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PhD Thesis

UNDERSTANDING AND IMPROVING PACING STRATEGIES DURING STANDARD DISTANCE TRIATHLONS IN AGE GROUP ATHLETES

Sam Shi Xuan Wu (M.Sc.)

This thesis is presented for the award of Doctor of Philosophy (Sports Science) from the School of Exercise and Health Sciences, Faculty of Health, Engineering and Science, Edith Cowan University, Western Australia

Principal Supervisor: Dr Chris R. Abbiss (Edith Cowan University)
Co-supervisor: Dr Jeremiah J. Peiffer (Murdoch University)
Co-supervisor: Prof Kazunori Nosaka (Edith Cowan University)

Date of Submission: 30 June 2014

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

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ACKNOWLEDGMENTS

This thesis is dedicated to my family, and all who have been part of this journey.

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ABSTRACT

Pacing is an integral aspect of performance during all exercise, including multi-sport events such as triathlon. However, to date, the optimal pacing strategies to adopt over an entire triathlon, as well as during each specific discipline (i.e. swim, cycle and run), is not well understood. Therefore, the primary purpose of this thesis was to identify and understand current pacing strategies adopted by highly performing triathletes across different triathlon distances. This research aids in identifying pacing strategies that may improve overall performance during triathlon.

In the first study, the influence of sex and race distance on the age-related declines in the sprint, Olympic, half-Ironman (HIM) and Ironman distance triathlons were examined. An earlier, larger and faster rate of decline ($p=0.01$) in performance with ageing was observed in females (≥30 years, 9.3%, 3.0% per decade respectively) and males (≥40 years, 5.9%, 2.2% per decade, respectively) for the longer events (half-Ironman and Ironman) compared with the shorter distances (sprint and Olympic, ≥50 years for both sexes). A larger magnitude of decline was observed in the swim discipline, as compared with the cycle and run disciplines (12.8%, 5.6%, 9.3% for females, 9.4%, 3.7%, 7.3% for males, in the swim, cycle and run disciplines, respectively). These results indicate that sex and race distance influence the age-related decline in triathlon performance and should be considered when manipulating training programs to attenuate the age-related declines in performance across different disciplines and distances. Furthermore, a greater emphasis should be placed on maintaining swim performance due to the rapid age-related decline observed in this discipline.

The second study within this thesis examined the influence of age and sex on cycle and run pacing during the sprint, Olympic, half-Ironman and Ironman distance triathlons in

top performing triathletes. Interestingly, females employed a more aggressive pacing strategy during the initial stages of the cycle discipline across all distances (sprint - 2.1%; Olympic - 1.6%; half-Ironman- 1.5%; Ironman - 1.7% higher relative to mean, as compared with males). Likewise, younger athletes (20-29 y) tend to start the run more aggressively during the sprint, Olympic and half-Ironman events (2.0 to 3.0% faster on average than other age-groups, $p<0.029$). These results indicate that various forms of pacing are adopted across different age-groups and sexes. Further, cycle and run pacing during triathlons also varies according to the distance of the event. Careful consideration of differences in biological sex, age and race distance should be taken into account when determining pacing in triathlon. Indeed, individuals may need to trial different strategies to develop their own optimal pacing profile for triathlon events of varying distances.

The purpose of the third study was to further examine the influence of distance on pacing during triathlon. The physiological response of well-trained age-group triathletes was examined during self-paced triathlons of varying distances. Eight well-trained male triathletes performed a sprint, Olympic and half-Ironman triathlon race, each separated by three weeks. Prior to the races, participants performed a cycle to exhaustion test to determine maximal aerobic power, $\dot{V}O_{2peak}$ and the power outputs corresponding to the first and second ventilatory thresholds,. A power meter (SRM) was fitted onto their bikes to determine power output and speed during the cycle discipline, while a global positioning system (GPS) was worn throughout the race to determine speed and heart rate throughout. The variability in power output during the cycle discipline was analysed using exposure variation analysis. Results showed that swim pacing was comparable across distances. Cycle pacing was similar during the sprint and Olympic cycle discipline (more even when compared with the half-Ironman). During the run, comparable pacing was observed during the Olympic and half-

