc tests. Effect size was calculated for significant differences using cohen's *d* effect size statistic in the same way as in chapter five. All statistical tests were carried out using IBM SPSS Statistics v.22.

6.3: Results

6.3.1: Normalised lap speed

Figure 6.1 shows the mean normalised speed (%) for male and female medallists and non-medallists. Female medallists display a significantly faster normalised speed in lap four and slower normalised speed in laps two and three than their non-medallist counterparts. The female medallists swam the last lap at 100.4 ± 0.1% compared

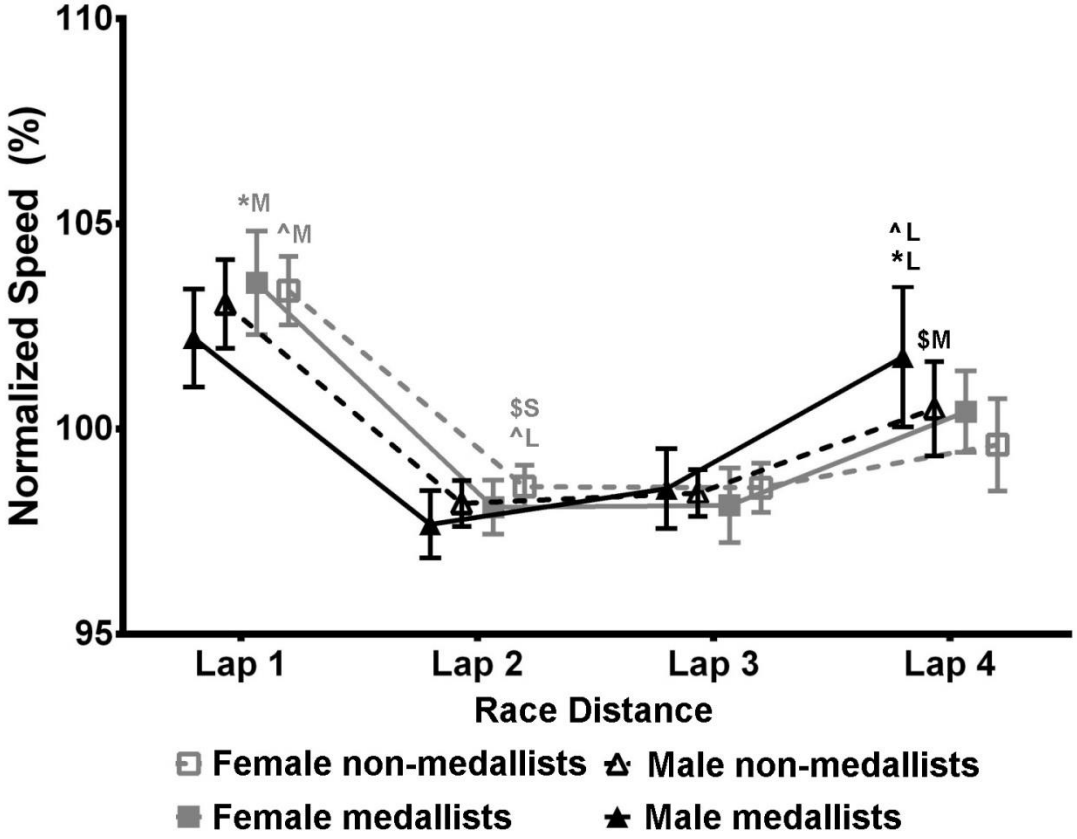


Figure 6.1: Differences between male and female medallists and non-medallists in normalised speed in 400 m swimming.

*Female medallists significantly different to male medallists;. ^ Female non-medallists significantly different to male medallists; $^{\$}$Female non-medallists significantly different to male non-medallists. S = small effect size, M = moderate effect size, L = large effect size. Data points offset for clarity.

to 99.6 ± 1.1% for the non-medallists which was 0.04m.s^{-1} faster in real terms (t = 2.505, df = 46, p = 0.016). In laps two and three, female medallists normalised speed was significantly less than the non-medallists (lap two: 98.1 ± 0.5% vs. 98.6 ± 0.7%, t = -2.956, df = 46, p = 0.005; lap three: 98.6 ± 0.6% vs. 98.1 ± 0.9%, t = -2.015, df = 46, p = 0.050) which equated to 0.02 m.s^{-1} in real terms in both cases. Female medallists and non-medallists did not differ in normalised speed in lap one (t = 0.602, df = 46, p = 0.550). Using a series of one-way ANOVAs to compare male and female pacing patterns in each lap, significant differences were found on laps 1, 2 and 4 (see table 6.1 for full statistical reporting). Female medallists were significantly faster than male medallists on lap 1, they tended to be faster on lap 2 and were significantly slower on lap 4. However, they were not different to male non-medallists on any lap. Similarly, female non-medallists were significantly faster than male medallists on laps 1 and 2 and significantly slower on lap 4. Compared to male non-medallists, the same non-medallist females were significantly faster on lap 2 and significantly slower on lap 4.

Table 6.1: Male and Female normalised speed differences on each lap.

Lap	ANOVA	Post Hoc	Effect Size
Lap 1	F = 5.841, df = 3, p = 0.001	Female medallists were significantly faster than male medallists (p < 0.001).	1.164 moderate
		Female medallists were not different to male non-medallists (p = 0.114).	-
		Female non-medallists were significantly faster than male medallists (p < 0.001).	1.006 moderate
		Female non-medallists were not different to male non-medallists (p = 0.239).	-
Lap 2	F = 8.474, df = 3, p < 0.001	Female medallists tended to be faster than male medallists (p = 0.051).	0.594 small
		Female medallists were not different to male non-medallists (p = 0.612).	-
		Female non-medallists were significantly faster than male medallists (p < 0.001).	1.327 large
		Female non-medallists were significantly faster than male non-medallists (p < 0.001).	0.597 small
Lap 3	F = 1.476, df = 3, p = 0.226	-	-
Lap 4	F =11.167, df = 3, p < 0.001	Male medallists were significantly faster than female medallists (p = 0.002).	1.161 large
		Female medallists were not different to male non-medallists (p = 0.843).	-
		Female non-medallists were significantly slower than male medallists (p < 0.001).	1.500 large
		Female non-medallists were significantly slower than male non-medallists (p = 0.007).	0.616 moderate

6.3.2: Relative to gold medal lap time

When the data was expressed relative to the gold medal winning lap times, significant differences between finishing position were found in female swimmers in laps three ($F = 3.906$, $df = 7$, $p = 0.002$) and four ($F = 7.626$, $df = 7$, $p < 0.001$). There were no differences in pace between finishing position found in laps 1 ($F = 1.631$, $df = 7$, $p = 0.155$) or 2 ($F = 2.090$, $df = 7$, $p = 0.067$). Post hoc LSD tests showed that 6th ($p = 0.017$) 7th ($p = 0.001$) and 8th ($p < 0.001$) positions were significantly slower than the gold medallists in lap 3 and that 5th ($p = 0.037$), 6th ($p = 0.002$), 7th ($p < 0.001$) and 8th ($p < 0.001$) positions were significantly slower than the gold medallists in lap 4. These differences and their effect sizes are shown in figure 6.2 along with male pace relative to the gold medallist for comparison. The differences between females in lap 3 are remarkably similar to those seen in males, however the final lap does not differentiate between medallists in females as it does in males.

6.3.3: Change in speed from previous lap

Male medallists increased their speed more than female medallists during the second half of the race, as can be seen in figure 6.3. In lap 2 the change in pace was not different ($F = 2.675$, $df = 3$, $p = 0.062$) between male or female medallists or non-medallists. In lap 3 the pace change was significantly greater ($F = 3.190$, $df = 3$, $p = 0.027$) in the male medallists compared to all other groups ($p = 0.045$, 0.015 and 0.004 when compared to male non-medallists, female medallists and female non-medallists, respectively). In lap 4, the change in pace was again significantly greater

($F = 10.620$, $df = 3$, $p < 0.001$) in the male medallists compared to all other groups ($p = 0.003$, 0.015 and < 0.001 compared to male non-medallists, female medallists and female non-medallists, respectively). In addition, the female medallists had an increase in pace significantly greater than female non-medallists ($p = 0.006$) but not the male non-medallists ($p = 0.800$). And finally, the male non-medallists had a significantly greater increase in pace then female non-medallists ($p = 0.004$). All of these are shown in figure 6.3 along with effect sizes.

6.4: Discussion

The female medallists in this study showed a significant end-spurt like their male counterparts (in chapter five) underlining the importance of having sufficient physiological reserve to increase pace in the final 100 m. Previously in chapter five, it was suggested that this pattern may be due to a lower physiological disturbance in medallists which could be due to faster $\dot{V}O_2$ kinetics, a greater critical speed and/or a greater aerobic capacity. The 100 m to 300-m portion of the race was where female medallists adopted a more conservative relative speed, again mirroring the pattern seen in male medallists. This reduction in speed could be due to a reduced stroke rate as seen by Thompson *et al.* (2000) in a similar portion of the 200 m breaststroke, although the differences in stroke and race length make this comparison difficult to validate. However, whilst the pacing pattern was similar between males and females, it was not the same. Female medallists and non-medallists were less conservative in lap 1 when compared to male medallists, and this was also the case with female non-medallists in lap 2, where they were also faster than male non-medallists. The impact of this difference was observed later in the race as male medallists were able

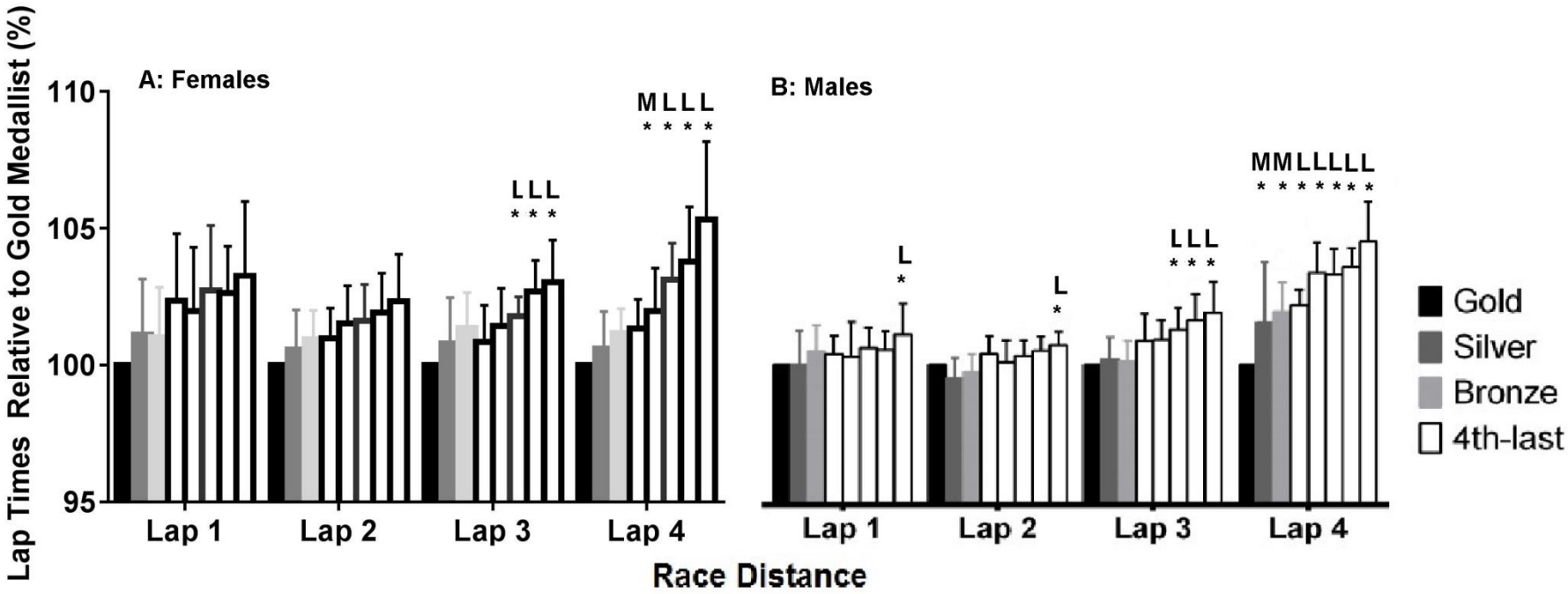


Figure 6.2: Lap times relative to the gold medallist for each lap in A: Female 400 m swimming and B: Male 400 m swimming. *Significantly slower than the gold medallist. T = trivial effect, M = moderate effect, L = large effect size.

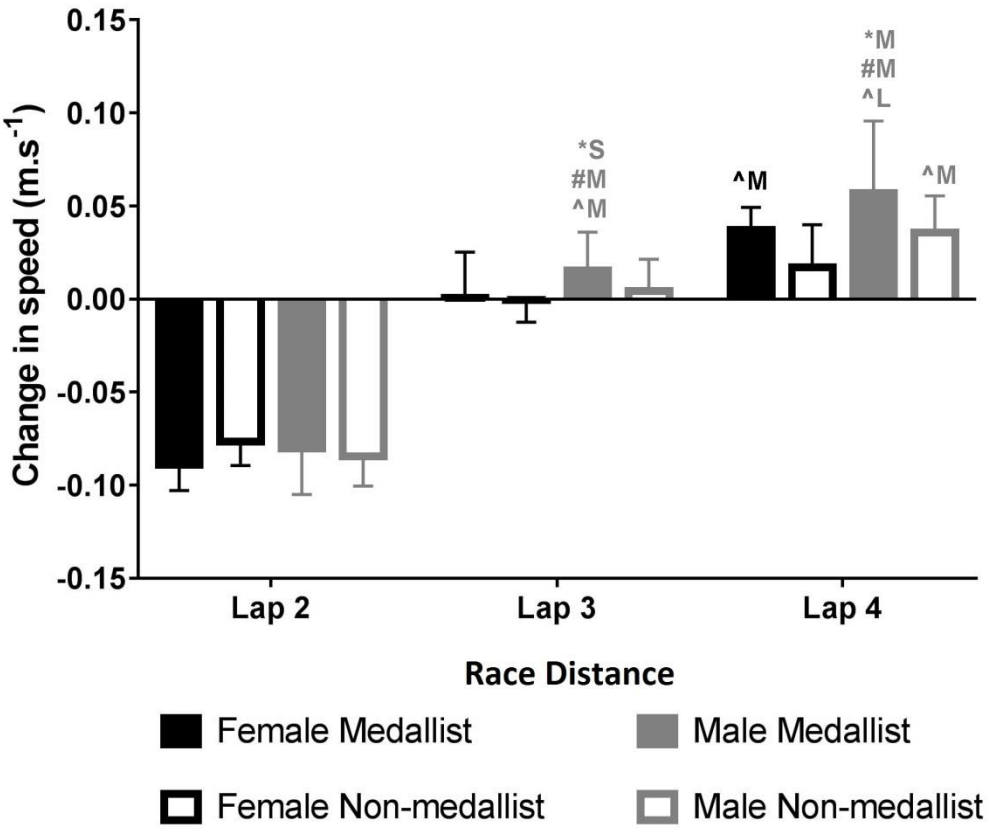


Figure 6.3: Changes in speed from the previous lap in male and female medallists and non-medallists. *Significantly greater pace change than female medallists, # significantly greater pace change than male non-medallists, ^significantly greater pace change than female non-medallists. S = small effect size, M = moderate effect size.

to produce a greater end-spurt than their female medallist counterparts and the same pattern was seen in the male and female non-medallists.

When analysing lap times relative to the gold medallists, female gold medallists showed a significantly faster pace than only three of their opponents compared to male gold medallists who were significantly faster than all of their opponents in the

final lap. There were also differences between sexes in the rate of pace change with male medallists showing an earlier and greater end-spurt than all other groups. The effect of these differences was the reduced end-spurt profile observed in female medallists. Females may not have felt the need to increase their speed as much at the end in order to win the race. One explanation supporting this theory may be in the intensity of the competition. For example, the winning margin from gold to silver in these data is more than twice as large in females (1.82s) compared to males (0.74s) potentially meaning that the closeness in positions towards the end of male races may drive additional increases in speed in the final stages by the winners. This idea is further supported with the finding that at the 300-m stage, female gold medallists had already built up 80% of their winning margin compared to the second placed swimmer, whereas males had only built up 31% of this same margin and relied on the final 100 m for the majority of their winning margin. Foster *et al.* (2014) proposed a similar idea following an analysis of world record times in the 1-mile running race which they suggest showed increased competition in male running compared to female running. Mauger *et al.* (2012) do not agree with this however, and suggest that because the women's world record for 400 m freestyle has been reduced six times between 2003 and 2010 and then twice more in 2014 where the record was broken twice in 2 weeks by the same athlete, the women's field is currently more competitive than the men's field where the record has only been broken once in this period. A second explanation is that females are either over confident early on and run out of physiological reserves by the end of the race, or that they do not have the same confidence as men to go slower early on and so do not have the physiological reserves required at the end of the race.

In order to test these scenarios, data from the last two world record performances for men and women in the 400 m freestyle were analysed, a world record being the ultimate in successful performances to compare against. The data (shown in figure 6.4) suggested that the intensity of competition may affect pacing patterns because the relative pace of the two female world record performances are faster in lap two and slower in lap four than both of the male world record performances. In other words, males have either chosen to, or have had to, swim at a greater speed in the final lap when setting a world record compared to women. Further research is needed to determine if the men and women pace differently due to differences in competition intensity.

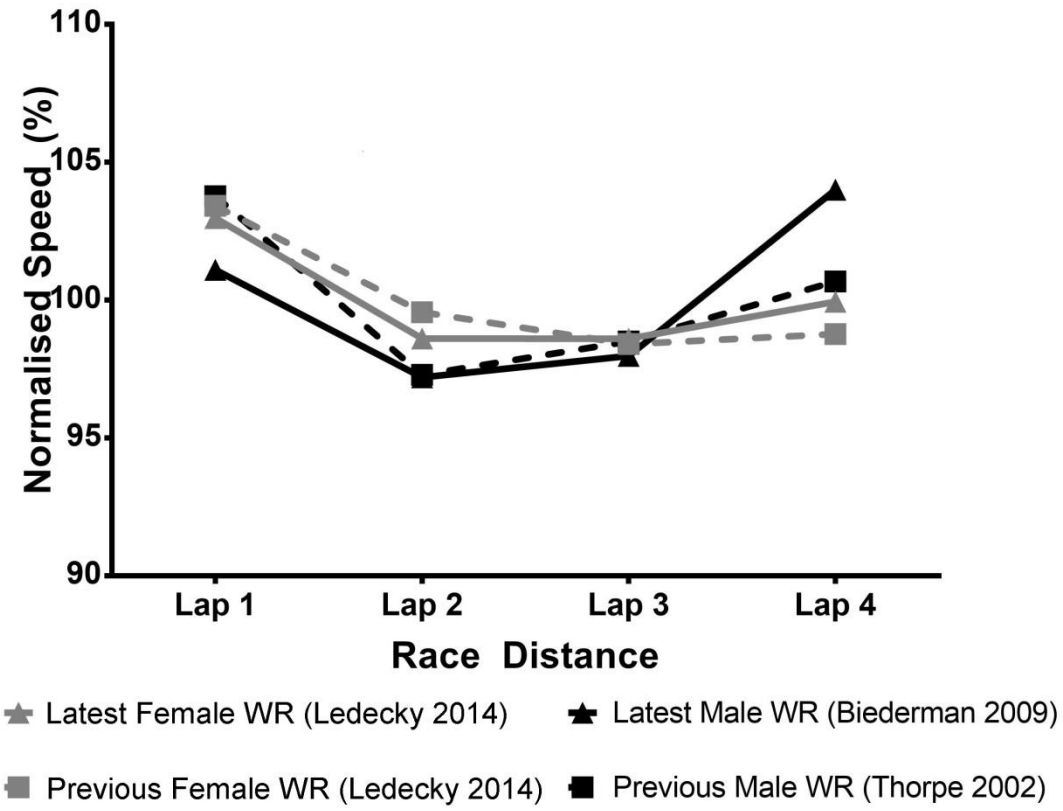


Figure 6.4: Recent male and female world record pacing patterns in 400 m swimming.

From a physiological standpoint, lower end-spurts may be a result of the reduced anaerobic power available to women because of the 25-28% reduction in the anaerobic enzymes PFK and LDH compared to men (Jaworowski *et al.* 2002) and the potential that this has to increase fatigue during maximal exercise of short duration (Lambert *et al.* 2013). An increase in swim speed towards the end of a 400 m race would significantly tax the anaerobic system and as such could explain lower end-spurts in women. Other physiological reasons for gender differences in pacing may be a result of the differences in central and peripheral fatigue mechanisms. In a very long event (over two h of cycling with interspersed sprints) it has been reported that males showed signs of both central and peripheral fatigue but women only signs of central fatigue (Glace *et al.* 2013). It was proposed that differences in ischemia related mechanisms, due to a larger muscle mass and a higher relative workload, may have been the cause of peripheral fatigue in men. In our study it may be that men were able to show a greater increase in pace in laps three and four compared to women because they were able to develop peripheral as well as central fatigue using up more of their physiological resources in the process. Some caution must be taken however, when interpreting the findings of Glace *et al.* (2013), due to the differences in exercise modality and intensity between a two h bike ride with intermittent sprints and a four min swim.