Ironman (more positive when compared with the sprint). Power output during the cycle discipline of the half-Ironman was more variable (standard deviation of exposure variation analysis: EVA_{SD}=3.21 ± 0.61) than the sprint cycle discipline (EVA_{SD}=3.84 ± 0.44). The results of this study indicate that well-trained triathletes pace differently during triathlons of various distances. Athletes may need to trial different pacing strategies based on race distance, fitness, discipline-specific strengths and race conditions in order to determine their individual optimal pacing strategies.

The aim of the final study within this thesis was to determine the influence of pacing during the swim on subsequent sprint triathlon performance. Nine well-trained triathletes performed three sprint triathlons with different swim pacing strategies. The swim of the sprint triathlons were work matched but pacing was manipulated to be either positive (i.e. speed gradually decreasing from 92 to 73% of an initial swim time-trial), negative (i.e. speed gradually increasing from 73 to 92% of the swim time-trial) or even (constant speed of 82.5% of the swim time-trial). Subsequent cycling and running were completed at a self-selected pace. When compared with the even (31.4 ± 1.0 and 67.7 ± 3.9 min respectively) and negatively paced swim (31.8 ± 1.6 and 67.3 ± 3.7 min respectively), faster cycle and overall triathlon times were achieved with a positively paced swim (30.5 ± 1.8 and 65.9 ± 4.0 min respectively). A lower RPE was observed following the positively paced swim time-trial (9 ± 2) when compared with the negatively pacing swim (11 ± 2). No performance differences occurred during the run discipline between trials. This indicates that a more conservative swim start strategy may improve sprint triathlon performance in age-group athletes.

The aim of this series of studies was to examine the pacing of top non-drafting age-group triathletes across various standard triathlon distances, in order to understand and improve pacing strategies. The series of four studies in this thesis research project has demonstrated the influence of biological sex, age and distance on performance and pacing during various standard triathlons. The results of this study are of significance to athletes, coaches and sport scientists, as the different pacing strategies adopted in males and females across various age-groups and triathlon distances can have implications for training and racing. Further, a more conservative positive swim pacing strategy could benefit sprint triathlon performance.

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LIST OF PUBLICATIONS

Most chapters of this thesis have been previously published in, or are under consideration in peer-reviewed journals. These publications are outlined below.

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Wu S.S.X., Peiffer, J.J., Brisswalter, J., Nosaka, K. & Abbiss, C.R. (2014). Factors influencing pacing in triathlon. *Open Access Journal of Sports Medicine*, *2014*(5), 223-234.

Chapter Three

Wu S.S.X., Peiffer, J.J., Brisswalter, J., Lau, W.Y., Nosaka, K. & Abbiss, C.R. (2014). Influence of race distance and biological sex on age-related declines in triathlon performance. Part A. *Journal of Science and Cycling*, *3*(1), 41-47.

Chapter Four

Wu S.S.X., Peiffer, J.J., Brisswalter, J., Lau, W.Y., Nosaka, K. & Abbiss, C.R. (2014). Influence of age and sex on pacing during Sprint, Olympic, Half-Ironman and Ironman triathlons. Part B. *Journal of Science and Cycling*, *3*(1), 48-54.

Chapter Five

Wu S.S.X., Peiffer, J.J., Brisswalter, J., Lau, W.Y., Nosaka, K. & Abbiss, C.R. (in review). Pacing strategies of well-trained triathletes during the swim, cycle and run disciplines of a sprint, Olympic and half-Ironman triathlon.

Chapter Six

Wu S.S.X., Peiffer, J.J., Brisswalter, J., Lau, W.Y., Nosaka, K. & Abbiss, C.R. (in review). Positive swim pacing improves subsequent sprint distance triathlon performance in well-trained athletes.

Additional publications arising from PhD research

Brisswalter, J., Wu S.S.X., Sultana F., Bernard T., & Abbiss, C.R. (2014). Age-related changes in cycling efficiency and maximal power in well-trained cyclists**.** *European Journal of Applied Physiology*.

CHAPTER ONE INTRODUCTION

1.1 Overview

This doctoral thesis contains four research studies that are aimed at describing, understanding and improving the distribution of pace across various triathlon distances. Specifically, the purpose of this research is to identify the pacing strategies self-selected by top performing triathletes during the swim, cycle and run disciplines of the Sprint, Olympic, half-Ironman and Ironman triathlons, and to improve the pacing strategy of a standard distance triathlon. The first study was performed in order to understand the age- and sex-related changes in overall swim, cycle and run and entire race performances across the Sprint, Olympic, half-Ironman and Ironman triathlons. The second study was developed in order to identify the age- and sex-related differences in pacing during the cycle and run disciplines of the four standard distance triathlons. Following this, Study 3 examined the influence of distance on the physiological response and self-selected pacing during the swim, cycle and run disciplines of sprint, Olympic and half-Ironman distance triathlons performed by well-trained triathletes. The final study was developed to identify a superior pacing strategy for age-group triathletes during the sprint distance triathlon. All chapters within this document will be presented in the form consistent with publication (i.e. abstract, introduction, methods, results and discussion).

1.2 Background

Triathlon is a unique sport consisting of a sequential swim, cycle and run, performed over a variety of distances.[18] Since the first Hawaiian Ironman (3.8 km swim, 180 km cycle and 42.2 km run) race in 1978,[71,79] the popularity of the sport has dramatically increased. This resulted in the development of several shorter events: sprint (750 m swim, 20 km cycle, 5 km run), Olympic (1.5 km swim, 40 km cycle, 10 km run), and half-Ironman (1.9 km swim, 90 km cycle, 21.1 km run).[18] To date, research on triathlon has primarily focused on evaluating the biomechanical and physiological constraints surrounding the sport. This includes, but is not limited to, the complex training structures designed to stimulate specific disciplinary modes and the difficulty in negotiating swim-bike and bike-run transitions.[69,71,141] In order to further enhance athletic performance, an understanding of the physiological demands of this sport, in terms of event selection and distance is needed. Triathlon success is largely dependent on an athlete’s ability to generate continuous power output, sufficient to overcome resistive forces experienced (i.e. hydrodynamic drag during the swim and gravity and aerodynamic resistance during cycle and run).[3] The distribution of this power output is referred to as pacing or a pacing strategy and is an integral aspect of triathlon performance.[5,69] Power output or pacing during a triathlon may be influenced by several factors including fitness, fatigue, environmental conditions, race tactics and technique.[3,18,69] Further, since the physiological demand of each race is influenced by race distance, different pacing strategies may be required to complete each distance in the best possible time.

In recent years, pacing during the triathlon has received increased attention.[5,19,21,69,70,94,165] Regardless, the major focus has been on elite (ranked <125 in International Triathlon Union) triathlete performance, which may not be characteristic of lesser grade competitors.[21,142] For instance, in elite Olympic distance triathlons, athletes are allowed to draft during the bike leg, allowing participants to conserve a significant amount of energy in order to improve subsequent running performance.[68,72,73] Moreover, during an elite race, the position achieved during the swim discipline largely determines whether the elite athlete obtains an advantageous position in the lead bike pack, which subsequently affects the overall outcome of the race.[165] In contrast, it is against race rules to draft during the cycling portion of an age-group (non-elite) Olympic distance triathlon.[68,72,73] Research by Hausswirth et al.[72] has demonstrated higher heart rate, oxygen uptake, expiratory flow and significantly slower subsequent running speeds when cycling alone as opposed to drafting the bike leg of a sprint distance triathlon. As such, the physiological demands of age-group racing may differ considerably from that of elite racing.