It has been reported that male and female swimmers follow the same pacing pattern in 100 m, 200 m and 400 m freestyle finals (Robertson *et al.* 2009) and in 100 m and 200 m breaststroke finals (Thompson *et al.* 2000). This was a different pattern to the data in this chapter which were the first to separate medal winning swims from the rest of the field, and so further investigation into gender differences in competitive

pacing and the mechanisms for it is needed. It is clear that future studies should continue to separate successful medal winning performances from the rest of the field to ensure that athletes and coaches can plan to win and that there should be an attempt to separate physiological from tactical effects.

In summary, female swimmers in the 400 m freestyle final demonstrate a pacing pattern that has a less intense end-spurt during the final stages of the race than their male counterparts. They also have greater between-athlete differences in speed in the earlier stages of the race. It is therefore, not appropriate to use data from male races to support the development of pacing strategies for female athletes in elite swimming. Further to this, the findings of this chapter open the possibility that pacing patterns may be specific to other independent factors such as age and ability level. An evaluation of elite athlete pacing patterns can be helpful to all swimmers and their coaches in preparing for an event. It is not clear whether or not developing swimmers should follow similar pacing patterns to those shown by elite swimmers, and therefore, it is not known what strategies should be employed and what expectations swimmers and coaches should have of developing athletes. The next chapter will investigate male and female pacing patterns in developing swimmers in the 400 m freestyle event in order to support the development of these athletes into the elite athletes that they are training to be.

Chapter 7: The pacing patterns of male and female development athletes in 400 m freestyle swimming

7.1: Introduction

There were approximately 61,000 swimmers registered to compete in ASA competitions in 2015, and of these approximately 49,000 were under 18 and 4,500 were 18-24 (Langham 2015). Chapters five and six identified that male and female medallists and non-medallists show different pacing patterns during high level competitive 400 m freestyle finals, however it is not clear if these same patterns are employed during races involving male and female developing athletes.

The ability to pace during a race in order to avoid early fatigue whilst finishing in the fastest time possible involves an interaction of factors including physiological capacity, the event itself (including distance, level of competition and environment) and psychological factors such as previous experience and motivation of the athlete (Faulkner *et al.* 2008). All of these factors will be in development during adolescence and mean that pacing patterns seen in elite athletes may be different in developing athletes. Micklewright *et al.* (2012) demonstrated that pacing patterns can be influenced by age and intellectual development in running by comparing the performances of children aged 5 – 14 y. Previous reports that a child's ability to perceive exertion improved as they move through Piaget's scale of intellectual development (Groslambert & Mahon 2006) appeared to be demonstrated during running performances because pacing patterns became more parabolic with age (Micklewright *et al.* 2012). From pre-operational (4 - 7 y), through concrete

operational (8 – 12 y), to formal intelligence periods (13 – 18 y) children changed their pacing patterns from a fast start negative pattern in the youngest age group to the u-shaped parabolic pattern in the oldest age group mirroring the pattern reported in elite adult runners and swimmers in chapters five and six. It was suggested that children learn their performance template early in their development (Micklewright *et al.* 2012) although the links to RPE, which may be important in an adults' performance template (Foster *et al.* 2009), were not made. It would be beneficial to investigate how pacing patterns in swimmers change as their cognitive ability develops, allowing the athletes to make more complex decision about pace before and during a swimming event.

Tucker (2009) emphasised the link between RPE and an anticipatory control of exercise intensity to ensure that total fatigue is not reached before the end of an event. The rate of RPE change has been shown to differ between glycogen depleted (faster RPE increase) and loaded states (slower RPE increase) but not the initial or final values in a fixed workload cycle to exhaustion (Baldwin *et al.* 2003), although this study was not able rule out other factors that could affect performance and pacing such as motivation to exercise because subjects were not incentivised to perform. In addition, changes to pacing in other parameters such as heat, hypoxia and diet are closely matched with changes in the rate of increase of RPE suggesting that this is an anticipatory factor based on the state of the body and the exercise environment when selecting exercise intensities during a self-paced bout (Tucker 2009). Much like motor skills, performance templates can be learned and developed in adults undertaking novel exercises (Foster *et al.* 2009), although it is not clear if

children have the same ability to learn these more optimal templates (Lambrick *et al.* 2013).

A performance template will also be affected by a swimmers' physiological ability which will develop over time. Even in the relatively short time period of 10-12 weeks, physiological changes due to swim training have been shown in $\dot{V}O_2max$ and $\dot{V}_E$ (Magel *et al.* 1975), vital capacity and total lung capacity (Clanton *et al.* 1987), as well as increases in muscle glycogen stores, metabolic enzymes (for example succinate dehydrogenase), muscle fibre capilliarisation and blood plasma volume in other aerobic training modalities (Wilmore *et al.* 2008), where similar results could also be expected from swim training. The changes reported above can be hard to measure over a long period of time however, it can be accepted that young swimmers would continue to develop physiologically during years of training as shown by case study data of 14-16 y old swimmers who had trained for at least six years and who had greater than average lung volumes and $\dot{V}O_2max$ and lower than average body fat percentage (Vaccaro *et al.* 1980).

In addition to these training effects, the process of maturation will improve physiological parameters such as muscle size, muscle strength and anaerobic fitness (Rowland 2005). Children develop an increased anaerobic capacity as they age because of additional muscle size, glycolytic enzymes (Ratel *et al.* 2010) and the increased ability to fully utilise type II muscle fibres (Dotan 2010). These changes appear to be greater in boys, who have shown enhanced anaerobic performance, muscle size and muscle strength compared to girls from as young as 10 y old. These differences may be attributable to differences in fat mass and muscle mass

development due to higher levels of circulating testosterone in boys (Van Praagh 2000). Aerobic performance is also enhanced in boys, measured as a higher relative $\dot{V}O_2$peak compared to girls of the same age, and can be attributed to greater muscle mass and greater blood haemoglobin concentration in boys (Armstrong & Fawkner 2007). These physiological changes can be brought about through both training and maturation, a process which can occur at different ages and speeds between and within boys and girls (Baxter-Jones & Sherar 2007), and will further affect the pacing patterns shown in swimmers at different stages of their development.

Successful pacing strategies take time to develop even in adults, and so given the development of the physiological and psychological factors in young athletes outlined above it is important to investigate the pacing patterns of young swimmers to assess the changes in pacing patterns with age. This will ensure that the pacing patterns shown to be successful in adults are not forced upon developing athletes, and help these same athletes to develop their pacing experience in a way suitable for their stage of development. This chapter aims to investigate how pacing patterns in successful young swimmers change with age.

7.2: Method

7.2.1: Data Sources

Lap data from the finalists of the 400 m freestyle (or declared winners results if no finals were held) from all Youth Championships and Age Group Championships events organised by the ASA in 2014. Age Group Championships are for swimmers

aged 10 to 14 and Youth Championships are for any swimmer aged 15-21 and are held by all seven regions separately. Developmental swimmers compete in these annual galas based on the ASA's regional structures in England (Table 7.1). Each region is required to license their Age Group and Youth Championship galas on dates set by the ASA. All 14 events were held in a 50 m pool with facility standards as described by FINA (2009) and used automatic timing boards and anti-turbulence lane ropes according to the ASA licensing criteria (Amateur Swimming Association 2015).

Regional competitions separate events by age so that typically 10 y, 11 y, 12 y, 13 y, and 14 y compete in age specific events in the Age Group Championship galas but 15-16 y and 17-21 y combine to compete in the Youth Championship galas. When the number of entries were too high or too low to allow for this breakdown, regions can alter this age group separation which occurred in London where 10-11 y olds combined, North East where 15+ y combined, North West where 10-12 y olds combined, and the South West where 10-11 y olds combined but 15 and 16 y olds competed separately. For the purpose of consistency across regions, participants were grouped by age in 2 y intervals forming groups of 10-12 y, 13-14 y, 15-16 y and finally a wider age group of 17-21 y due to the small number of entries in this age group. This type of age grouping has been done before in swimming research for similar comparative reasons (Zingg *et al.* 2014). In addition, a comparison between pacing in age groups associated with the Piagetian groups of concrete operational (CON; 10-12 y) and formative intelligence (FOR; 13-18 y) was carried out. Table 7.1 contains the source for each ASA region gala results which include lap times from each event at both the Youth and Age Group Championships.

Due to technical problems with the automatic timing systems at the non-starting end of the pool, 50 m split times were not available for eight Age Group and eight Youth Championships races. In a small number of races (n=9) there was not a full line up of eight finalists competing in the 400 m freestyle event. In addition, there were four individual swimmers' records that had one or more 50 m split time missing and so these were excluded from analysis because lap speeds and changes in lap speeds could not be fully calculated.

Table 7.1: Source information for regional gala results.

Region	2014 Age Group Championships source	2014 Youth Championships source
East	http://eastswimming.org.uk/swimresults/2014/Bagcats/index.htm	http://eastswimming.org.uk/swimresults/2014/Youth/index.htm
North-East	http://asaner.org.uk/results/2014results/agegroup/index.htm	http://www.asaner.org.uk/results/2014results/youths/index.htm
North-West	http://www.swimnorthwest.org/doc/2014%20age%20groups/webpages/	http://www.swimnorthwest.org/doc/2014%20youth/webpages/
South-East	http://www.swimmeets.org/calendar/showevent.php?id=33	http://www.swimmeets.org/calendar/showevent.php?id=32
South-West	http://www.swimwest.org.uk/results/2014/Bagcats/	http://www.swimwest.org.uk/results/2014/Youth/
Midlands	http://www.midlandchampionships.org.uk/results/ag14/index.php	http://www.midlandchampionships.org.uk/results/yc14/index.php
London	http://www.londonswimming-results1.org/asalondon/LBMeet14/webpages/index.htm	http://www.londonswimming-results1.org/asalondon/LYMeet14/webpages/index.htm

7.2.2: Participants

Taking into account the information provided above, 50 m split times for the 400 m freestyle final were collected from 295 participants from 40 events. Table 7.2 shows the total participants by sex and age from the seven regions.

Table 7.2: Participants included in the study by sex and age group

Sex	**10 -12 y**	**13–14 y**	**15-16 y**	**17-21**
Male (n)	47	48	36	33
Female (n)	39	32	35	25

7.2.3: Data analysis

All statistical tests were carried out using IBM SPSS Statistics v.22. Lap velocity was normally distributed with skewness and kurtosis of each lap between 0.5 and -1.0 for all laps (George & Mallery 2010). A 4-way (lap x age x gender x performance) factorial ANOVA with repeated measures on lap was employed to analyse differences in normalised lap velocity. The performance categories were medallists and non-medallists and the age categories were 10-12 y, 13-14 y, 15-16 y, 17-21 y. Where an interaction or main effect was found, further analysis followed using an appropriate factorial or one-way ANOVA and LSD post hoc tests with the exception of the main effects for sex and performance where independent t-tests were used to look for the differences between two groups. A Cohen's *d* effect size was calculated for all significant differences (using the same categories shown in section 4.2.2). A 2-way ANOVA with repeated measures on lap was carried out using Piaget's age groupings of CON (10-12 y; n = 86) and FOR (13-18 y; n = 209) with post hoc independent t-tests by lap as above. Significance was set at p = 0.05.

7.3: Results

Table 7.3: 4-way ANVOA results table

Effect	**F**	**Hypothesis df**	**Error df**	**p**
Lap x Age x Sex x Performance	0.874	21	784	0.625
Lap x Sex x Performance	0.283	7	273	0.960
Lap x Age x Performance	1.254	21	784	0.198
Lap x Age x Sex	1.600	21	784	0.043
Lap x Performance	3.623	7	273	0.001
Lap x Sex	3.581	7	273	0.001
Lap x Age	3.177	21	784	< 0.001
Lap	1336.74	7	273	< 0.001
Age	6.736	3	-	< 0.001
Sex	12.961	1	-	< 0.001
Performance	17.157	1	-	< 0.001

7.3.1: Age

A significant lap x age effect was found and post hoc LSD tests reported that pacing patterns in 10-12 y were different to 15-16 y (p=0.00) and 17-21 y (p=0.005) groups. In addition, pacing patterns in 13-14 y were significantly different to 15-16 y (p=0.005). A series of eight one-way ANOVAs (one for each lap) and post hoc LSD tests were able to isolate the differences between age groups and these are shown in table 7.4 and figure 7.1 displays these graphically.

Table 7.4: P value reporting of age group comparisons (with effect size where a significant difference was found)

Lap 1 ANOVA F = 6.371, df = 3, p < 0.001

	10-12 y	13-14 y	15-16 y	17-21 y
10-12 y		0.061	**<0.001 (0.680)**	**0.036 (0.348)**
13-14 y			**0.013 (0.396)**	0.705
15-16 y				0.055
17-21 y				

Lap 2 ANOVA F = 0.917, df = 3, p = 0.433

	10-12 y	13-14 y	15-16 y	17-21 y
10-12 y		0.366	0.210	0.131
13-14 y			0.710	0.498
15-16 y				0.751
17-21 y				

Lap 3 ANOVA F = 1.888, df = 3, p = 0.132

	10-12 y	13-14 y	15-16 y	17-21 y
10-12 y		0.337	0.214	**0.019 (0.399)**
13-14 y			0.758	0.146
15-16 y				0.257
17-21 y				

Lap 4 ANOVA F = 5.052, df = 3, p = 0.002

	10-12 y	13-14 y	15-16 y	17-21 y
10-12 y		0.213	**0.033 (0.336)**	**0.050 (0.328)**
13-14 y			**0.001 (0.526)**	**0.002 (0.519)**
15-16 y				0.964
17-21 y				

Lap 5 ANOVA F = 6.363, df = 3, p < 0.001

	10-12 y	13-14 y	15-16 y	17-21 y
10-12 y		**0.035 (0.321)**	**<0.001 (0.553)**	**<0.001 (0.630)**
13-14 y			0.144	0.066
15-16 y				0.654
17-21 y				

Lap 6 ANOVA F = 3.383, df = 3, p = 0.019

	10-12 y	13-14 y	15-16 y	17-21 y
10-12 y		0.945	**0.005 (0.446)**	0.221
13-14 y			**0.007 (0.436)**	0.253
15-16 y				0.170
17-21 y				

Lap 7 ANOVA F = 0.617, df = 3, p = 0.605

	10-12 y	13-14 y	15-16 y	17-21 y
10-12 y		0.818	0.485	0.331
13-14 y			0.366	0.244
15-16 y				0.763
17-21 y				

Lap 8 ANOVA F = 4.494, df = 3, p = 0.004

	10-12 y	13-14 y	15-16 y	17-21 y
10-12 y		0.765	0.067	**0.001 (0.550)**
13-14 y			0.128	**0.003 (0.505)**
15-16 y				0.135
17-21 y				

Significant differences are shown in bold

A 2-way ANOVA identified a lap x age interaction ($F = 5.95$, $df = 7$, $p < 0.001$) when the participants were separated into CON and FOR groupings. Participants in CON started the race relatively faster with a normalised speed of 111.3% vs. 110.3% ($t = 3.468$, $df = 293$, $p = 0.001$, $d = 0.436$ small), slowed down more mid-race in lap five (97.4% vs. 98.0%, $t = -3.88$, $df = 293$, $p = 0.001$, $d = 0.486$ small) and sped up more in the final 50 m of the race (102.4% vs. 101.7%, $t = 2.11$, $df = 293$, $p = 0.036$, $d = 0.269$ small) compared to swimmers in FOR. These results are shown in figure 7.2.

7.3.2: Age and sex

There was a significant lap x age x sex interaction and a series of 2-way ANOVAs (age x sex) with LSD analysis for each lap revealed that the interaction was found in laps two, three and eight between boys and girls in different age groups as shown in table 7.5. Figure 7.3 shows these differences and highlights that the greater end spurt seen in male swimmers is a result of speed increases in males in the two younger age groups. When sex and age were analysed using Piaget's age group categories, no interaction was seen ($F = 0.131$, $df = 7$, $p = 0.243$).

A significant main effect for sex was found with differences between males and females identified. Post hoc t-tests showed that males were relatively faster in the final 50 m compared to females ($t = 3.25$, $df = 293$, $p = 0.001$, $d = 0.375$ small) and females tended to be relatively faster in the preceding 300 m to 350 m section ($t = -1.94$, $df = 293$, $p = 0.054$, $d = 0.228$ small). These differences can be seen in figure 7.4. There were no differences in other sections of the race.

Table 7.5: Post hoc analysis of the lap x age x sex interaction including 2-way ANOVAs for the age x sex interaction by lap and LSD results for all comparisons with effect sizes where appropriate.

Lap					
1		F = 0.860	df = 3	p = 0.462	
2		**F = 2.958**	**df = 3**	**p = 0.033**	
	Lap 2 LSD	Male 10-12 y	Male 13-14 y	Male 15-16 y	Male 17-21 y
	Female 10-12 y	**0.013 (0.553)**			
	Female 13-14 y		0.241		
	Female 15-16 y			0.953	
	Female 17-21 y				0.104
3		**F = 3.460**	**df = 3**	**p = 0.017**	
	Lap 3 LSD	Male 10-12 y	Male 13-14 y	Male 15-16 y	Male 17-21 y
	Female 10-12 y	0.393			
	Female 13-14 y		0.177		
	Female 15-16 y			**0.022 (0.539)**	
	Female 17-21 y				**0.037 (0.548)**
4		F = 1.026	df = 3	p = 0.381	
5		F = 1.387	df = 3	p = 0.247	
6		F = 0.830	df = 3	p = 0.478	
7		F = 0.295	df = 3	p = 0.829	
8		**F = 2.890**	**df = 3**	**p = 0.036**	
	Lap 8 LSD	Male 10-12 y	Male 13-14 y	Male 15-16 y	Male 17-21 y
	Female 10-12 y	0.064			
	Female 13-14 y		**<0.001 (0.776)**		
	Female 15-16 y			0.095	
	Female 17-21 y				0.408

Significant differences in bold.

7.3.3: Performance

A significant main effect for performance was found and post hoc t-tests showed that medallists had a relatively slower normalised speed than non-medallists in the first 50 m ($t = -4.97$, $df = 293$, $p < 0.001$, $d = 0.568$ small) which may be because the dive start section of the race (the first 15-m) lowers the speed differential between the two groups and/or because of the pacing pattern employed. Medallists showed a relatively faster speed than non-medallists between 300-m to 350 m ($t = 2.03$, $df = 293$, $p = 0.043$, $d = 0.239$ small) but not in any other part of the race which is particularly unexpected in the final 50 m ($t = 1.281$, $df = 293$, $p = 0.201$) of the race (see figure 7.5). There was no performance x age interaction when separated into the four age group categories ($F = 1.25$, $df = 21$, $p = 0.198$) or into Piaget's two age groups ($F = 1.36$, $df = 7$, $p = 0.220$).

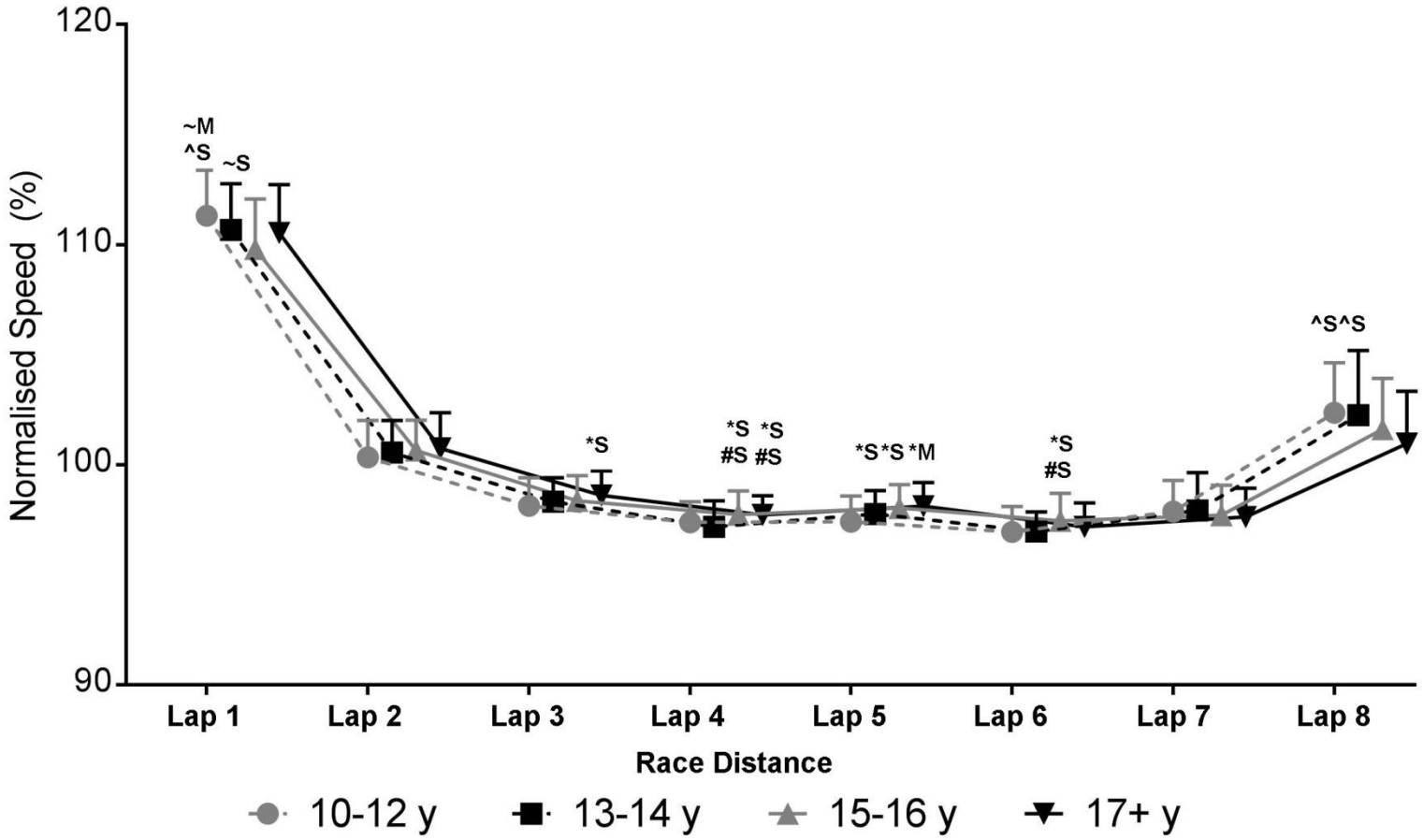


Figure 7.1: Pacing pattern of four age group categories. *Significantly faster than 10-12 y, # significantly faster than 13-14 y, ~ significantly faster than 15-16 y, ^significantly faster than 17+ y. S = small effect size, M = moderate effect size. Data points offset for clarity.