While an athlete's overall velocity determines performance during a triathlon, the power output an individual generates during an event does not always relate directly to their velocity. Indeed, unpredictable external conditions, factors such as wind, temperature and topography can result in a discontinuity in power output and velocity.[144,167-169] In order to control for the effects of external conditions, the majority of recent triathlon pacing studies have been conducted under laboratory conditions.[11,12,34,50,70,73,111,148] Recent research, however, has identified discrepancy between results obtained from field settings when compared with laboratory testing.[69,167,169] For example, Vogt et al.[167] found that due to the abrupt changes in power output during professional road cycling, the time spent both below lactate threshold and 1mMol above the lactate threshold was lower when compared with experimental settings. Thus, comprehensive pacing studies conducted in the field are needed to help delineate optimal and sub-optimal pacing in triathlon.

The current field-based triathlon pacing research has focused primarily on the Ironman distance[5,89,92] and elite performance.[19,21,94,142,165,166] This research has shown that athletes typically pace positively (characterised by a gradually declining speed throughout the duration of an event[3]) during the Ironman distance triathlon possibly due to the development of fatigue.[5,88] It has been suggested that the physiological cause of fatigue during prolonged endurance exercise may be due to depletion of muscle glycogen stores,[30] increase in core body temperature[60,170] and/or the accumulation of metabolites such as potassium[15] and hydrogen[46] ions. While it is possible that similar physiological mechanisms control age-group triathlon pacing, differences in race regulations between elite and age-group subjects may result in differences in physiological stress during age-group and elite triathlon events. Thus, investigations towards the factors influencing pacing during various triathlons distance in age-grouped individuals are needed.

Since the self-selection of one's pacing can influence overall triathlon performance,[18,69] the manipulation of pacing strategies is a likely mechanism that can enhance an individual's performance. Indeed, studies of elite triathletes have previously shown that the position at 350-400 m into the swim is highly correlated ($r = 0.97$ and 0.99, $p<0.01$ for females and males, respectively) with the position reached at the end of the swim.[94] Isolated cycling position is also correlated with final position ($r = 0.68$ and 0.52, $p<0.01$ for women and men, respectively).[94] Further, running performance is well correlated with overall position (coefficients of correlation from 0.71-0.99, $p>0.01$)[94,165,166] during an Olympic distance triathlon. These findings indicated that the manipulation of any of these disciplines may alter overall triathlon performance. To date, only two studies have examined the effect of manipulation in pacing on triathlon performance. Hausswirth et al.[70] examined the effect of varying run speed during a simulated Olympic distance triathlon in a controlled setting. Running speed was altered for the first kilometre to 5% faster (+5%), 5% slower (-5%) or 10% slower (-10%) as compared with a control run (where -5% and -10% were close to overall mean speed achieved during the control run). Overall run time was observed to be faster in the -5% run (33 min 48 s) as compared with the +5% (36 min 18 s) and -10% (34 min 47 s), but not different with the control run (33 min 20 s). Additionally, Peeling et al.[121] investigated the effect of altering swim intensity on subsequent sprint triathlon performance. The authors manipulated swim velocity to 80-85%, 90-95% and 98-102% of a standalone swim time trial and found better overall triathlon performance with 80-85% as compared with the 98-102% pace.[121] Together, these findings indicate that age-group triathletes could benefit from manipulation in pacing during specific portions of a standard triathlon. However the optimal pacing strategies specific to triathlons of various distances remain unknown.

1.3 Significance of the Research

The multi-sport event that is triathlon requires careful manipulation of pacing in order to minimise fatigue and achieve the best possible performance. Despite a growing body of knowledge regarding exercise and pacing, there is very limited research pertaining to pacing in triathlon. Furthermore, the differences in pacing and performance across triathlon distances between sexes of various age-groups remain unknown. Therefore, research is required to further understand the age-, sex- and distance-related differences in pacing during triathlons, in order to develop pacing strategies to improve triathlon performance.