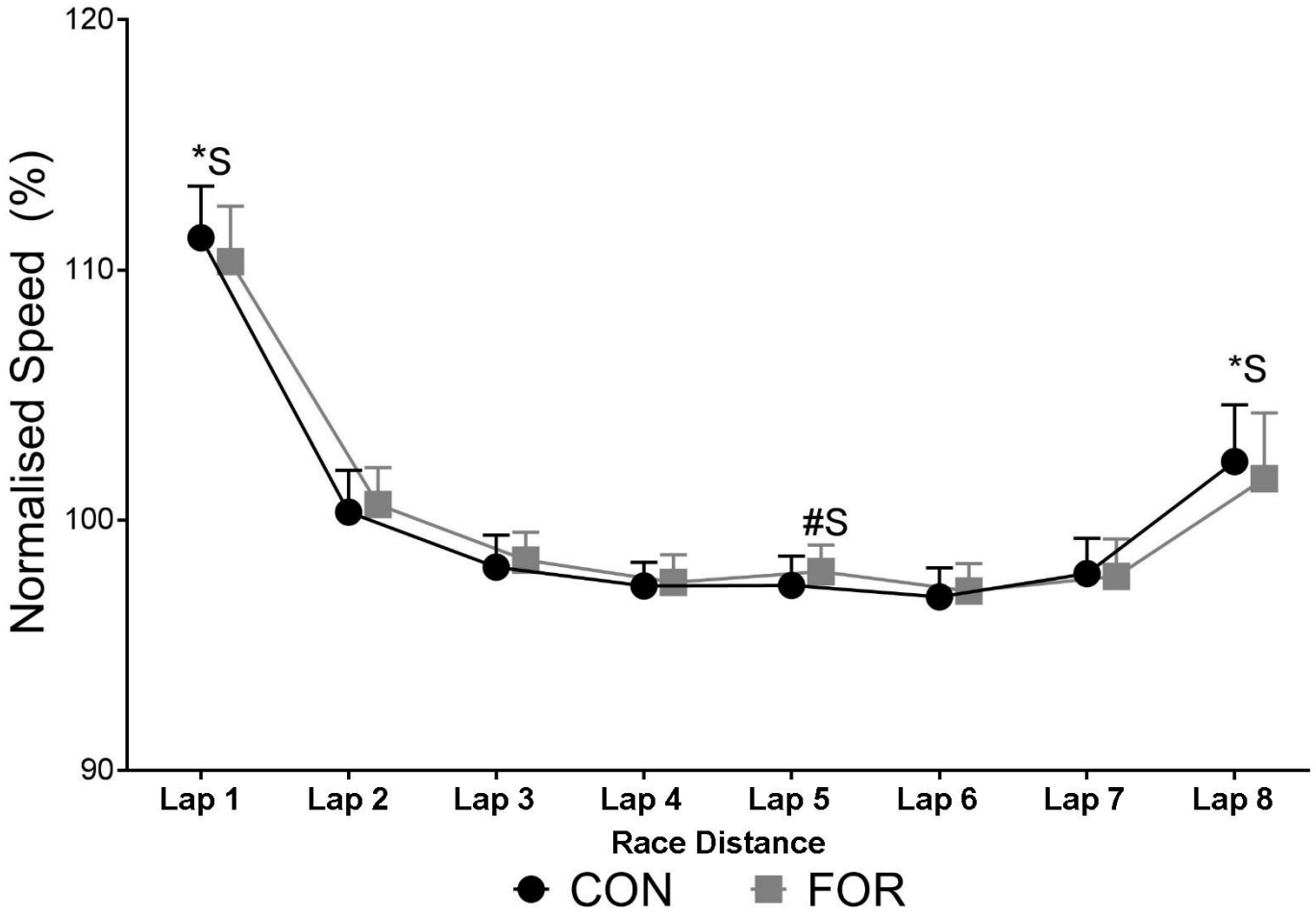


Figure 7.2: Pacing patterns of swimmers in concrete operational (CON) and formal intelligence (FOR) groups. *CON group significantly faster relative speed. # FOR group significantly faster relative speed. S = small effect size. Data points offset for clarity.

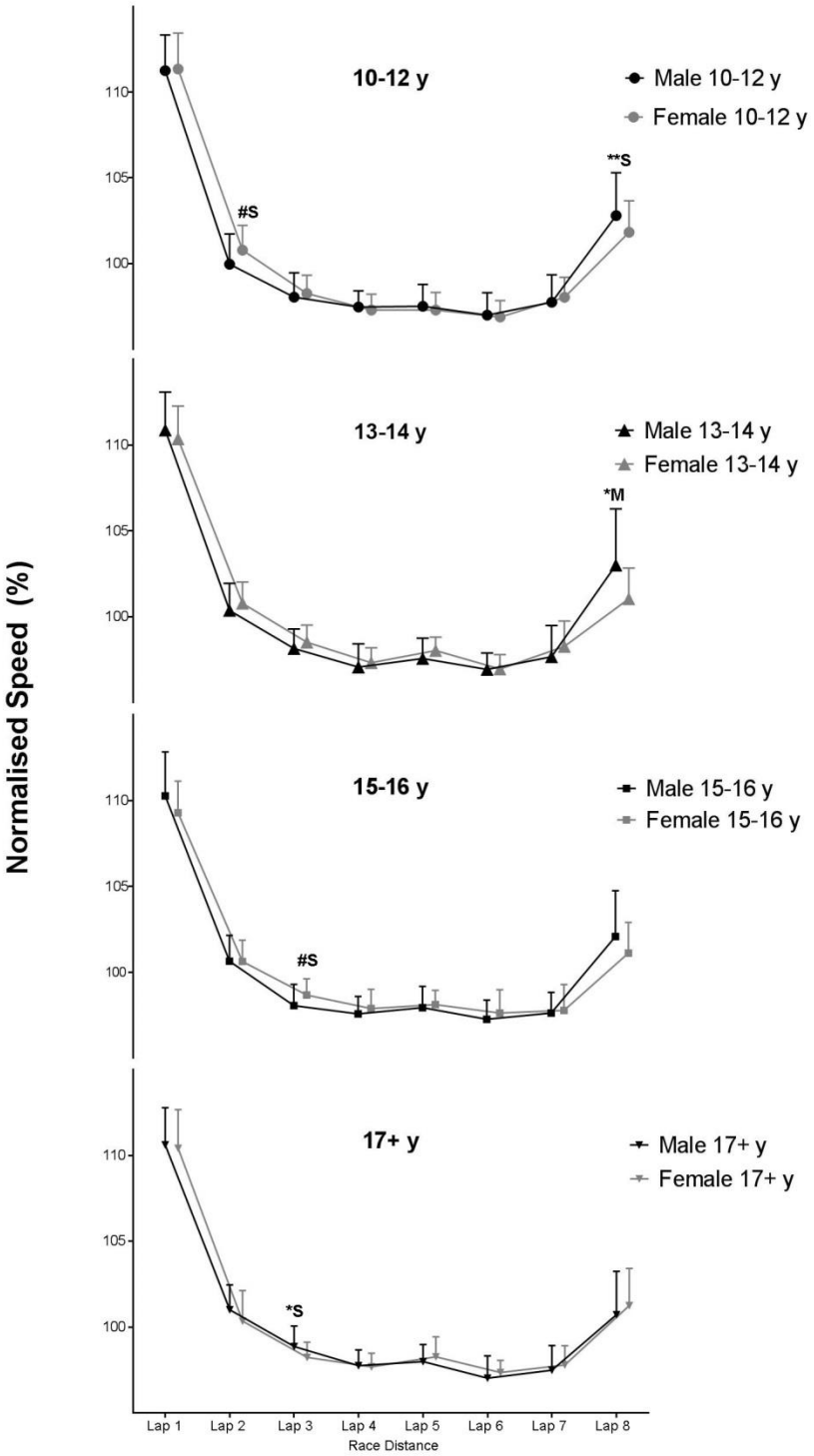


Figure 7.3: Pacing pattern of males and females by age group. *males significantly faster than females; # females significantly faster than males; **trend for males to be faster than females. S = small effect size, M = moderate effect size. Data points offset for clarity.

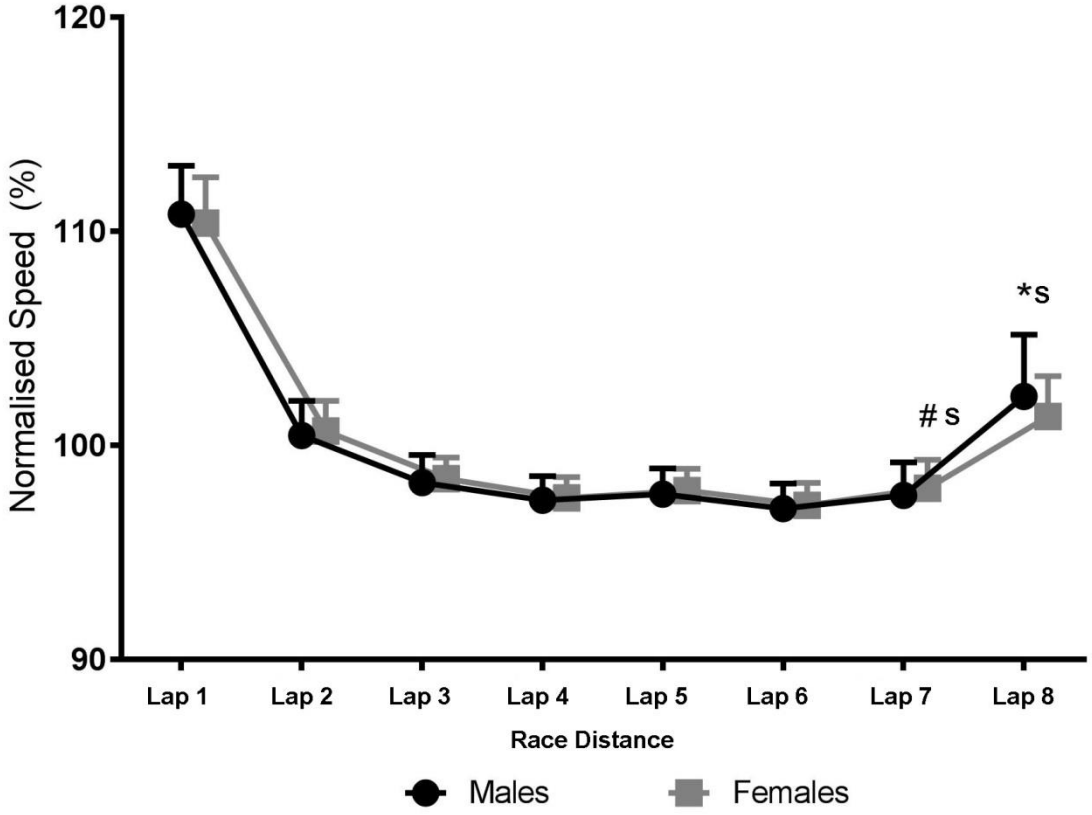


Figure 7.4: Pacing patterns of males and females – all age groups. * males significantly faster than females; # trend for females to be faster than males. S = small effect size. Data points offset for clarity.

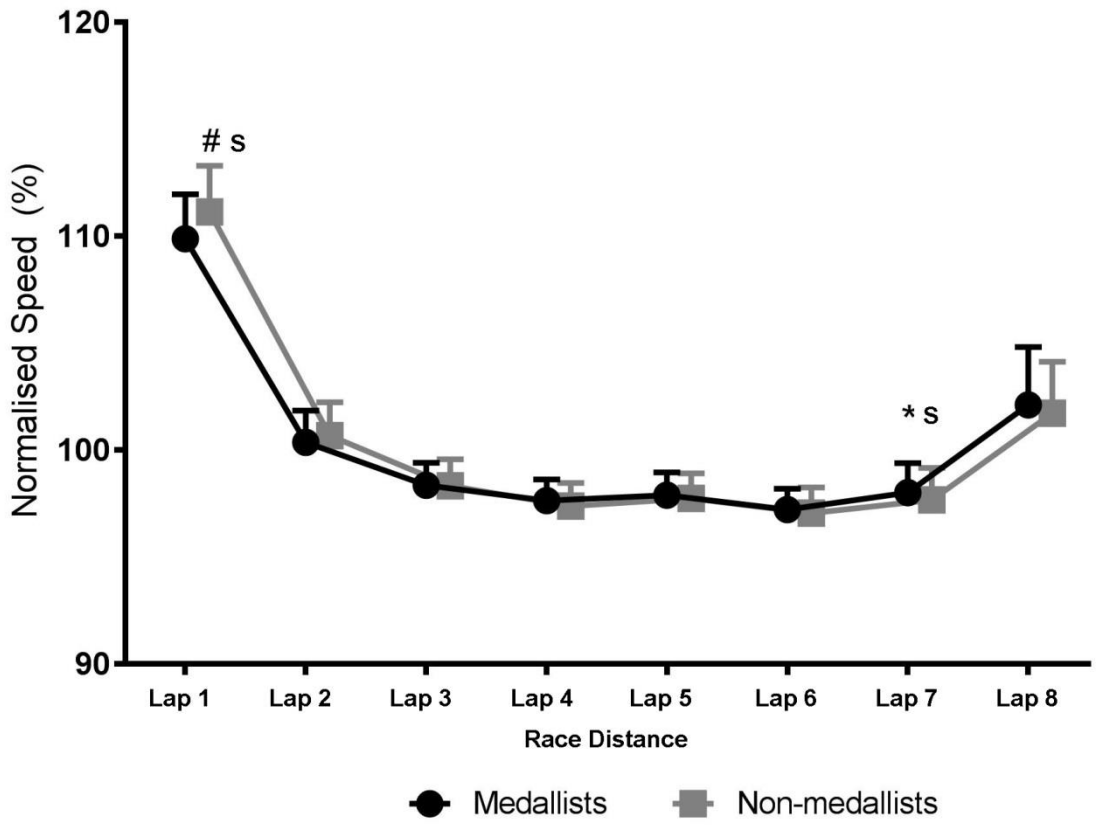


Figure 7.5: Pacing patterns of medallists and non-medallists – all age groups. [#]*non-medallists significantly faster; *medallists significantly faster.* M = moderate effect size; S = small effect size. Data points offset for clarity.

7.4: Discussion

The aim of this chapter was to determine age differences in pacing patterns. The analysis suggests that 10-12 y old swimmers set out faster, slow down more mid-race and then speed up more at the end of the race than 15+ y old swimmers. 13-14 y old swimmers also set out faster and slow down more then 15+ y olds. When the participants were separated into Piaget's groups the same pattern was also seen with CON swimmers swimming faster in the first and last laps and slower in the middle of the race compared to swimmers in the FOR group. In the CON group children can relate an element to its neighbouring element (Goswami 2008), and in this chapter it can be seen that these individuals adopt a U-shaped pacing pattern by slowing down or speeding up relative to the previous lap, possibly depending on their perceived exertion. This would reinforce the link between perceived exertion and pacing (Tucker 2009) and although widespread debate about the best method to capture this exertion rating in children exists within the literature (Groslambert & Mahon 2006, Eston & Parfitt 2007) it is probable that children develop the ability to perceive effort by the concrete operational years (Groslambert & Mahon 2006).

The greater end-spurt seen in the younger swimmers is physiologically surprising because these athletes almost certainly have a reduced anaerobic capacity (Van Praagh 2000, Armstrong & Fawkner 2007, Ratel *et al.* 2010) and lower recruitment of type II muscle fibres (Dotan 2010) than older swimmers. At the end of a 400 m race, an increase in pace would tax anaerobic energy systems and so where these capabilities are fully utilised, it should be the older swimmers that show the greatest end-spurt. This would suggest that the physiological mechanisms behind pacing

patterns in swimming may be masked by sub-optimal choices made about pace by younger swimmers as they develop their own performance template.

This ability to recognise fatigue and then try to pace accordingly in 10-12 y olds in the current study was seen in children in a 4-min running task where a slower start and faster finish was characteristic of children 9 y old or less and who were in the concrete operational group (Micklewright *et al.* 2012) and in a 4-min, 800-m TT in 9-11 y olds (Lambrick *et al.* 2013). The FOR group in this study (13+ y old) produced a significantly flatter U-shaped pacing pattern compared to the younger swimmers with a slower start and end and faster middle of the race. This group may have used their additional increased awareness of RPE and fatigue (Groslambert & Mahon 2006) and/or their learned RPE templates (Foster *et al.* 2009) to better reproduce the successful parabolic pacing patterns. As these parabolic patterns are more successful (as was shown in chapters five and six), swimmers in the FOR group may have learned from watching elite swimmers and/or learning from their own performances. Whilst it is not certain that all children develop optimal pacing patterns over subsequent performances, the young swimmers in this chapter will have probably been competing regularly for a number of years and as such are not novices trying to learn a new task in a short space of time like the participants in Lambrick *et al.* (2013), but will have had the benefit of multiple performances to reflect on and high quality coaching input to support their development.

An interesting note is that the younger participants in both the current study and in Micklewright *et al.* (2012) started off at a higher pace, however the younger swimmers in the current study produced a larger end-spurt than older swimmers

because they slowed down more mid-race compared to younger runners in Micklewright's study where the end-spurt was much less pronounced than in older runners. This could be because the runners in Micklewright *et al.* (2012) performed their race in isolation compared to the swimmers who were competing in the final of gala event with seven fellow swimmers. In addition, Micklewright *et al.* (2012) specifically chose a novel situation in which to test their participants (a 150 m running track), compared to the current chapter where it was not possible that swimmers were in a novel situation because they have to record a qualifying time to enter the competition, quite apart from the normal convention of swimming development that sees regular competitive galas take place throughout the year. The novel situation the young runners found themselves in would have meant that they had no template (for RPE, power output or some other factor) with which to base their performance on. The young swimmers in the present study on the other hand, would be expected to have a performance template, and therefore they used this to good effect to slow down mid-race allowing for a U-shaped pacing pattern to be deployed.

A consistent feature of data collected in this chapter was a relatively faster 200 m to 250 m section of the race followed by a slower 250 m to 300-m section, creating a fast-slow-fast-slow-fast pattern, or W-shaped pacing. In the FOR group, the increase in relative pace at this stage was significantly greater than in the CON group. This pattern can also be seen in males and females (figure 7.4) and medallists and non-medallists (figure 7.5). A small increase in pace in the 200 m to 250m section of a 400 m swimming trial was also noticeable in Skorski *et al.* (2014a) in junior swimmers when pace was self-selected or a slow start was enforced. The increase in

relative pace of approximately 3% during this section of the race, based on data in the current chapter, led to an improvement in overall time by an average of 1.05s. A W-shaped pacing pattern has not been discussed previously in the literature and is an emerging notion from this chapter that requires further investigation in the pacing of 400 m swimming.

A limitation in the analysis of these data are the differing rates of maturation that can be seen in children. Pre-pubertal children do not show sex differences in stature and body mass but these parameters start to change at around 12 y for girls and 14 y old for boys using PHV as an indicator of maturation (Beunen & Malina 2008) and include differences in lean body mass and muscle mass. The increased cost of exercise with additional fat mass seen in adolescent girls may be less detrimental to performance in swimming than in other sports due to buoyancy effects which raise more of a swimmers surface area out of the water. Nevertheless, this and other physiological changes, such as increased $\dot{V}O_2$peak, greater left ventricular mass (Janz & Mahoney 1997) and greater muscular strength increases (Buchanan & Vardaxis 2009, Boyd & Bee 2010) will affect swimming performance. The participants in this study were separated by biological age and not using physiological/anthropometric markers or cognitive markers such as the Piagetian conservation tasks used in Micklewright *et al.* (2012). Given the large variation in the onset of puberty and of PHV in young people (Granados *et al.* 2014), the creation of age groups based solely on chronological age may mask some of the pacing differences that may be found if swimmers were categorised based on a measurable physiological or psychological parameters. Further the attainment of PHV in girls is, on average, two years ahead of males (Beunen & Malina 2008) which may mask or

confound sex differences in pacing patterns. A study design that is able to isolate one of physical maturation, cognitive development or training adaptations, would ideally be developed to investigate pacing in developing swimmers in the future.

A further limitation to the practical application of pacing patterns seen in this chapter arises from the use of a single annual performance. Firstly, most developing swimmers compete multiple times at each gala and so the scheduling of the 400 m freestyle race may have an impact on the pacing patterns seen if, for example, the race follows a series of earlier swims by an individual on the same day or on preceding days. Secondly, all swimmers, including developing swimmers, compete regularly throughout a season which will have training peaks and troughs designed to minimise accumulated fatigue and maximise performance at selected races. If, during higher training loads with greater accumulated fatigue, performance is affected (Turner 2011), it would follow that pacing patterns may also be affected and therefore it would be beneficial to follow swimmers over a longer period of time to analyse multiple performances.

Boys had an increased end-spurt compared to girls as also seen in senior swimmers in chapter six and suggests that this pattern of pacing is a feature of male and female differences in all competitive swimming. However, it was surprising that when the swimmers were categorised into one of four age groups, this increased end-spurt was seen in 10-12 y and 13-14 y olds (and was close to significant in 15-16 y olds) but not in the oldest swimmers, particularly as neither pattern appeared to result in a more successful performance. This was surprising given the likelihood that the oldest swimmers should have had the most developed glycolytic pathway (Van Praagh

2000, Armstrong & Welsman 2007, Ratel *et al.* 2010) needed to produce an end-spurt. In the 17+ y age group there was less than a full complement of eight swimmers in 60% of the finals analysed and therefore, heats were not needed to slim down the field. This is probably a result of a near two-thirds drop in the number of registered 18 y old swimmers compared to the number of registered 12 y olds (Langham 2015). This may have made the race less competitive and resulted in easier wins, with less of an end-spurt for the successful swimmers in the older age groups. In fact data from this chapter would suggest this to be the case because the mean margin from 1st to 4th place (i.e. between the gold medal and no medal) was 5.9s in 10-12 y but was 16.1s in 17+ y olds. This analysis would suggest that this should be addressed by the ASA regional competition organisers as it is not preparing these older swimmers with appropriate pacing templates that they will need to employ once they begin to compete in senior competitions.

The main finding of this chapter was that age affects pacing patterns in swimming. This highlights the importance for young swimmers to have pacing education during their training and competitive race time in which to practice and develop their ability to pace effectively. It is also important for coaches of developing swimmers to take into account physiological and psychological capabilities before setting pacing strategies. These capabilities may change throughout a season either positively (e.g. from training adaptations, positive mood states or the development of more effective performance templates) or negatively (e.g. accumulated fatigue from high training loads or negative mood states). The next chapter will attempt to measure some of these factors and assess their impact on pacing during competitive performances.

Chapter 8: The effect of training load and affect on pacing patterns over a season in middle distance male and female development swimmers.

8.1: Introduction

Swimmers will typically follow an annual periodised plan that segments their training activities into an ordered structure designed to build from one training block to the next. Periodisation has been widely practiced following the writings of L.P.Matveyev and T.Bompa in the 1960s and 1980s respectively, promoting the practice of step wave changes in exercise modes, load, intensity and volume between mesocycles and microcycles. More recently the use of block periodisation has emerged which is similar to its predecessor but with shorter and more specific training cycles (Issurin 2010). Both traditional and block training periodisation have similar effects on physiological markers such as $\dot{V}O_2$peak and ventilatory threshold (García-Pallarés *et al.* 2010). In addition, periodised training plans are known to affect athlete mood, with periods of high training volume associated with high mood disturbance. This was seen in swimmers when the constructs of depression, anger, vigour, fatigue and confusion fluctuated correspondingly with fluctuations in weekly swim distance (Raglin *et al.* 1991).

The widespread practice of undertaking periodised training will therefore, be expected to affect swimming performance throughout a season. Following on from chapter seven's findings which suggested that coaches should take physiological and

psychological development into account when setting pacing templates, this chapter will investigate pacing patterns, training loads and mood over an annual periodised training year in developmental swimmers.

In swimming literature, much of the focus when studying periodisation has focussed on the impact of the taper section of the periodised year (Mujika *et al.* 2002, Mujika *et al.* 2007, Papoti *et al.* 2007, Thomas *et al.* 2008, Trinity *et al.* 2008, Hellard *et al.* 2013). Mujika *et al.* (2002) investigated the effects of a taper on a range of swimming events before and after a three week taper period leading up to the 2000 Sydney Olympic Games. Swimmers in this study improved their swim time in 25 out of 26 events from pre to post taper by a magnitude that would make the difference between a medallist and non-medallist finishing position (Mujika *et al.* 2002). Hellard *et al.* (2013) similarly reported a mean performance improvement of 1.7% following a three week taper period in swimmers. Taper periods appear to be the most investigated periods in the literature presumably because of their importance leading up to competitive performances and the shorter data collection period required. However, some literature has examined the impact of training load over longer periods of the training year. Muñoz *et al.* (2014) reported the effects of an 18-week training programme on triathletes. They controlled the training loads based on set HR ranges, which were themselves based on each individual's anaerobic and aerobic thresholds. They found a positive correlation between the time spent in a training zone at or below aerobic threshold and ironman triathlon performance. Another study attempted to describe training load variation in swimmers and relate this to performance (Stewart & Hopkins 2000). They reported some strong correlations between higher weekly training distance and better race performance in

middle distance swimmers (200 m and 400 m distances). There were other relationships between specific parts of the periodised year, for example higher session distance in the speciality phase and shorter rest duration during the build-up and speciality phase were both related to improved swim performance (Stewart & Hopkins 2000).

Whilst increasing the training load should improve performance as suggested above, it may also increase the negative mood states experienced by swimmers over the long term (Raglin *et al.* 1991) and short term (O'Connor *et al.* 1991), a finding also found in non-swimmers (Wittig *et al.* 1992). It is known that age affects mood disturbance with older swimmers showing increased hardiness and less mood variation than younger athletes (Goss 1994) which may result in a lower training load impact on mood in other athletes. More recent research does not show a link between mood state and training load in swimmers (Faude *et al.* 2008) and the same can be seen in other sports (Filaire *et al.* 2004, Hernández *et al.* 2009). One reason for this disparity may be the complex nature of mood and its sub-constructs like those measured in the Profile of Mood States Questionnaire (vigour, tension, depression, anger, fatigue and confusion). In order to simplify the measurement of mood, Rhoden and West (2010) developed the "Worcester Affect Scale" (WAS). This tool has shown construct validity when measuring high level experiences and feelings and encompasses mood and emotion in a given situation. It is a practical and simple tool to gather frequent and regular measures of positive and negative affect (Rhoden & West 2010). Mood state, and in particular affect, may dissociate changes in RPE from physiological activity according to Renfree *et al.* (2012) who designed a study to assess the relationships between affect, RPE, peripheral physiological status and pacing

patterns during a fast and a slow 20 km cycle TT. They reported that a faster TT was the result of greater PO in the first 18 km of the trial and not the final 2 km end-spurt which was demonstrated by all subjects in both their fast and slow trial. During the fast and slow trials RPE did not differ at any point, however affect was significantly different with a higher positive affect during the fast trial, and higher negative affect during the slow trial. In addition, BLa was significantly higher following the fast trial and blood pH status significantly lower despite iEMG during the fast trial being less than that of the slow trial. This led the authors to suggest that affect is a key construct in the regulation of pace during exercise and may reflect peripheral physiological status (Renfree *et al.* 2012). In this study, affect was used to assess mood during exercise, however this would be a potentially useful tool to measure mood over a longer period of time to assess the interplay between affect and training load leading up to a performance and the pacing patterns during that performance. In other sports, positive affect prior to a competition has had a direct beneficial impact on performance (Sanchez *et al.* 2010) and a direct beneficial impact on self-efficacy which in turn has been shown to lead to better performances (Treasure *et al.* 1996).

The literature above suggested that periodised training means that an athlete's physiological markers and mood state may fluctuate during a season and that these changes will impact swimming performance. However, all of the measures of mood and performance in the literature are limited to a single performance with race time the only measure, and no investigations have been published into the pacing of these performances. Developing swimmers will compete in events regularly through the season, therefore this chapter aims to track the effect of training load and affect on

changes in the pacing of performance of developing middle distance swimming over a year.

8.2: Methods

8.2.1: Selection of Participants

Twenty-seven swimmers and their parents from the elite development squads of a regional swimming club were initially approached. At a briefing meeting attended by all subjects and parents, the study design was explained and covering letters (Appendix 1) and information sheets (Appendix 2) were distributed. Participants were told that if informed consent was given (Appendix 3), they would be asked to complete a training diary following each of their training sessions and record the contents of each session, an overall RPE for the session, and a positive and negative affect value using the WAS. Participants and their parents were informed that ethical approval for the method had been provided by Northumbria University (Appendix 4). Participants were asked to complete their diary as near to 30-min post session as possible and to record each and every session. Participants were told that they would be compiling the training diary for a trial one month period and that some of them would be asked to continue to maintain the diary for 12-months. During this time coaches provided detailed session plans, attendance records and notes for each swimmer about their completion of the planned session. Following the trial period eight swimmers were identified as keeping excellent training logs via a thorough cross-check of the information provided by the coaches and the training diaries. Of these eight swimmers, six were identified as predominantly middle distance

freestylers (200 m and 400 m) and were therefore asked to continue maintaining the diaries for 12-months. One parent removed their consent for their child to be part of the project and two swimmers did not complete records for the full period leaving a sample of three swimmers.

8.2.2: Participants

Case study one (CS1) was a freestyle specialist competing regularly at 200 m and 400 m distances and training in the elite squad. Case study two (CS2) was a freestyle specialist competing at 200 m and 400 m distances. Case study three (CS3) was a freestyle specialist who competed regularly at 200 m and 400 m distances. Table 8.1 provides descriptive data of the participants and Figure 8.1 gives an example of the data collected from the participant in case study one.

Table 8.1: Descriptive data of chapter 8 participants.

	CS1	CS2	CS3
Sex	Female	Male	Female
Age (y)	15	15	13
Stature (m)	1.81	1.78	1.65
Mass (kg)	59.0	62.3	51.1

8.2.3: Competitive Performances

Records of 50 m split times for all long course competitive performances were kept for all ASA regulated 200 m and 400 m freestyle races. Lap time data were collected from digital timing boards used in all ASA regulated competitions. Lap time data were collected through a variety of methods including paper based records provided

by the competition organiser, online from the club, or ASA website or from the swimrankings.org website which collates race times including split times for the majority of ASA regulated competitions or from the individual swimming club's gala records. FINA points (1000 FINA points is equal to the current senior world record) for each performance were provided for comparison.

8.2.4: Training load measure

Training loads were calculated using the session-RPE TRIMP method as discussed previously (see section 2.9.1). In order to accurately collect the time spent training including rest periods, swimmers recorded their training set including repetitions, repetition time and rest time which was summed to give session time. The need to wait 30-min before deciding on the RPE for the session was highlighted in the training diary in order to extract an RPE representative of the whole session and not merely the final component (Foster *et al.* 2001). The total time spent training (swim time + rest time) was multiplied by a session-RPE rating to give a sessional TRIMP. This was further summed into a weekly training load. The mean training load in the pre-taper (4-6 weeks before competition) and the taper (1-3 weeks before competition) was used for analysis.

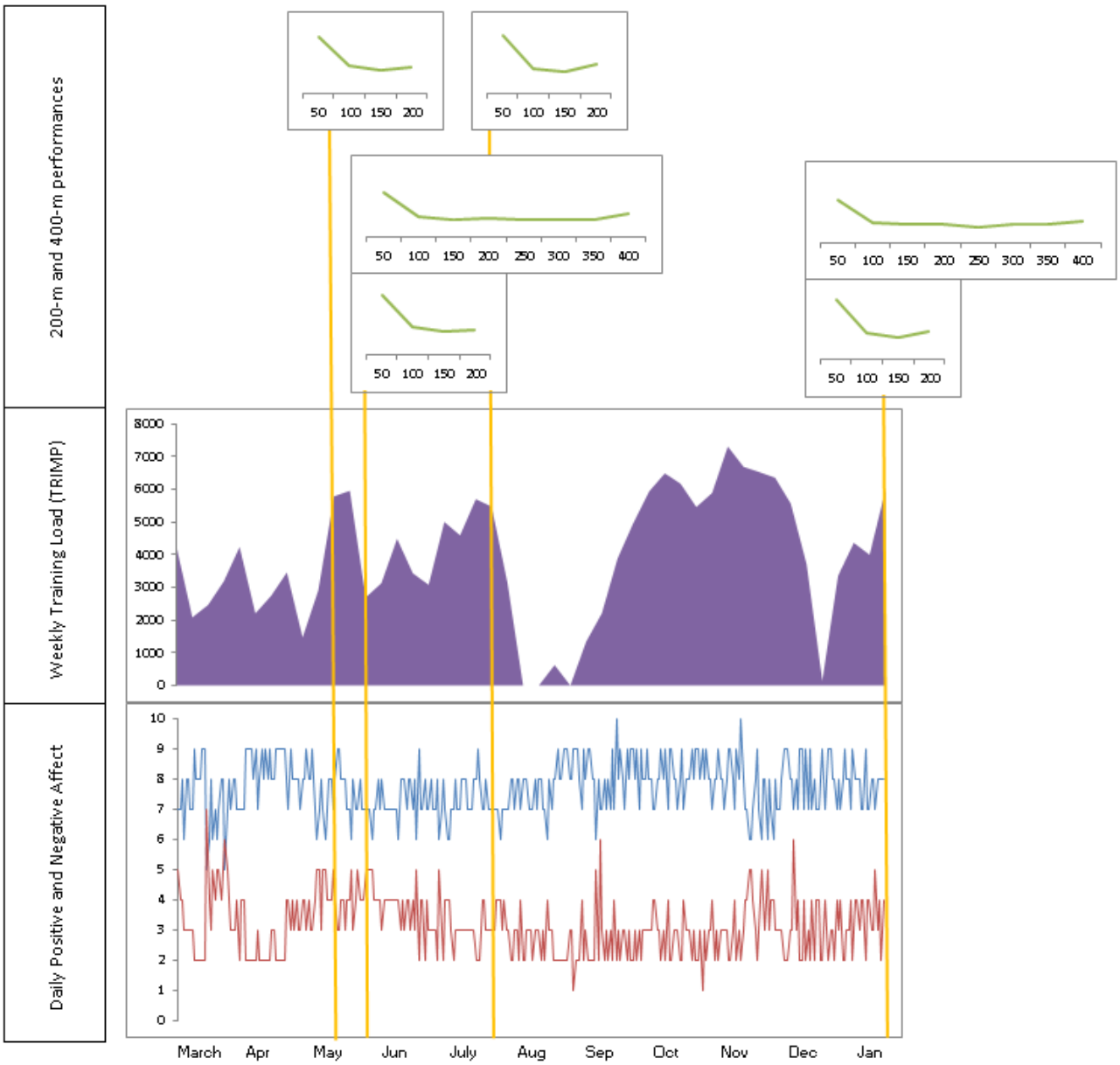


Figure 8.1: Overview of races, training load and affect in Case Study 1. 200 m and 400 m pacing patterns in green; training load TRIMP in purple; positive affect in blue and negative affect in red.

8.2.5: Affect scale

The WAS (Rhoden & West 2010) (see section 2.10 for details) was completed following every training session for positive and negative affect asking the question "how positive do you feel right now" and "how negative do you feel right now" an on a 1 to 10 scale. Median weekly positive and negative affect was calculated in the same pre-taper and taper periods as for training load. The range was provided as a measure of variance because each data set contained results from only one individual and so to remove outlying results would reduce validity.

8.2.6: Training diary completion

Each training diary consisted of an introductory page, instructions page and 50 training log pages (Appendix 5). At least once a month an unannounced pool visit took place to validate training diary data since approximately 20% of athletes over-report and 17% under-report training duration (Borresen & Lambert 2006). At these visits swimmers would be provided with a new diary and their current diary taken from them. All diaries were anonymised and stored in a safe location.

8.2.7: Validation

Fourteen training diary validation visits took place providing 20 individual swimmer sessions for comparison. CS1 had six comparable sessions, CS2 had nine comparable sessions and CS3 had five comparable sessions. A Pearson correlation was

completed for each individual swimmer for session swim distance and total session time.

8.3 Results

8.3.1: Validation of training diaries.

There was good agreement between training diary swim distance recorded by participants and by the researcher during the 14 validation visits. A Pearson correlation coefficient of 0.97, 0.94 and 0.99 was found for participant CS1, CS2 and CS3, respectively. There was also good agreement between training diary training time recorded by the participants and by the researcher during the same visits. Once again a Pearson correlation efficient was used and r values of 0.97, 0.99, and 0.95 were found for CS1, CS2 and CS3, respectively.

8.3.2. Case Study 1

Competitive performances, training load and affect changes were collected during a 45-week period from February 2013 to January 2014 for CS1 who competed in 400 m freestyle races during week 12 and week 46 and in 200 m freestyle races in weeks 10, 12, 20 and 46.

8.3.2.1: 400 m freestyle performances

Pacing during the first half of the race was similar for both 400 m freestyle performances (figure 8.2). In the second half of the race however, week 12 shows a flatter profile with a small increase in velocity during the penultimate 50 m and a more predominant end-spurt during the final 50 m compared to week 46 which shows a decrease in normalised velocity in the 200- to 250 m section followed by a less intense but longer end-spurt beginning at 250 m. Both performances were gold medal swims, however the week 12 total time of 4:32.02 (679 FINA points) was 8.9 s (616 FINA points) better than the swim in week 46.

Average training loads over a three week period leading up to the best race performance were higher in the pre-taper (mean weekly TRIMP 7,683) and taper (TRIMP 14,672) periods when compared to the corresponding pre-taper (TRIMP 7,218) and taper (TRIMP 14,341) periods prior to the slower performance.

Affect values for the pre-taper and taper periods leading to the 400 m races are shown in more detail in figure 8.3. Median (± range) positive affect in the pre-taper and taper periods leading to the most successful 400 m performance of the year were 8 ± 3 and 7 ± 3 respectively which was similar to the comparative pre-taper period (8 ± 2) but lower than that found in the taper period (8 ± 2) leading to the week 46 race. Median (± range) negative affect over a three week period was higher in the pre-taper (3.5 ± 3) and taper period (4 ± 2) leading to the best 400 m performance compared to the comparative pre-taper (3 ± 2) and taper (3.5 ± 3) leading to the slower 400 m performance.

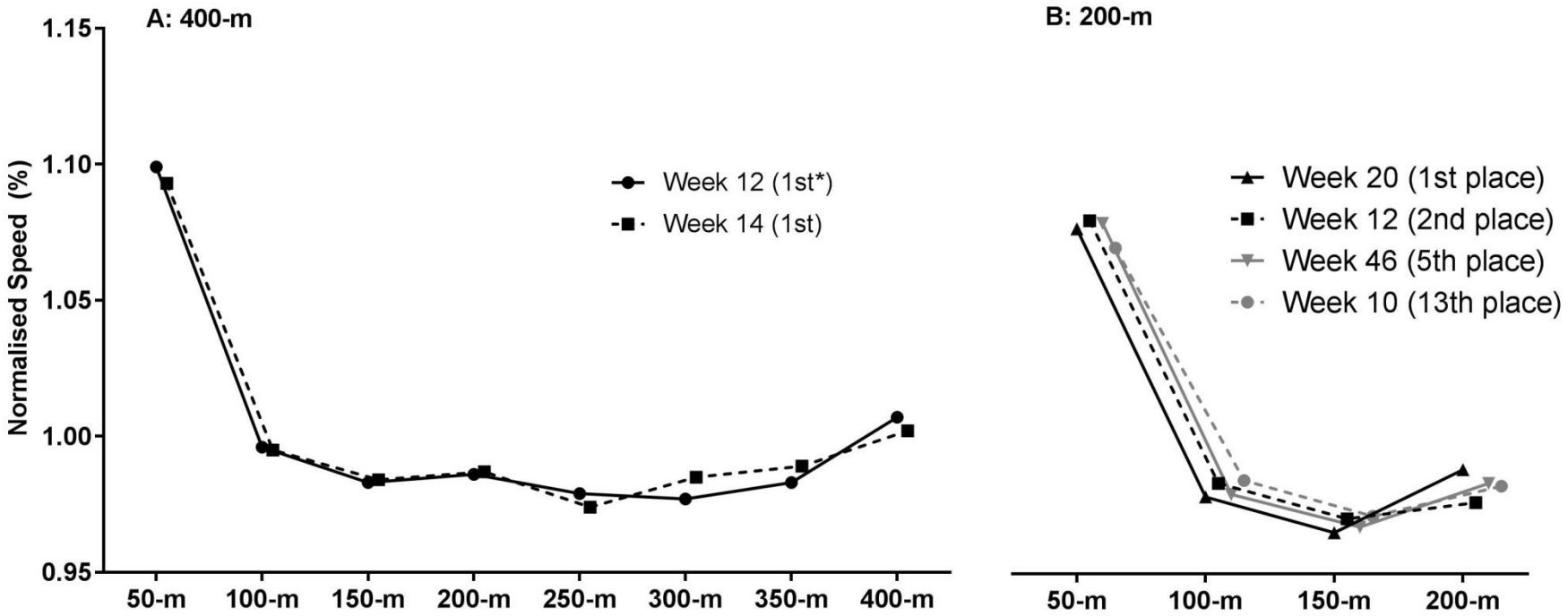


Figure 8.2: 400 m and 200 m freestyle pacing patterns in CS1. Data points offset for clarity. *denotes better finishing position where finishing pace is duplicated.