1.4 Purpose of the Research

The overall purposes of this PhD thesis was to understand and evaluate the pacing strategies adopted by triathletes of different age and biological sex in various triathlon distances, and to develop an improved pacing strategy for age group triathletes. Thus, the purpose of Study 1 was to examine the effect of biological sex on the age-related declines in swimming, cycling, running and overall performances within the sprint, Olympic, Half-Ironman and Ironman triathlons. Subsequently, the purpose of Study 2 was to investigate the influence of biological sex and age on the pacing strategies adopted during the cycle and run disciplines of the four triathlon distances. To investigate the specific influence of race distance on pacing in triathlon, Study 3 examined the self-selected pacing strategies and physiological responses adopted by well-trained triathletes during the swim, cycle and run disciplines of sprint, Olympic and half-Ironman distance triathlon races. Finally, the purpose of Study 4 was to investigate the effect of three swim pacing strategies on subsequent performance during a sprint distance triathlon.

1.5 Research Questions

The research questions in this PhD thesis are answered by four separate studies, as listed below:

1.5.1 Study 1

What is the influence of biological sex and age on swimming, cycling, running and overall performances during the sprint, Olympic, half-Ironman and Ironman distance triathlons?

1.5.2 Study 2

What is the effect of biological sex and age on pacing strategies adopted during the cycle and run disciplines in the sprint, Olympic, half-Ironman and Ironman distance triathlons?

1.5.3 Study 3

What is the influence of triathlon distance on pacing, power output and heart rate of well-trained triathletes during a sprint, Olympic and half-Ironman (HIM) triathlon?

1.5.4 Study 4

What is the effect of a positive (relatively fast-start), negative (relatively slow start) and even swim pacing on subsequent sprint triathlon performance?

1.6 Definitions of Selected Abbreviations

ANOVA: Analysis of variance

ATP: Adenosine triphosphate

ACT: Australian Capital Territory

bpm: beats per minute

EMG: Electromyography

EVA: Exposure variation analysis

EVA_{SD}: Standard deviation of the exposure variation analysis matrix

HIM: Half-Ironman

HR_{max}: Maximum heart rate

IP: Pacing index

MANOVA: Multi-variate analysis of variance

MAP: Maximal aerobic power

PB: Power band for exposure variation analysis

rh: relative humidity

SD: Standard deviation

SRM: Schoberer Rad Meßtechnik: A portable power monitoring system for bicycles

STT: Swim time trial

TB: Time band for exposure variation analysis

TT:	Time trial event
$\dot{V}O_2$:	Oxygen consumption
$\dot{V}O_{2\,max}$:	Maximal oxygen consumption
$\dot{V}O_{2peak}$:	Peak oxygen consumption
VT_1:	First ventilation threshold
VT_2:	Second ventilation threshold
$\bar{x}$:	Mean

CHAPTER TWO : REVIEW OF LITERATURE

FACTORS INFLUENCING PACING IN TRIATHLON

This review of literature provides the background information relevant supporting the research studies of this PhD thesis. The main focus of this review was to identify and illustrate the specific intrinsic and extrinsic factors influencing pacing in triathlon. Further, the effectiveness of current pacing strategies adopted in triathlon is discussed.

2.1 Abstract

Triathlon is a multi-sport event consisting of sequential swim, cycle and run disciplines performed over a variety of distances. This complex and unique sport requires athletes to appropriately distribute their speed or energy expenditure (i.e. pacing) within each discipline as well as over the entire event. As with most physical activities, the regulation of pacing in triathlon may be influenced by a multitude of intrinsic and extrinsic factors. The majority of current research focuses on the Olympic distance, whilst much less literature is available on other triathlon distances such as the sprint, half-Ironman and Ironman distances. Furthermore, little is understood regarding the specific physiological, environmental and inter-disciplinary effects on pacing. Therefore, this chapter discusses the pacing strategies observed in triathlon across different distances, and elucidates the possible factors influencing pacing within the three specific disciplines of a triathlon.