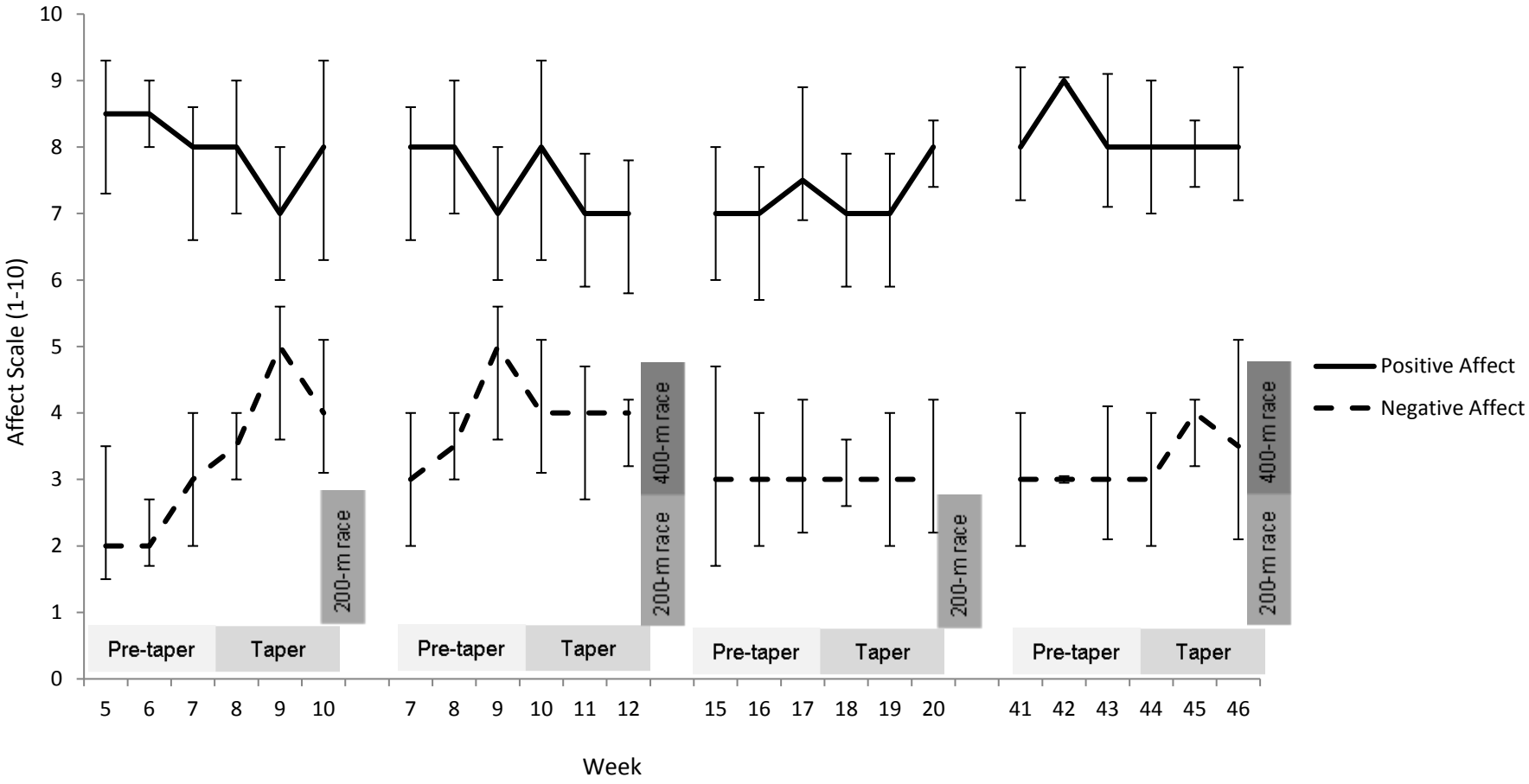


Figure 8.3: Median positive and negative affect in the 6-week periods leading to 200 m and 400 m races in CS1. Error bars = range.

8.3.2.2: 200 m freestyle performances

The 200 m freestyle performance during week 20 (figure 8.2) was the best performance of the year (1st place in 2:11.36s, 636 FINA points) and also had the largest end-spurt and the slowest normalised speed in laps two and three of the four races. The other three races displayed flatter pacing patterns even though all three were the same reverse J-shaped pattern. CS1 was placed 2nd (622 FINA points), 5th (575 FINA points) and 13th (621 FINA points) in the races in week 12, 46 and 10, respectively.

Training loads in the pre-taper and taper periods are shown in figure 8.4 arranged by finishing position. Mean weekly training loads in the taper period followed a clear pattern with the best performance containing the highest training load at 5104 TRIMPs with a reducing training load in line with worsening performances (4891, 4780 and 2618 TRIMPs for the 2nd, 5th and 13th placed performances, respectively). Mean weekly training loads in the pre-taper were also highest prior to the best performance (3672 TRIMPs) and reduced when compared to the 2nd and 5th placed performances (2561 and 2406 TRIMPs respectively). In an anomaly to this pattern, the pre-taper training load prior to the worst performance was not the lowest at 3065 TRIMPs.

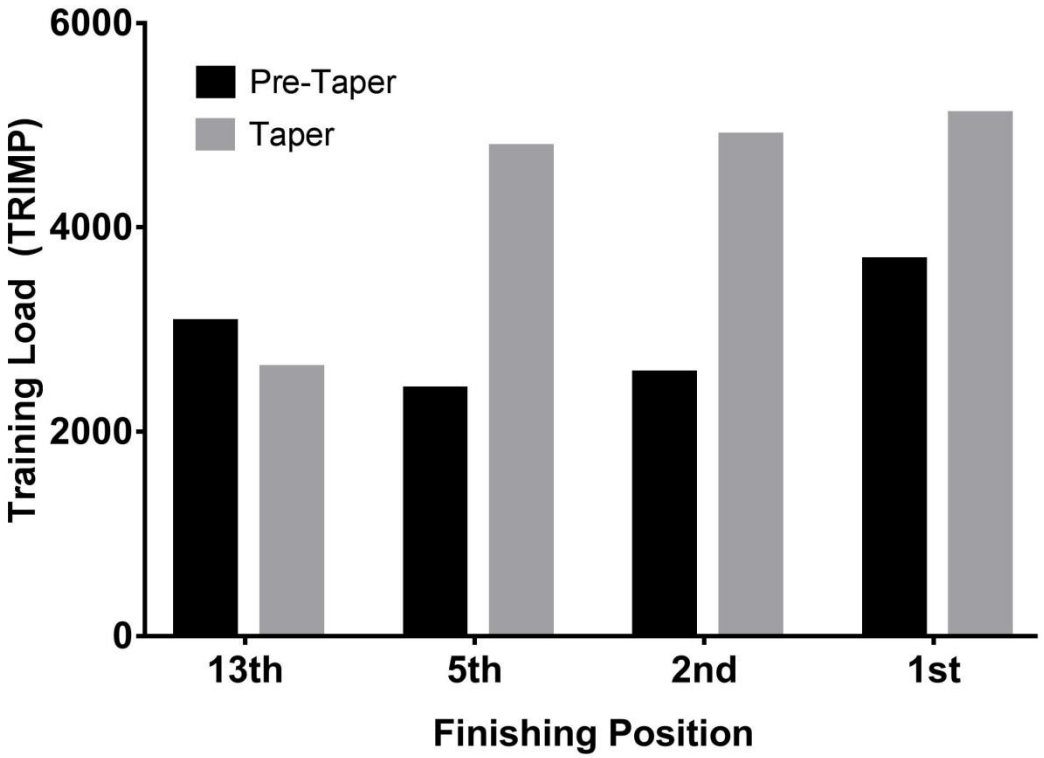


Figure 8.4: Mean weekly training loads in pre-taper and taper periods by finishing position in the 200 m freestyle in CS1.

Affect values for the pre-taper and taper periods leading to the 200 m races are shown in detail in figure 8.3 and in order of finishing position in figure 8.5. Median (± range) positive affect was lower in the pre-taper (7 ± 3) and taper (8 ± 2) periods leading to the best performance than in the periods leading to most other performances. Median (± range) positive affect in the pre-taper period was 8 ± 3, 8 ± 2 and 8.5 ± 2 prior to the 2nd, 5th and 13th placed performances respectively. In the taper periods, mean positive affect was 7 ± 3, 7 ± 2 and 8 ± 3 in the same sequence of worsening performances. Median (± range) negative affect in the pre-taper periods was 3 ± 3, 3.5 ± 3, 3 ± 2 and 2 ± 2 in the best to worst performances respectively. In the same order, taper period median negative affect was 3 ± 2, 4 ± 2, 3.5 ± 3 and 4 ± 2 respectively.

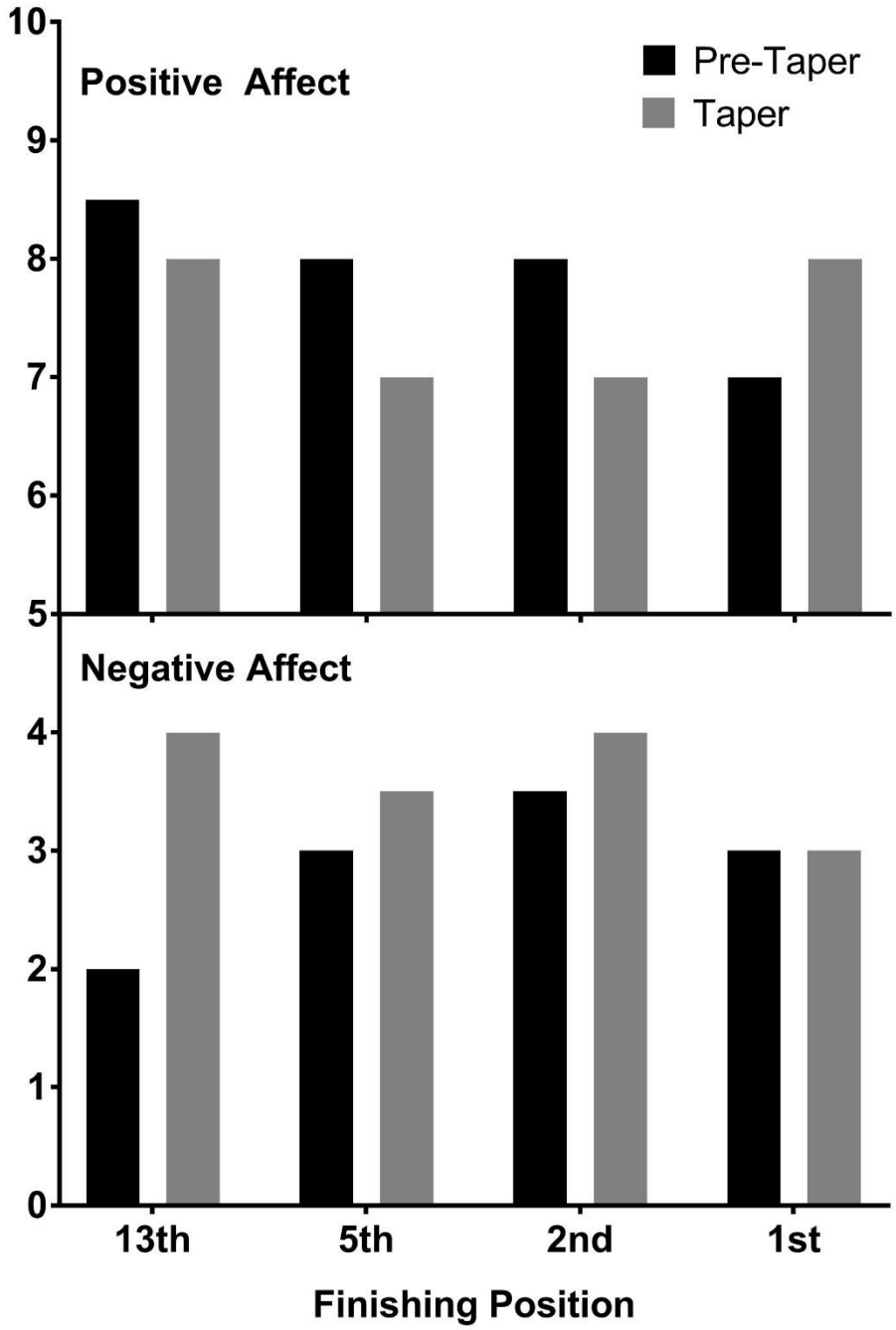


Figure 8.5: Median positive and negative affect by finishing position in the 200 m freestyle in CS1.

8.3.3: Case Study 2

CS2 compiled 49 weeks of data including competitive performances, training load and affect from February 2013 to March 2014. CS2 competed in a 400 m freestyle race during week 49 and in 200 m freestyle races in weeks 36 and 46.

8.3.3.1: 400 m freestyle performances

The single 400 m performance came at the end of the monitoring period and CS2 was placed in 23rd position in this event in a time of 4:35.38s (510 FINA points) and is shown in figure 8.6. Mean weekly training load in the pre-taper and taper period leading up to this race was 4418 and 3111 TRIMPs respectively. Training load was more variable in this participant than in any other. Median (± range) positive affect was 7 ± 4 in the pre-taper period and 6 ± 5 in the taper period. Median (± range) negative affect was 3 ± 5 in the pre-taper period and 3 ± 3 in the taper period prior to the race.

8.3.3.2: 200 m freestyle performances

The best 200 m performance by CS2 was in the race in week 46 finishing in 15th place in a time of 2:10.90s (473 FINA points). This was better than the performance in week 36 by 1.8s (454 FINA points) although the finishing position was the same.

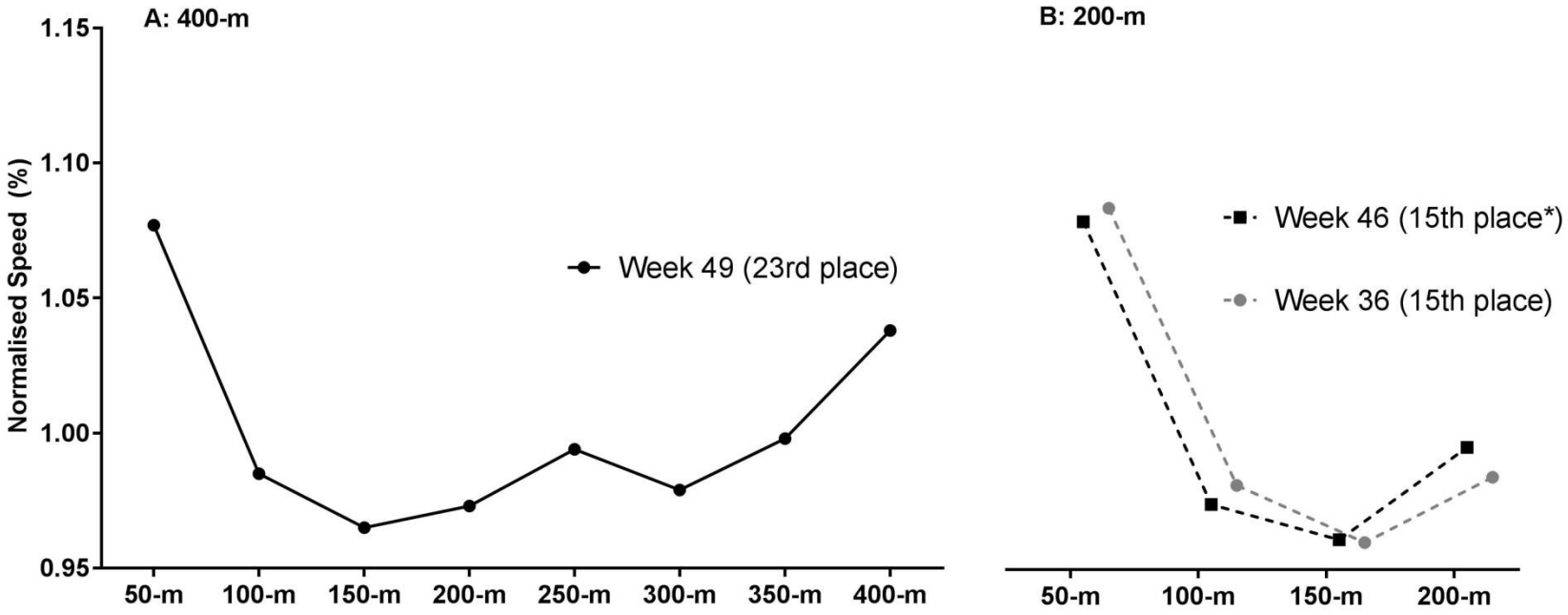


Figure 8.6: 400 m and 200 m freestyle pacing patterns in CS2. Data points offset for clarity. *denotes better finishing time where finishing position is duplicated.

Figure 8.6 shows that the faster race is characterised by a slower normalised velocity in the first 100 m and faster end-spurt in the final 50 m compared to the slower race where the profile is a flatter reverse J-shape.

The training load in the 6-weeks leading up to the superior performance in the week 46 race was higher in the pre-taper (mean weekly TRIMPs 4418) and lower in the taper (3111 TRIMPs) than training loads in comparative periods prior to the week 36 race (pre-taper mean training load 3577 TRIMPs and taper mean training load 3717 TRIMPs).

Affect measures for the pre-taper and taper periods can be seen in figure 8.7. Median (± range) positive affect was 5.5 ± 5 in the pre-taper and 7 ± 4 in the taper leading to the better performance in week 46. In the comparative periods leading to the slower race in week 36, median positive affect was higher in the pre-taper (6.5 ± 5) and lower in taper (6 ± 4). Median (± range) negative affect was 4 ± 4 in the pre-taper and 3 ± 5 in the taper period leading to the better performance. In the comparative periods leading to the slower performance, median (± range) negative affect was lower (3 ± 3) in the pre-taper and the same (3 ± 3) in the taper period.

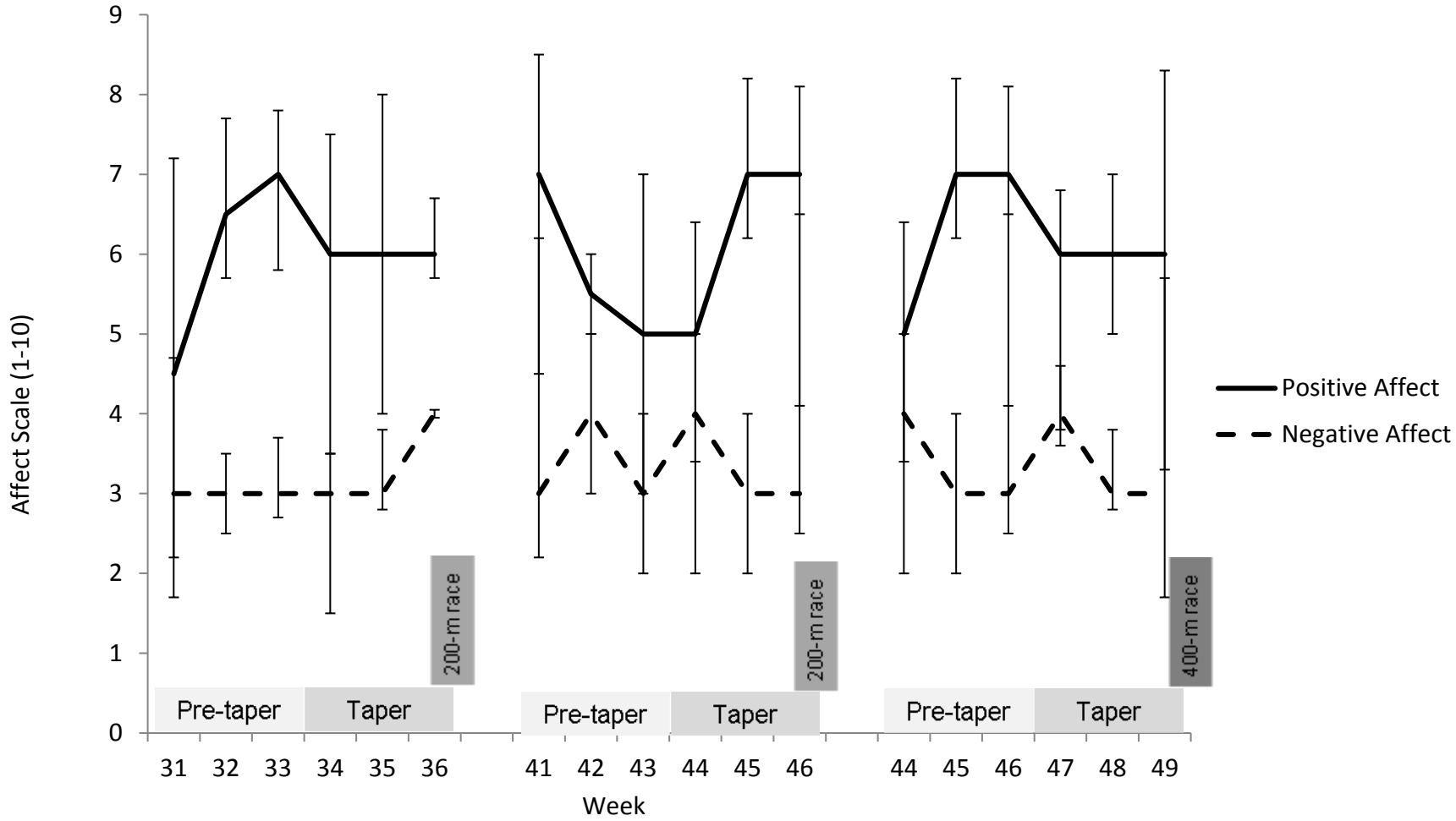


Figure 8.7: Median positive and negative affect leading up to 200 m and 400 m race performances in CS2.

8.3.4. Case Study 3

Competitive performances, training load and affect changes were collected for CS3 during a 36-week period from February 2013 to November 2013. CS3 competed in 400 m freestyle races during weeks 7, 12, 15 and 36 and in 200 m freestyle races in weeks 7, 12, 13 and 36.

8.3.4.1: 400 m freestyle performances

Figure 8.8 shows the four 400 m performances recorded by CS3 during the monitoring period. The best finishing position of fifth place occurred in week 12 with a time of 4:52.70 (548 FINA points). The remaining races ended with a sixth place in a time of 4:54.99 (532 FINA points) in week 36, an eleventh place in a time of 4:54.36 (534 FINA points) in week 7 and finally the lowest finishing position of 15th in week 15 in surprisingly the best finishing time of 4:50.74s (554 FINA points). The pacing pattern during week 12 (the best finishing position) can be described as W-shaped with higher normalised velocity in the first lap, middle lap and final 2 laps. The pacing pattern in the fastest performance (week 15) was U-shaped, however the end-spurt seen here (100.2% and 100.8% at 350 m and 400 m respectively) was lower than has been seen in previous chapters and may explain the lower finishing position.

Training loads (figure 8.9) in the pre-taper and taper periods leading up to the best performance in the week 12 race were higher than before any other race performance

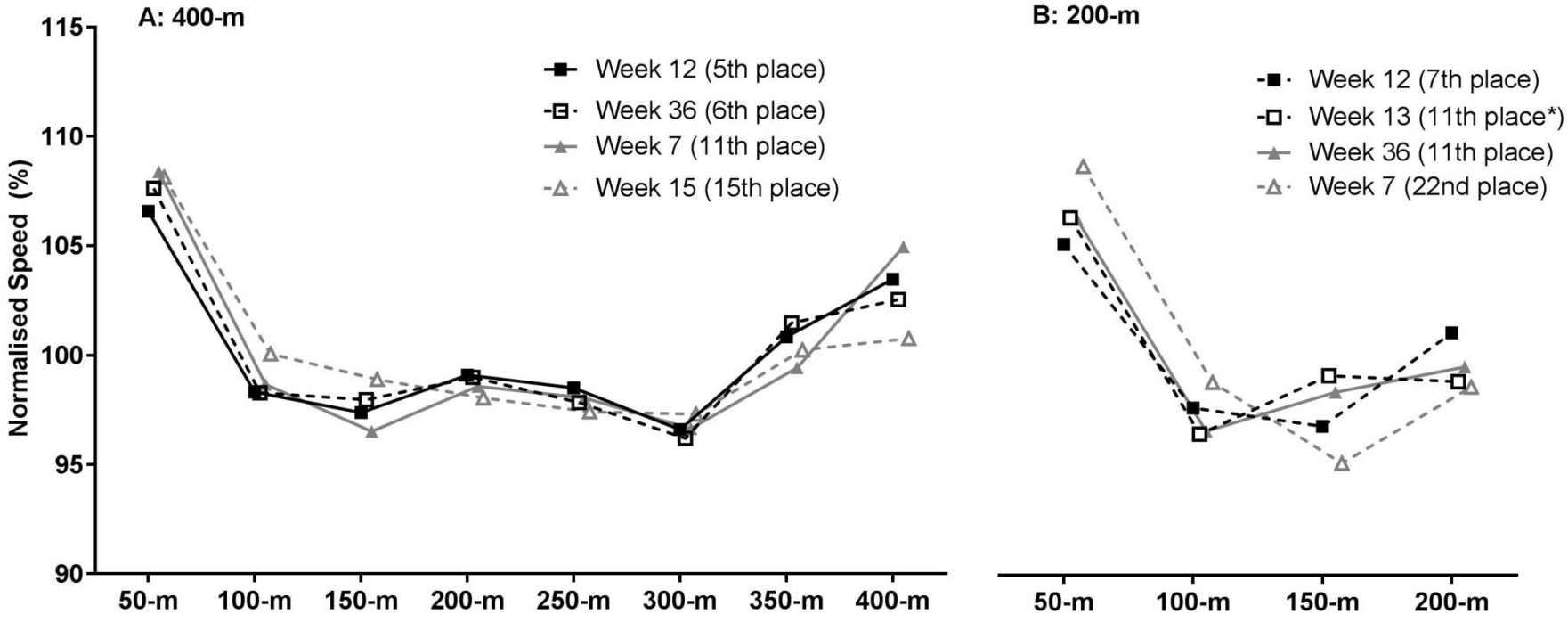


Figure 8.8: 400 m and 200 m freestyle pacing patterns in CS3. *denotes better finishing time where finishing position is duplicated.

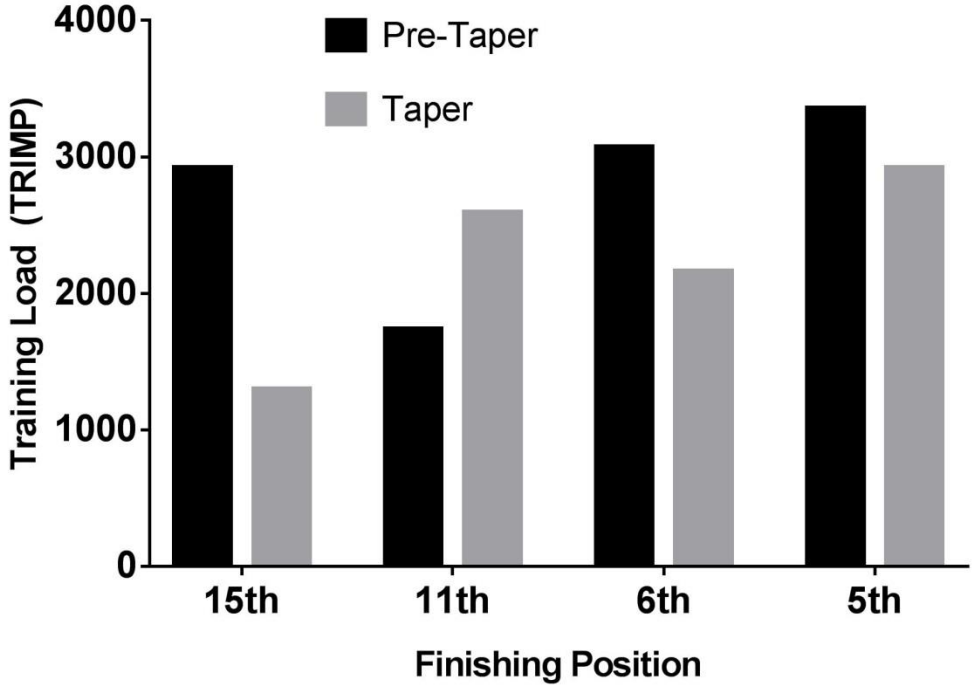


Figure 8.9: Training loads by 400 m freestyle finishing position in CS3.

at 3346 TRIMPs and 2911 TRIMPs respectively. Pre-taper training loads were 3062, 1731 and 2911 TRIMPs in the periods leading to a 6th place, 11th place and 15th place finish. Taper training loads were 2153, 2586 and 1289 during the build up to the same 6th, 11 and 15th place finishes, respectively.

Median affect measures are shown in figure 8.10 in the pre-taper and taper periods leading to 400 m races including the weeks that overlap due to regular racing at this time in the season. In the pre-taper and taper periods leading to the best 400 m performance in week 12, median (± range) positive affect in the pre-taper and taper periods was 6 ± 5 and 5.5 ± 4, respectively, and median negative affect was 4 ± 5 and 4.5 ± 4. In descending order of performance, median positive affect in the pre-taper

periods were 5.5 ± 3, 6 ± 4 and 5.5 ± 4 and in the taper periods were 6 ± 6, 6 ± 3 and 6 ± 5. In descending order of performance, median negative affect in the pre-taper periods was 4.5 ± 4, 3 ± 4 and 4.5 ±4 and in the taper periods was 4 ± 5, 4 ± 3 and 4 ± 6. Mean TRIMP and median affect values were affected by both the cross-over of pre-taper and taper periods and by large ranges showing high fluctuations in positive and negative affect during these periods.

8.3.4.2: 200 m freestyle performances

The pacing patterns of the four 200 m performances can be seen in figure 8.8. Week 12 is a good example of a reverse J-shaped pacing pattern characterised by a fast final 50 m after slow and slower laps two and three. Week 12's race was the best finishing position performance (7th in a time of 2:21.29s, 511 FINA points). The race in week 7 was the lowest finishing performance (22nd) in a race time of 2:25.22s (470 FINA points) and contained a noticeably slower normalised velocity in the 3rd lap than other performances, elongating and skewing the reverse J-shaped pattern to the right. The races in weeks 13 and 36 both had an 11th place finish and were the second slowest (2:24.40s, 478 FINA points) and slowest (2:25.74s, 465 FINA points) finishing times respectively. The pacing pattern in week 13 is unusual in that normalised velocity increases in lap three only to decrease in lap four and so is the only race not to show a reverse J-shaped curve. In week 36, normalised velocity increased during the final two laps, but by a relatively slower amount compared to other races, with the result that the final end-spurt is less than that of the faster and better finishing week 12 race.

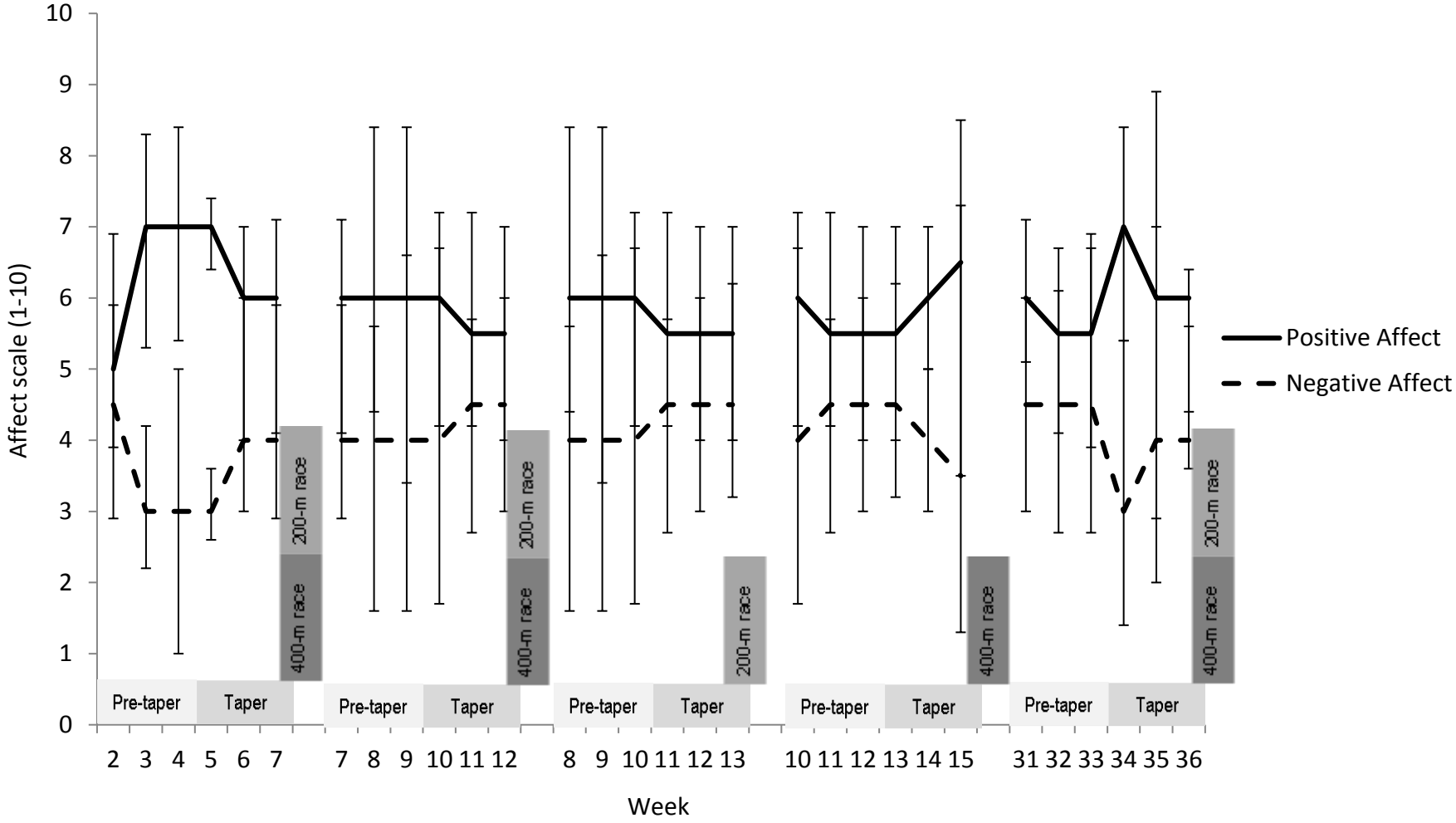


Figure 8.10: Median positive and negative affect leading up to 200 m and 400 m race performances in CS3.

Training loads in the lead up to all four races can be seen in figure 8.11 and show a trend for higher loads in both pre-taper and taper periods prior to better performances. Mean weekly training load in the pre-taper prior to the best performance in week 12 was 3346 TRIMPs and in the taper period was 2911 TRIMPs. In order of decreasing performance, the pre-taper periods had training loads of 2766, 3062 and 1731 respectively whilst during the taper for the same periods training loads were 2772, 2153 and 2586 TRIMPs, respectively.

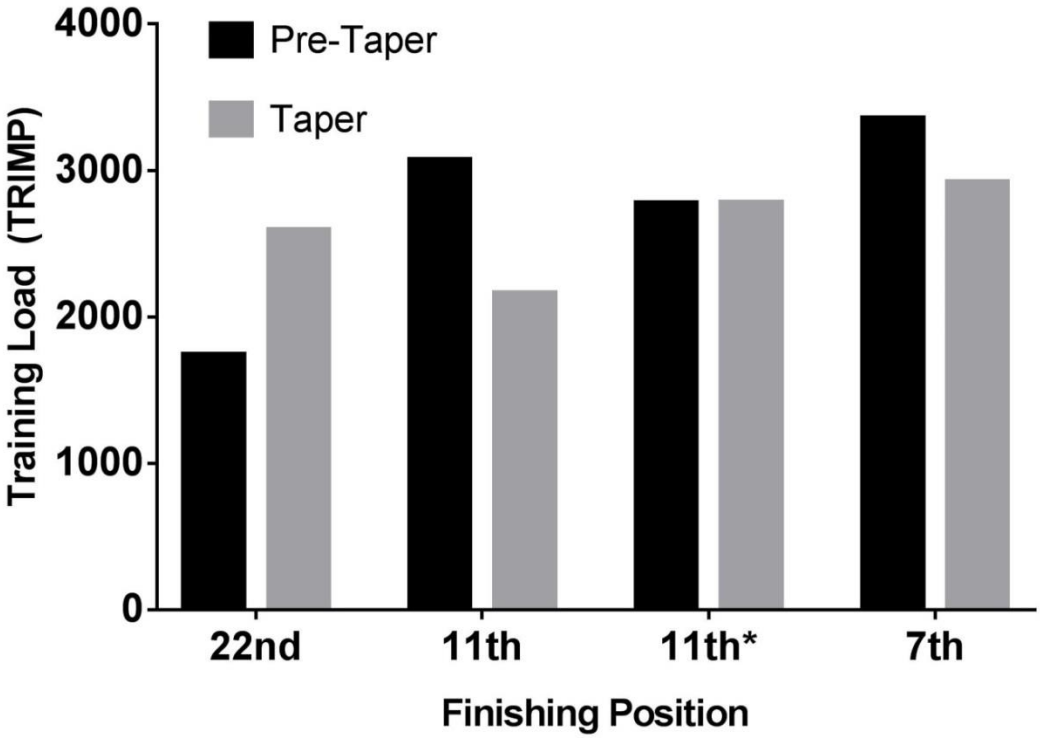


Figure 8.11: Training loads by finishing position in the 200 m freestyle in CS3.

Median affect values prior to the 200 m races are represented in figure 8.10 and similarly to the 400 m performances, are characterised by higher variance (ranges) than other participants. There was a tendency for positive affect to drop as performance improved in both the pre-taper and the taper and for negative affect to increase in the taper periods as performance improved (figure 8.12). Median (± range) positive affect in the pre-taper period in descending order of performance was 6 ± 5, 6 ± 5, 5.5 ± 3, 6 ± 4 and in the taper was 5.5 ± 4, 5.5 ± 4, 6 ± 6 and 6 ± 3 in the same periods. Median (± range) negative affect in the pre-taper period in descending order of performance were 3 ± 5, 4 ± 5, 4 ± 4 and 3 ± 4 and in the taper were 4.5 ± 4, 4.5 ± 4, 4.5 ± 5 and 4 ± 3 in the same periods.

8.4 Discussion

The principle finding of this chapter was that better 200 m and 400 m performances tended to be associated with preceding periods of higher training loads and lower median positive affect. Higher training loads in the pre-taper and taper were associated with better finishing positions in two of the case studies for both 200 m and 400 m freestyle performances (CS1 and CS3). In the remaining case study training load was higher in the pre-taper prior to the best 200 m race but not in the taper (CS2). Unlike Mujika *et al.* (2002), who gave an example of a typical training distance during the pre-taper and taper period, or Stewart and Hopkins (2000) who based their findings on coach questionnaires, this finding is based on an individually measured training load taking training time and intensity into account. Training load in this chapter is a function of training time x session intensity (RPE) and so higher training loads may be a result of longer training sessions or more intense training

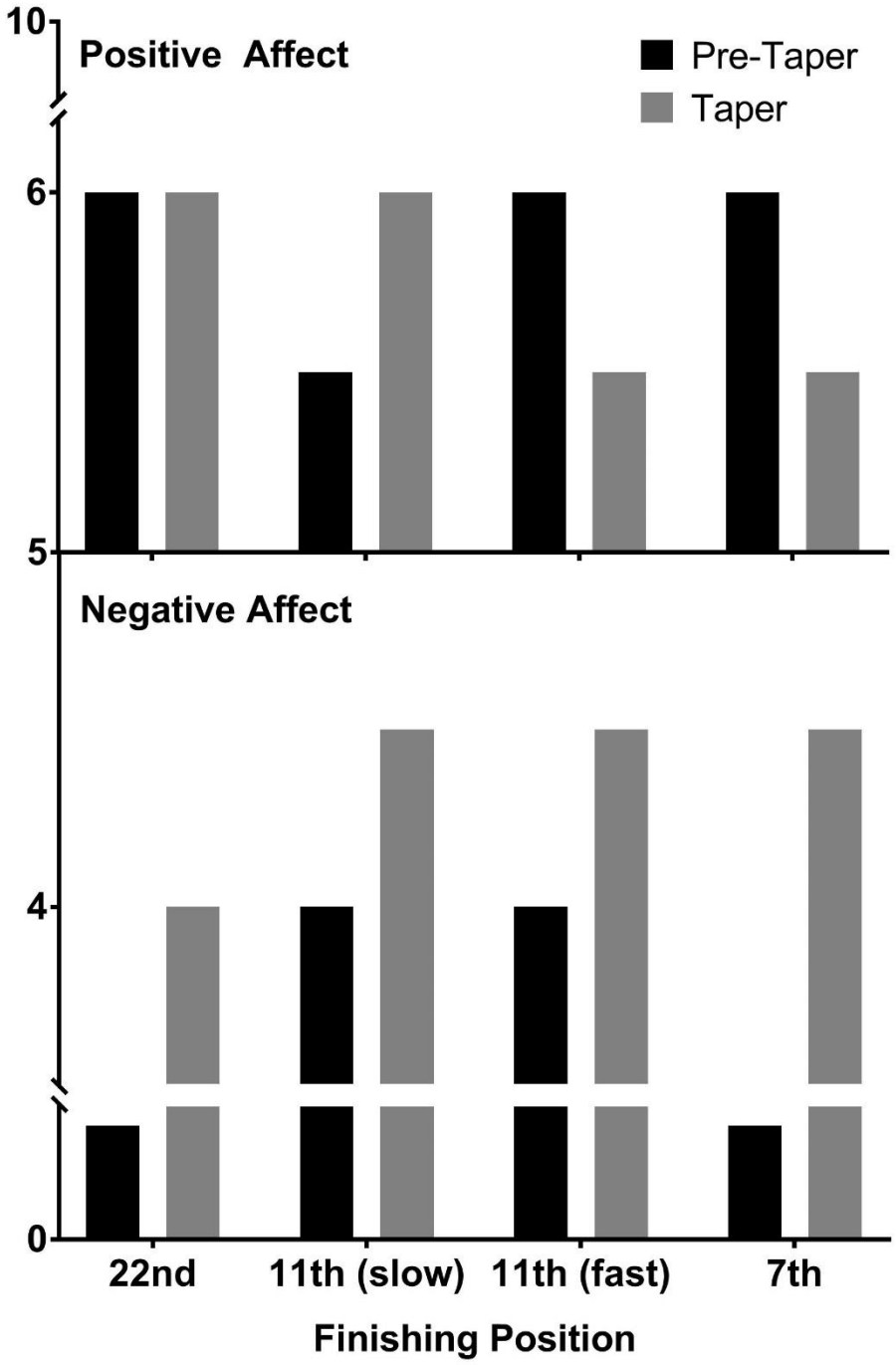


Figure 8.12: Median weekly positive and negative affect in pre-taper and taper periods by finishing position in the 200 m freestyle in CS3.

sessions. In this instance, whilst training distance did track training load closely, training time fluctuations were even more similar (data not shown) which is to be expected given that swimmer's land training will add time but not distance to the calculations. This would suggest that the coach did not reduce training time or training distance during taper periods as would be expected. However, by not following this traditional pattern, (Mujika *et al.* 2002, Hellard *et al.* 2013) finishing positions were improved. This mirrors the findings of Trinity *et al.* (2008) who reported an improved performance following a higher intensity taper with a greater swim distance compared to performances that followed a lower intensity, lower swim distance taper.

These data also appear to agree with Stewart and Hopkins (2000) who reported a positive correlation between weekly and session training distance during the taper (and in earlier training blocks), and middle distance swimming performance. It should be noted that in the Stewart and Hopkins (2000) study, reductions in weekly and session training distances were seen in the taper and so presumably their data support less of a reduction during the taper, rather than the increase in time and distance that are associated with improved performance in this chapter. The results of these case studies are somewhat surprising given the large amount of reported physiological gains to be made as a result of reducing training load in a taper which include increases in neuromuscular function, muscle size, $V\dot{O}_2max$, running economy, serum testosterone, erythrocyte volume and anti-inflammatory immune cells and decreases in muscle damage and circulating cortisol (Wilson & Wilson 2008). The same review article also lists improvements in positive affective mood states (reduced anxiety, depression and anger and increased vigour) and lower sleep

disturbance as non-physiological benefits (Wilson & Wilson 2008), of which more will be discussed later.

The best 400 m swim performances by CS1 and CS3 in this chapter had similar pacing pattern characteristics to those associated with success in previous chapters. For example, figure 7.5 describes the significant increase in pace between 300-m and 350 m in developing swimmers who win a medal compared to non-medallists. In addition, figures 5.2 and 6.1 describe a significant increase between 300-m and 400 m in elite medallists compared with non-medallists. Both CS1 and CS3 demonstrate a greater increase in pace at this point in their most successful race compared to less successful ones. Results from chapter seven also suggested that it is beneficial to slightly increase pace in the middle of the race creating a W-shaped pacing profile, a phenomenon seen in successful 400 m performances by CS1 and CS3 in this chapter. The reduction in training load during a taper is designed to reduce accumulated fatigue (Turner 2011) and so it would appear that both CS1 and CS3 benefitted from their increased training load despite reporting potentially higher fatigue levels. The training loads may not have been sufficiently fatiguing before their best performance and so they did not need a taper reduction in training load in order to pace their race optimally. However, CS1 and CS3 had mean weekly swim distances of 36.7 km and 24.2 km respectively during the taper periods which is higher than distances of 30 km (Mujika *et al.* 2002) and 20 km (Trinity *et al.* 2008) reported in the literature and suggests that they were not training unduly lightly. Greater training adaptations in the individual's anaerobic power resulting from increased training load may have provided the extra energy needed to execute the end-spurt (Hill 1999, Corbett 2009), which in the most successful races was of a greater magnitude than in the other races.

In their best 200 m performances, all three case study swimmers showed a reverse J-shaped pacing pattern with a higher magnitude of end-spurt than their less successful races. In addition, all swimmers had a greater training load in the pre-taper period of this successful 200 m race compared to all of their other races and two of the three (CS1 and CS3) also had a higher training load in the taper period prior to this race. This follows a similar pattern to that seen in the 400 m data in this chapter and in this thesis more generally, whereby an enhanced performance is associated with an end-spurt of a higher magnitude. The association between a higher training load and improved finishing positions may be due to the same reasons given previously surrounding an increased anaerobic capacity which would have potentially an even greater role to play in this shorter event as the anaerobic contribution would already be greater than in a 400 m swim (see section 2.1, p10).

This was the first study to monitor positive and negative affect in athletes over an extended period of time and may explain the high participant drop-out rate. Positive affect during the taper period was at its lowest prior to the best 400 m performance in CS1 and was low (but not the lowest) prior to the best performance in CS2. During the taper periods prior to the best 200m races, positive affect was lowest in CS1 and CS2 and low (but not the lowest) in CS3. Figures 8.5 and 8.12 display a trend for reducing positive affect as finishing position improves in both the pre-taper and taper periods in CS1 and CS3. Negative affect did not show the same pattern confirming that it is independent from the positive affect variable (Watson & Clark 1997). In CS1 and CS3 both the highest and lowest weekly mean negative affect values were seen prior to the most successful 400 m and 200 m races and in CS2 affect was not different in the taper between the most and least successful 200 m races. These data,

which would need confirming in better controlled trials with higher subject numbers, would contradict other studies showing that better performances tend to be preceded by high positive and low negative affect (Sanchez *et al.* 2010) and high self-efficacy as a result of high positive affect (Treasure *et al.* 1996). A limitation of this chapter is that all participants trained under the direction of the same coach who did not reduce training load in the typical manner prior to competition. The better performances seen in this chapter may have occurred despite these high training load taper periods.

Affect has been linked to regulation of exercise after it was found that high positive affect was associated with an improved TT performance and low negative affect was associated with a worse TT performance (Renfree *et al.* 2012). In this study, and during the slower TT, a lower power output was speculatively linked to higher central nervous system activation to reach the same RPE and so it was suggested that negative affect could have been a marker of peripheral fatigue which was preventing the recruitment of additional muscle fibres. During the improved TT, a higher power output and lower central nervous system activation allowed for an increase in pace over the first 90% of the race and was associated with high positive affect. In the current chapter, there was no evidence that changes to training load were associated in any way with changes in affect. The three studies given here as examples (Treasure *et al.* 1996, Sanchez *et al.* 2010, Renfree *et al.* 2012) measured affect immediately prior to or during athletic performance. In the current chapter, affect was measured after every training session and averaged to give a mean weekly value. The method used in this chapter was not able to provide information about affect immediately before or during competitive performances. Nonetheless, there were

trends for a lower positive affect in the lead up to better performances that could be investigated further. It may be that because affect might inform the central nervous system of peripheral fatigue which in turn can affect RPE, power output and pace, a lower positive affect in the weeks prior to a race means the potential for a relative improvement in affect, and therefore, in the regulation of exercise during a race. This is a speculative suggestion and would need investigating further. Alternatively, affective feelings in the weeks leading to a race performance may not impact on the performance itself.

An additional finding of this chapter was that better 400 m performances once again followed the W-shaped pacing pattern identified as optimal for this event in developing swimmers in chapter seven. In this chapter, increases in pace were seen at the 150 m section of the race as well as at the start and end of the race. This differs from the 200 m pacing pattern where a reverse J-shaped pacing pattern was associated with a better finishing position. It is interesting that in the analysis of 400 m performance in previous chapters, where data were split into four 100 m sections (e.g. chapters five and six), the reverse J-shaped pattern also appeared to be the most successful although a W-shape cannot be shown because only four time points are used.

The major limitation to this chapter was lower than expected available data points and participants. The low recruitment of participants was due to the taxing demands of maintaining accurate training diaries over a long period of time. The collection of detailed training information was planned in order to provide an accurate picture of the time spent either training or recovering from training. However, it appears that a

simplification of the data collection surrounding training time could have enhanced participant recruitment, thereby providing richer data for full statistical analysis and would still lead to a usable measure of training load if multiplied by a session-RPE value. The SwimBritain training app is already in widespread use by swimmers who record their session swim distances. An adaptation to this application to include swim time and session-RPE (the software could even prompt entry of the data 30-min after the session to maintain RPE validity) could increase access to, and usability of, swim training data. In addition to complex training data collection, one of the swimmers in this chapter (CS2) competed far less regularly during this training year than was expected at the start of it due to commitments away from the pool. This led to a reduction in comparable 200 m and 400 m swim performances.

During the middle of the season, regular competitions led to an overlap of the three week taper and pre-taper periods. Not including a particular race performance because it took place within six weeks of another race would have reduced the validity of the performance data and, therefore, all competitions were used despite this overlap from one pre-taper or taper to the next, but this did inevitably lead to the duplication of some data points.

The main findings of this chapter were that better finishing positions in 200 m and 400 m freestyle swimming may be associated with an increased training load and lower positive affective state in the pre-taper and taper periods prior to the race. However, this phenomenon and the possible mechanisms behind it need further work with improved data collection methods and larger participant pools to be confirmed.

Chapter 9: General discussion and directions for future research

9.1: Thesis aims

The aim of this thesis was to report optimal pacing patterns in middle distance running and swimming events by differentiating between medallist and non-medallist performances in competitive races. Specifically the aims of the experimental chapters were:

- To analyse the pacing patterns used by successful elite male 1500 m runners and 400 m freestyle swimmers and show how these differed from non-medallists.
- To analyse the pacing patterns used by successful elite female 400 m freestyle swimmers and show how these differed from non-medallists and from male swimmers.
- To analyse the pacing patterns used by male and female developing 400 m freestyle swimmers and how these patterns changed with age.
- To analyse the effect of training load and affect on changes in pacing patterns in developing middle distance swimmers over a year.

9.2: Reflections on pacing patterns

Throughout this thesis, a parabolic pacing pattern in competitive races that emphasises a slower start or middle section and a faster end-spurt has been consistently shown to differentiate medallists from non-medallists. This thesis has shown that in head-to-head races, the ability to conserve energy in the middle of the

race in order to produce a faster end-spurt is more evident in medallists in both male and female, elite and developing swimmers in the 400 m freestyle event and in male elite runners in the 1500 m event when compared to the pacing patterns of non-medallists. This has not been demonstrated in the literature before because medal and non-medal winning performances have not previously been separated when analysing pacing in these events.

9.2.1: Pacing in the last quarter of the race

In 1500 m running, male medallists showed a significantly faster end-spurt of moderate effect size in the final 400 m quarter of the race compared to non-medallists. The increase in speed by male medallists during this lap was 2.3% in relative terms. Male 400 m swimmers also had a significantly faster end-spurt of moderate effect size in the last quarter of the race than their non-medallist competitors, by 1.3% in relative terms. Female 400 m swimming medallists were significantly faster with a moderate effect size in the last quarter of the race by 0.8% than non-medallists. Finally, male and female developing swimmers who won a medal were significantly faster with a small effect size in the last quarter of the race, and more specifically in the 300-m to 350 m section of the race, by 0.4% compared to non-medallists. In addition, in male swimmers, this last quarter of the race can also differentiate between winning a gold medal and winning a silver or bronze medal. This requirement to increase pace in the last quarter of these events in order to win a medal has not been shown before in the literature.

An interesting finding in this thesis arose from the use of 50 m split times in chapters seven and eight compared to 100 m split times used in the previous chapters. The data in chapters seven and eight suggest that the increased magnitude of the end-spurt in medallists compared with non-medallists may occur during the penultimate 50 m section of the race and not in the last 50 m. There were no differences in the increase in speed in the final 50 m between medallists and non-medallists in developing swimmers but comparable data was not analysed in senior swimmers in chapters five and six because 100 m split times were used. The increase in the CV in the final 50 m in both medallists and non-medallists in chapter seven (the final lap CV was 2.65% and 2.38% in medallists and non-medallists respectively compared to 1.4% and 1.5% in the previous lap) suggests that some swimmers may be struggling to cope with the increased velocities of the previous 50 m, whilst others may have too much left in reserve by the end of the race. This is an area for future research and highlights the need for higher frequency data collection of velocity when analysing pacing patterns. This is possible in swimming but not in running until such time as the governing bodies of the sport regularly employ the use of transponder chips to automatically collect high frequency split times of all runners, and make this data available to researchers.

9.2.2: Pacing in the first three quarters of the race

In order to be able to increase pace at the end of a race, it is likely that runners and swimmers need to conserve energy earlier in the race. Like the end-spurt, this was consistently seen in performances by medallists compared to non-medallists, however in different sections of the race. Male 1500 m runners who won a medal ran the

second of four laps at a significantly slower pace of moderate effect size compared to non-medallists by 1.1% in relative terms. Male swimmers were significantly slower in both the first and second of four laps by 0.9% (moderate effect size) and 0.5% (small effect size) than the relative pace of non-medallists. Female 400 m swimming medallists were significantly slower than their non-medallist competitors in lap two and three of four by 0.5% in relative terms in both instances, which showed a moderate effect size. Finally, developing swimmers who medalled were significantly slower than non-medallists in the first 50 m of the 400 m swim by 1.3% which showed a moderate effect size. Whilst the need to conserve pace in the earlier parts of the race was seen in all medallists, the exact location of this conservation period differed between sexes and ages though there were some overlapping features. However, the consistency of the reduction in pace prior to the initiation of an end-spurt at 75% of race distance suggests that this is a necessary tactic in order to win a medal which has not been shown before in the literature.

9.2.3: W-shaped pacing pattern

The findings of chapters seven and eight signify the potential for a new, as yet un-identified, pacing pattern to exist in 400 m freestyle swimming. Groups of developing swimmers in these chapters displayed a consistently faster middle section of the race that started at either 150 m or 200 m, which was followed by a reduced pace in the following laps before the initiation of the end-spurt from 300-m (W-shaped pattern). This was seen in figure 7.3 in 13-14 y, 15-16 y and 17+ y olds, in figure 7.4 in males and females and in figure 7.5 in medallists and non-medallists. This pattern was also seen in six of the seven races swum by the swimmers in

chapter eight. Unlike the findings of the previous chapters, this pacing pattern did not differentiate medallist and non-medallist performance. Due to the use of 100 m split times in chapters five and six, it is not possible to say if the W-shaped pacing pattern existed in these participants and others have not shown this pattern in 400 m freestyle swimming due to use of the same 100 m split time method (Robertson *et al.* 2009) or because it was not included as an option for analysis (Mauger *et al.* 2012), presumably because this pattern has not been previously discussed when alternative pacing patterns have been presented (Abbiss & Laursen 2008). The same W-shaped pattern was seen during an investigation of 400 m pacing in swimmers aged 14-23 y with fast-slow-fast-slow-fast pacing pattern in both a free-paced swim and a swim with an enforced slow start but not when a fast start was enforced (Skorski *et al.* 2014a).

9.2.4: Training load and affect

The findings of chapter eight suggest that the best performances a) follow similar pacing patterns to successful athletes in previous chapters, b) are preceded by low mean positive affect and c) are preceded by high training load. The latter two findings are not in line with the current literature where more optimal performances are associated with a reduced training load during a pre-race taper in order to maximise physiological benefits (Wilson & Wilson 2008, Turner 2011) and with higher positive affect values before (Sanchez *et al.* 2010) and during (Renfree *et al.* 2012) competition. Based on chapter eight, it is not clear whether training load and affect in the six weeks leading up to a competitive middle distance event directly affect the pacing pattern seen during the race.

9.3: Underlying mechanisms

Athletes in middle distance events must ensure that their regulatory system and performance template, whether this template be based on RPE (Mauger *et al.* 2009, Tucker 2009) or power output, allows for this increase in pace to take place ensuring that exercise reserves are fully utilised at the end, but not before the end, of the race (Amann 2011). An increase in power output at the end of a race may be possible due to an increased anaerobic contribution in this part of the race (Corbett *et al.* 2012) and/or an increased aerobic contribution earlier in the race, which saves anaerobic capacity for use later on (Bailey *et al.* 2011) and the interaction of these make up an athlete's performance template. These three mechanisms are discussed in the following sections.

9.3.1: Contribution of the anaerobic energy system

The magnitude of the end-spurt seen in elite males was larger than that seen in elite females, which in turn was larger than that seen in developing swimmers of both sexes. It is likely that the end-spurt is fuelled by an increase in the rate of anaerobic yield and an increase in the total anaerobic contribution (Corbett *et al.* 2012) and findings in this thesis would support this view. Corbett *et al.* (2012) measured an approximately 10% increase in total anaerobic output during a three min cycle race which led to an increased power output during the second half of the cycle race and led to a performance improvement of 2%. Previous research into energy systems contribution has shown that 1500 m runners of both sexes progressively reduce the anaerobic energy system contribution until the last 400 m where it is increased to fuel

an end-spurt in pace (Duffield *et al.* 2005). Males are known to have increased glycolytic enzyme (PFK and LDH) capacity (Jaworowski *et al.* 2002), greater muscular cross-sectional area which creates a greater metabolic demand and increases mechanical compression potentially reducing oxygen supply (Russ & Kent-Braun 2003), and a greater ability to develop peripheral fatigue (Glace *et al.* 2013) than females. The higher magnitude end-spurt seen by males compared to females in chapter six may be due to the optimal use of this additional energetic resource (Duffield *et al.* 2005). In addition, adults are known to have greater anaerobic power and capacity than children (Williams *et al.* 2001, Ratel *et al.* 2010). The higher end spurt seen by elite swimmers compared to developing swimmers provides further support to the link between anaerobic power and end-spurt magnitude.

This increased anaerobic power may also be part of the reason for success in medallists compared to non-medallists. If a greater end-spurt is needed to win a medal, as seen in chapters five, six and seven, it may be that these more successful swimmers have an enhanced anaerobic system which makes them more likely to win. Alternatively, in a physiologically homogenous group such as elite athletes, the winners may have executed a more optimal pacing pattern thus utilising their anaerobic resources to their maximal advantage, compared to a non-medallist with similar anaerobic resources who executed a non-optimal pacing strategy. It is this competition between the physiological and the tactical/psychological that can blur the interpretation of performance data like those collected in this thesis.

9.3.2: Contribution of the aerobic energy system

Male and female, elite and developing medallists have consistently demonstrated that they were prepared to reduce their normalised speed to a greater extent in earlier parts of the race compared to non-medallists. This was interpreted throughout this thesis as an energy saving pacing tactic to ensure that the energetic resources were available in the last quarter of the race to produce a greater end-spurt than non-medallists. These medallists would need to be in touch with their opponents by the 75% point in the race for this tactic to work and so the aerobic power available to athletes will clearly have a performance effect. Earlier it was suggested that the aerobic system contributes between 77% and 84% of the total energy spend in 1500 m running and between 80% and 95% in 400 m swimming (table 2.1). It would appear that optimal use of this energetic resource involves sparing the anaerobic system resources for later on and so it could be argued that the greater the aerobic power of an individual, the faster their conservation period could be. It was interesting to see that during the conservation period swum by 400 m male and female swimmers when compared to non-medallists, the absolute speed was higher in the medallist group.

The summary of pacing in the first three quarters of the race (section 9.2.2) suggested that male and female elite and developing athletes save energy in different sections of the race. Those that saved energy early on (elite male swimmers and developing male and female swimmers) appear to risk slower $\dot{V}O_2$ kinetics, and therefore, a greater oxygen deficit (Bailey *et al.* 2011), a situation that would not appear on the face of it to save non-oxidative energy capacity for later on in the race. However, Bailey *et al.* (2011) used untrained participants and, because training may positively influence the

speed of the primary component of $\dot{V}O2$ kinetics (Jones & Koppo 2005), this may not be a good comparison to use. In any case, Corbett *et al.* (2012) reports contradicting evidence that faster starts and finishes did not change the aerobic energy yield over the course of a 2 km cycle TT whereas anaerobic energy yields were higher in these cases than in slower starts and finishes.

In contrast to early 'slowness', there were examples of reduced pace occurring mid-race in medallists compared to non-medallists in 1500 m male runners and 400 m female swimmers. In 1500 m running there are tactical advantages associated with positioning oneself higher up the field as early as lap one (Renfree *et al.* 2014) and so this may explain the mid-race (as opposed to early race) slowdown in these athletes which could ensure a better position in the pack. Runners have a markedly greater end-spurt in the final lap compared to swimmers and so this mid-race slowdown, which was at speeds associated with velocity at $\dot{V}O_2$max in elite runners (Billat *et al.* 1994), appears to have conserved the anaerobic system optimally for use during the end-spurt. Whilst the literature cannot provide the same evidence for swimmers, it is probable that the same tactical reasons are not valid because there is no competition for space due to the use of lane ropes, there is less competition for drafting positions because these same lane dividers reduce the benefits of drafting in swimming and because there is no change in the distance swum due to positioning within the lane.

9.3.3: Performance template

Tucker (2009) proposed that individuals may develop a planned RPE response for a planned activity and in doing so provide a template for the body to compare to in

order to aid decisions about central motor drive. The model suggests that if the actual and planned RPE at a given time do not match, the central drive can be increased or decreased accordingly until they do. It is not clear yet that RPE is an independent variable in exercise regulation, as Tucker proposes, or if current and expected RPE are a result of changes to exercise intensity based on a performance template that uses power output as the independent variable. Regardless, the existence of a performance template gives rise to the need for athletes to develop an optimal performance template for their event. According to Foster *et al.* (2009) this template can be learned by adults through repetition in middle distance rowing and cycling. This was not repeated in children who did not change their pacing pattern despite repeated attempts of a middle distance exercise trial in a novel situation (Lambrick *et al.* 2013) and would suggest that some children may not be able to learn a performance template in the same way as adults appear to be able to.

Due to the consistency of pacing patterns seen by elite middle distance medallists in these events (with an early or middle conservation period and an end-spurt), it would appear that these athletes have developed an optimal pacing pattern with which to win a medal. It would also appear that developing swimmers who win a medal had also developed a similar U-shaped template and this would infer that these young athletes were able to learn an optimal performance template. In the youngest age group, 10-12 y olds should learn to increase the pace of the mid-race section in order to reduce the relative speed at the start and finish given that their age would suggest a less developed anaerobic resource. Consequently, as age and performance increased, a flatter U-shaped pacing pattern emerged (figure 7.3). This pattern is reinforced when comparing the 400 m pacing patterns of developing medallists and non-

medallists (chapter seven) and case studies one to three (chapter eight) who represent the highest, medium and lowest standards of competing developing swimmers respectively. Case study one, a 15 y old who recorded two first placed 400 m swims, had a flatter pacing pattern more akin to the medallist performances at the regional championships, compared to case studies two and three who had faster end spurts akin to the non-medallists at the regional championships. Taken together this would appear to show that better swimmers learn to pace their normalised speed more optimally than less successful and younger swimmers. In addition, case study one's swims show a higher level of consistency (shown by low variation at each 50 m split time between performances) than case study three. Medallists in chapter seven show a smaller CV at each time point than non-medallists, suggesting that the pacing template has become more engrained with age and improved performance.

9.4: Limitations to the methodology

Chapters five to seven assumed that the highest profile race of the season is the most appropriate for analysis of optimal athletic performance. The methodology took account of the Olympic, World or European championship event in each year for elite athletes and the annual regional championship for developing athletes. However, athletes may plan their performance development over multiple years and in the case of developing athletes, a model for planning training (such as Balyi's Long Term Athlete Development model) may span over many years. Therefore, the collection of data in chapters five, six and in particular in chapter seven was not able to account for athletes using these competitive events as development opportunities and instead assumed that the aim of all competitors was an optimal performance.

Chapters five and six sample pace throughout the 400 m swimming and 1500 m running events at four intervals to allow for comparisons across sports and across chapters. The use of higher frequency split times in chapters seven and eight, and the subsequent findings of pacing changes that were isolated to smaller race sections (such as the mid-race increase in pace to form a W-shaped pattern or the isolation of the end-spurt to 300-m to 350 m section), highlight the possibility that the full pacing picture of elite athletes may have been somewhat masked. This was a result of the development of a novel data collection method for 1500 m running data (chapter three) that utilised the start/finish line as the only reference point suitable for the identification of split times for each athlete. However, new methods for collecting split times in competitive situations from automated transponder chips located on the athlete, provide a potential opportunity for improving the understanding of pacing patterns in elite track running by increasing the number of performances available for analysis.

Chapter eight analysed the pacing patterns, training load and mood state of three swimmers from the same elite squad from a single swimming club. These swimmers trained under the direction of the high performance coach at the club, and therefore, the training methods used may not be typical of developing swimmers training at other clubs. In particular, the finding that training load increased in the lead up to competitive performances appears to be at odds with the typical pattern of tapering training load in the three weeks prior to competition. Indeed, this finding was at odds with the expectations of the performance coach himself who thought he had planned taper periods in-line with normal practices. In addition, the size and varied ability

level of the sample might be considered a limitation. Therefore, the external validity of these case studies outside of this individual swimming club may have been impeded.

9.5: Future research directions

The findings of this thesis would suggest that medal winning (or another measure of success if appropriate) should be an independent variable in future investigations of optimal pacing patterns in competitive sport. Previously much research has grouped together performances from all competitors in an event in order to analyse the pacing of the event (see table 2.1). However, the analysis of pacing in these cases may have masked optimal patterns, for example by blunting the optimal end-spurt or increasing the average normalised pace during a conservation period in middle distance events. For example, based on data in chapters five and six, combining medallists and non-medallists data would have reduced the medallist's normalised velocity by 0.5% and 1.7% in swimming and running respectively, in the final lap. In addition, chapter eight suggests that a more consistent pacing may be associated with improved performance and, therefore, it may be that combining successful and unsuccessful athletes together further masks the optimal pacing pattern for the event.

The chapters investigating developing swimmers raise a number of future research directions, not least further investigation into the relationship between lower positive affect, increased training load and improved pacing and performance. The data resulting from the three case studies in chapter eight do not allow definitive links between training load, affect and optimal pacing patterns to be made due to the low

number of participants under the direction of a single coach, however further investigation of these trends is warranted. The suggestion that more optimal pacing patterns were associated with higher training loads and lower positive affect in the weeks preceding the race seems at odds with expectation both in the training literature (Wilson & Wilson 2008, Turner 2011) and mood state literature (Wilson & Wilson 2008, Sanchez *et al.* 2010, Renfree *et al.* 2012). This could be achieved with automated training data collection methods to reduce the burden on the participant of completing a session by session detailed diary. In addition, the emergence of a W-shaped pacing pattern in developing swimmers is of interest. The increase in mid-race pace in these swimmers may have a basis in physiological or tactical mechanisms that have not been explained in this thesis. Alternatively, the W-shaped pacing pattern may be the result of the higher sampling rate of swimming velocity employed in this chapter compared to previous chapters. Other researchers have used 100 m split times to analyse a 400 m freestyle swimming event (Robertson *et al.* 2009, Skorski *et al.* 2013) as was used in chapters five and six and many others have used four race portions to analyse other sports (Corbett 2009, Brown *et al.* 2010, Muehlbauer *et al.* 2010a, Muehlbauer *et al.* 2010c, Foster *et al.* 2014). However, it may be that the senior swimmers also employ a W-shaped pacing pattern which the method used in chapters five and six could not show, or that the W-shaped pacing pattern may be used in middle distance junior swimming only. A further extension of the work completed in this thesis on developing swimmers would be the analysis of national and international competitive performances to see if these were more like their developing swimmer colleagues, or if in fact the success of these young people was associated with more elite pacing patterns.

Both pool swimming and track running have distinct competitive seasons of short course and long course, and indoor and outdoor seasons respectively. In long course swimming and outdoor running, the pool and track are twice as long as in short course swimming and indoor running. Despite competing over the same distance, this affects the performance of both 400 m freestyle and 1500 m running events. Running indoors on a 200 m track tends to increase the event time (current male and female world records are approximately five seconds longer) because the time spent running a bend is greater than on a 400 m outdoor track and this type of running is slower than running in a straight line. Conversely, in the pool, short course 400 m freestyle swimming is faster than long course swimming (4-12 s improvement in world record time in women and men) because of the increased opportunity to push off from the wall and swim underwater as part of the normal turn. In addition the physiological disturbances that occur in the short course version are different to long course swimming (Keskinen *et al.* 2007). The data collected in the current thesis are exclusively from long course swimming and outdoor track running, and therefore, the pacing patterns reported as optimal here may not be optimal in the short course and indoor track versions of these events. Investigations into the pacing patterns in these shorter format events would be beneficial.

9.6: Practical implications

The sections above outline the pacing patterns, and potential underlying mechanisms for them, reported in this thesis. These patterns will have practical implications for training and competitive strategies for elite and developing athletes as they and their coaching teams develop a “what it takes to win” performance plan (English Institute

of Sport 2016). Based on the findings of this thesis, the main implications for coaches and athletes are that:

- Medallists consistently show a pattern of greater reduction in pace during a conservation period in the first three-quarters of a race, and a greater increase in pace during an end-spurt in the last quarter of a race, when compared to non-medallists. Therefore, planning to adopt a similar race strategy would appear to increase the chance of winning a medal.
- Pacing patterns are different between male and female elite swimmers in terms of the location of the conservation period. Therefore, pacing strategies should not cross-over between sexes and instead should be based on the sex specific patterns used by medal winning swimmers. Male swimmers had an earlier conservation period and a larger end-spurt compared to females.
- Pacing patterns change during the development of younger swimmers, and therefore, strategies derived from optimal pacing patterns seen in adults should not be forced onto younger athletes. In particular, the pacing patterns seen in the youngest swimmers were the most different to elite athletes. There should be an expectation that pacing patterns will become more optimal and more consistent with improving age and performance.
- Performance templates can be learned by young swimmers therefore, time and effort should be directed at this area of development by coaches and young swimmers through use of paced time trials (for example using an aqua-pacer device to control stroke rate) and competitive situations.

9.7: Conclusion

Based on the findings of the four experimental chapters in this thesis, the following conclusions can be made:

- Male medallists in 1500 m running and 400 m swimming events conserve energy in the first part of the race by slowing their relative pace, so that they can increase pace during the end-spurt by more than the non-medallists.
- Female medallists in elite swimming developed a similar performance template to males by slowing relative pace earlier in the race in order to increase pace during the end-spurt. However, the conservation period in women's races appeared later in the race and the end-spurt requirements tended to be lower than that seen in male medallists.
- Developing swimmers in the early stage of their competitive career (10-12 y) may need to learn a performance template that lowers their first and last lap pace but increases their mid-race pace.
- Developing swimmers should base their pacing strategies on age appropriate performance models and not on pacing patterns used by elite athletes. Developing swimmers may need to increase pacing consistency between events in order to improve their finishing position.
- High training load and low positive affect in the weeks leading up to a race in developing swimmers can improve finishing position during competitive races.

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Appendix 1: Covering letters

Graham Mytton
PhD Student
Department of Sport and Exercise Sciences
School of Life Sciences
Room 431 Northumberland Building
Northumbria University
NE1 8ST
Tel: 07946 874730

Email: graham.mytton@northumbria.ac.uk

26th February 2013

Dear Parent/Guardian,

My name is Graham Mytton and I am a PhD student at Northumbria University. I graduated in 2004 with a first class honours degree in Sport and Exercise Science (BSc) from Northumbria University. In 2010 I was also awarded my masters degree from Sunderland University, which explored the relationship between fatigue and muscle recruitment in upper body exercise. I wish to continue this research on a broader scale by investigating the pacing strategies used by athletes in swimming and running.

In collaboration with CoSASC I would like to explore the effects that training regimes have on performance, in particular the changes athletes make to their pacing strategy during competitive races. We are suggesting that training volumes will affect an athlete's ability to pace him or herself during a race.

I am therefore writing to you to consider this proposal and to ask your permission for your child's participation. Full details are outlined in the information sheets provided, one for yourself and the other for your child. Just to make you aware that all members of the research team have CRB clearance and that CoSASC have agreed to take part in this research project. If you have any questions or would like to discuss this issue further please do not hesitate to contact me on the details provided above. Whilst we expect the experience to be both an educational and fulfilling experience, there is no obligation that your child must participate and they will be at no disadvantage if they do not wish to take part.

If you are happy for your child to be involved, please return the ***informed consent form*** in the envelope provided to your child's coach.

Thank you for your cooperation in this matter.

Yours Faithfully,

Graham Mytton.

Appendix 2: Information Sheets

PARENT INFORMATION (SWIMMING)

TITLE OF PROJECT: Pacing strategies in middle distance running and swimming events.

Participant ID Number:

Principal Investigator: Graham Mytton

Investigator contact details:
Department of Sport and Exercise Sciences
School of Life Sciences
Room 431 Northumberland Building
Northumbria University
NE1 8ST
Tel: 07946 874730
Email: graham.mytton@northumbria.ac.uk

What is the purpose of the project?
Pacing strategies are used by athletes to vary their speed in a race in order to complete it in the least possible time. A key area of pacing research centres on changeable or un-changeable pacing templates. Data has been presented that would suggest that pacing strategies in a laboratory setting are un-changeable. For example we know that stimuli such as light, sound and knowing the distance you have covered do not affect athletes which would suggest that these pacing strategies are "hard-wired" and set prior to competition. On the other hand some studies have shown that deceptive feedback given to the athletes in terms of does affect pacing strategies. It has also been suggested that pacing strategies could be affected by your current training regime.

This study aims to investigate when and how pacing strategies change between different competitions, athletes and times of the year in 400m swimming and 1500m running.

Athletes striving for excellence would benefit from this kind of analysis to develop their knowledge of pacing strategies that have been shown to be successful at the highest level and would build on the theoretical basis already developed in the literature.

2. Why has my child been selected to take part?
Your child has been highlighted by his or her coach as being a talented athlete in one of the events this research is focussing on.

3. What will me and my child have to do?
Your child will be asked to keep a training diary that records things like distance covered and timings for each training session and give each session an overall score for tiredness. Your child might need yours or the coach's help with this. This should take around 15 minutes to complete. It will be necessary to complete this 30 minutes after training so this may lengthen your child's training session.
In addition I will visit your child's training sessions once a month to collect heart rate

data whilst they train. This is measured using a chest strap which your child can fit themselves in the changing room. The heart rate information is stored on the device and downloaded at a later date.
When your child competes in races I will be collecting your child's lap times too. These times will come from the published results sheets at each competition your child attends.

4. What are the exclusion criteria (i.e. are there any reasons why my child should not take part)?
No. Your child has been selected on the basis of their sporting ability as being suitable for this project.

5. Will my child's participation involve any physical discomfort?
Your child will be undertaking their normal training regimes as directed by the club coaches so this may cause physical discomfort. However your child will not be asked to do anything over and above this normal training if they part of the research group.

6. Will my child's participation involve any psychological discomfort or embarrassment?
No.

7. Will my child have to provide any bodily samples (i.e. blood, saliva)?
No.

8. How will confidentiality be assured?
An identification number will be used instead of your child's name in order to prevent association between participant and data set. Documents containing your child's name against ID numbers will be stored separately from those containing ID numbers and in a locked filing cabinet. All documents containing information about your child will be stored in a locked filing cabinet and only accessed by the researcher named above and only used for the originally intended purpose unless express informed consent is granted by yourself and your child**.** All electronic data will be stored on password-protected computers.

9. Who will have access to the information that me and my child provide?
Only the Principal Investigator (email:graham.mytton@northumbria.ac.uk) will have access to the data.

10. How will my child's information be stored / used in the future?
All electronic data collected from you and your child will be stored on password-protected computer for 5-10 years following completion of the study and then destroyed. The information provided from you and your child will only be used for the purpose of this study. The data may be presented at conferences and also published in peer review journals. At no point will your child's identity be associated with their results.

11. Has this investigation received appropriate ethical clearance?
Yes, the study has received full ethical approval from the School of Life Sciences Ethics Committee. If you require confirmation of this please contact the Chair of this committee, stating the title of the research project and the name of the principle investigator.
Chair of the School of Life Science Ethics Committee (Dr Les Ansley)

Northumberland Building
Northumbria University
Newcastle upon Tyne
NE1 8ST
Email: les.ansley@northumbria.ac.uk

12. Will my child receive any financial rewards / travel expenses for taking part?
No.

13. How can I withdraw my child from the project?
You are reminded of your right to withdraw your child from the study at any time. If you choose to do so, please email the Principal Investigator (email: graham.mytton@northumbria.ac.uk), giving your child's confidential participant number code (on top of this sheet) and all your data will be deleted. Please note however that it might not be possible to withdraw your child's individual data if the data has already been analysed/published – so please contact the investigator within one month of the project end date if you do wish to withdraw your data.

14. If I require further information who should I contact and how?
Please do not hesitate to contact me (Graham Mytton – Principal Investigator) using the following contact details:
Department of Sport and Exercise Sciences
School of Life Sciences
Room 431 Northumberland Building
Northumbria University
NE1 8ST
Tel: 07946 874730
Email: graham.mytton@northumbria.ac.uk

CHILD INFORMATION (SWIMMING)

Congratulations! You are being asked to take part in an exciting project with your swimming club. If that sounds good just read on and see if you still like the idea at the end!! ☺

I would like to monitor your training and race times over a season to see how they change. This will mean you will need to complete a training diary after every session showing things like how far and fast you swam. This will probably take around 15 minutes and you should do it 30 minutes after your training session. Once a month I will come to your training session and ask you to wear a heart rate monitor whilst you train. I will also be collecting your lap times when you take part in races.

If you can't take part or you don't want to that is fine. If you start the study and you don't like it and want to drop out then that is no problem either.

Thank you, for reading this! Hope you are as excited as I am!

Graham ☺

Appendix 3: Informed Consent form

INFORMED CONSENT FORM (SWIMMING)

TITLE OF PROJECT: Pacing strategies in middle distance running and swimming events.

Principal Investigator: **Graham Mytton**

Participant Number: _____

please tick where applicable

I have read and understood the Information Sheets.	☐
I have had an opportunity to ask questions and discuss this study and I have received satisfactory answers.	☐
I understand I am free to withdraw from the study at any time, without having to give a reason for withdrawing, and without prejudice.	☐
I agree to take part in this study.	☐
I would like to receive feedback on the overall results of the study at the email address given below. I understand that I can request access to my personal data by completing a subject access request form available from the principal investigator. Email address……	☐
I understand that I can request access to my personal data by completing a *subject access request* form available from the principal investigator.	☐

Signature of participant..... Date.....……..

(NAME IN BLOCK LETTERS).....……

Signature of Parent / Guardian in the case of a minor

.....

Signature of researcher..... Date.....……..

(NAME IN BLOCK LETTERS).....……

Appendix 4: Ethics approval

Faculty of Health & Life Sciences
Northumberland Building
Newcastle upon Tyne
NE1 8ST
Tel: 0191 227 4476

Tuesday 11th 2012

Dear Graham and Zig,

I am writing to you to inform that your submission to the Faculty Ethics Committee entitled "pacing strategies in middle distance running and swimming events" (code RE17-04-12813) has now been formally approved, and you are free to begin data collection. Please note however that the Committee recognizes that the proposed study raises some methodological concerns, and that the supervision team and Progression Board are responsible for monitoring these issues.

Yours sincerely,

NJ Neave

Dr Nick Neave (Chair)

Chair Faculty Ethics Committee

Dr Les Ansley

Chair of Departmental Subcommittee

Appendix 5: Athlete Training Diary

Athlete's Training Diary




Number: _____.

INFORMATION

Congratulations! You are being asked to take part in an exciting project with your swimming club. If that sounds good just read on and see if you still like the idea at the end!! ☺

I would like to monitor your training and race times over a season to see how they change. This will mean you will need to complete a training diary after every session showing things like how far and fast you swam. Once a month I will come to your training session and ask you to wear a heart rate monitor whilst you train. I will also be collecting your lap times when you take part in races.

If you can't take part or you don't want to that is fine. If you start the study and you don't like it and want to drop out then that is no problem either.

Thank you, for reading this! Hope you are as excited as I am!

Graham ☺

Instructions

Thanks for agreeing to take part in my study – the information you provide me will only be used to help me research the effects of swimmers' training on their race performance. However I hope you find it useful to record what you do and how you feel – just as an elite athlete would do every day too! There are 3 main sections to complete and they are outlined below:

Please record the date, time and location of your session.

Stage 1: log the details of **all the training** you have done in **this session**. You can complete this during training or straight after you have finished. Include **everything** you have done here whether it was in the pool or in the gym!

Date: Time: Location:

Set repeats	Swim repeats	Distance (m)	~~Average~~ time	Turnaround time	Training description

Please use an extra sheet if you need it!

This section is to record <u>all of your land and pool</u> training. If you need more space you can use an extra page or just squeeze it all in.

<u>30 minutes after</u> your session you need to tell me how your workout was today and how you feel today. Please complete all three tasks.

Stage 2: Tell me how you **feel** after your session. You need to rate **how hard** your session was out of 10, tell me how **happy or sad** you are using the faces below and finally tell me how **positive and negative** you feel. You need to do **<u>30 minutes after</u>** your session has ended.

A. How was your workout? *Circle a number*

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

B. Are you happy or sad? *Put a cross on the line.*

C. How do you feel at the moment? *Circle a number*

How positive do you feel right now?

1	2	3	4	5	6	7	8	9	10
Not at all positive									*Extremely positive*

How negative do you feel right now?

1	2	3	4	5	6	7	8	9	10
Not at all negative									*Extremely negative*

Stage 1: log the details of **all the training** you have done in **this session**. You can complete this during training or straight after you have finished. Include **everything** you have done here whether it was in the pool or in the gym!

Date: Time: Location:

Set repeats	Swim repeats	Distance (m)	Average time	Turnaround time	Training description

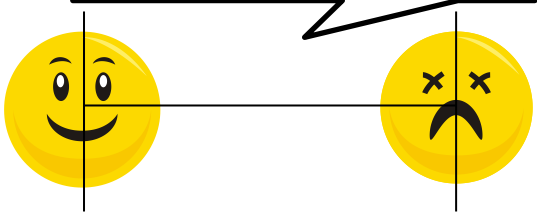
Please use an extra sheet if you need it!

Stage 2: Tell me how you **feel** after your session. You need to rate **how hard** your session was out of 10, tell me how **happy or sad** you are using the faces below and finally tell me how **positive and negative** you feel. You need to do **30 minutes after** your session has ended.

A. How was your workout?
Circle a number

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

B. Are you happy or sad?
Put a cross on the line.



C. How do you feel at the moment? *Circle a number*

How positive do you feel right now?

Not at all positive ***Extremely positive***

How negative do you feel right now?

2 3 4 5 6 7 8 9 10

Not at all negative ***Extremely negative***