2.2 Introduction

Triathlon is a unique sport that consists of consecutive swim, cycle and run disciplines completed over a variety of distances. The origin of triathlon is unclear; however the first officially organised Ironman triathlon was conducted in Hawaii in 1978 with only 12 participants.[97] Over the last 30 years, the popularity of this sport has increased tremendously, driving the emergence of other shorter (i.e. sprint, Olympic, half-Ironman) and longer (i.e. double to 20x Ironman) distances as well as other formats of triathlons (i.e. off-road).[135] Of these, the most popular standard triathlon distances include the sprint (swim: 0.75 km, cycle: 20 km, run: 5 km, ~1 h), Olympic (swim: 1.5 km, cycle: 40 km, run: 10 km, ~2 h), half-Ironman (swim: 1.9 km, cycle: 90 km, run: 21.1 km, ~4-5h) and Ironman (swim: 3.8 km, cycle: 180 km, run: 42.2 km, 8-17 h). Due to the large variations in distances and thus exercise duration, the metabolic demands and physiological responses during such races are likely to considerably vary.[18,90]

It is well accepted that the distribution of speed, work or energy expenditure throughout an exercise task is extremely important to optimise performance.[3,49,50] This pattern of energy expenditure or distribution of speed is known as "pacing" and, although often used interchangeably, differs slightly to the term "pacing strategy" which refers to a conscious ‘strategy’ or plan to manipulate effort. Indeed, it has been proposed that the distribution of speed throughout an exercise task may be partially regulated on a ‘subconscious’ level,[112] and therefore presumably disjointed somewhat from the athletes’ pre-race strategy or plan. Within this context, energy expenditure is constantly regulated in response to complex interactions between peripheral feedback and central drive to ensure physiological systems are maintained within homeostatic or manageable limits, whilst delaying the negative effects of fatigue and thus maximising performance.[1,5,20,32-35] More recently, Edwards and Polman[44] introduced the concept of a "pacing awareness" model, which provides an alternative theory by proposing that pacing regulation occurs via relative states of awareness, ranging from minimum (sleep) to maximum (fully aware), rather than exclusive sub-conscious or conscious states. For instance, minor corrections in homeostasis require little or no conscious awareness to accomplish, however, strenuous activities involving large metabolic disturbances such as glycogen depletion necessitates a more conscious approach requiring significant behavioral alterations.[44] It is plausible that metabolic demands will differ among the several disciplines and various competition distances within triathlon and thus the levels of sub-conscious and conscious awareness.[5]

To date, studies examining the mechanisms that influence pacing have focused on single sport events such as running,[87,157] cycling,[8,10,49,50,102] swimming[140,154] and rowing.[53] The majority of these studies have identified possible factors regulating pace, including the availability of fuel substrates,[90,114,128] thermoregulation,[2,114] previous experience,[56,102,171] knowledge of exercise duration,[56,111] physical fitness,[128] cognitive capacity,[100] mood,[117,131] peripheral feedback[56] and central regulation.[3,90] However, the majority of these studies has been performed under laboratory conditions and may not precisely replicate the demands during actual triathlon competition. Understanding pacing during such events is complex since athletes are required to not only distribute their effort over the entire event but also over each independent discipline. Indeed, recent studies have demonstrated that the self-selected pacing patterns differ greatly during the swim,[94,121,165,166] cycle[5,21,94,165,166] and run[70,93,94,165,166] portions of triathlon events.

The sport of triathlon provides a unique model for pacing analysis, due to the involvement of sequential swim, cycle and run disciplines in continuum, and the ability to examine the influence of race distance on pacing. To date, a comprehensive review examining factors that may be responsible for differences in pacing over various triathlon distances and disciplines is currently lacking. As such, the strategy or strategies that assist in optimising performance during the various standard triathlon events is presently unclear. Therefore, the purpose of this review is to: i) identify factors regulating and influencing pacing in triathlon, ii) discuss the effectiveness and provide recommendations as to the currently adopted pacing strategies in triathlon, and iii) examine the influence and relationships of performance during individual disciplines on/with subsequent and overall triathlon performance.

2.3 Factors influencing pacing in triathlon

Of the multitude of factors influencing pacing, some important factors associated with triathlon performance include: exercise distance/duration,[98] race dynamics (drafting conditions,[69] influence of other competitors[16,156]), environmental factors (sea currents, wind velocities,[11,34] topography[12,18,148]), transitions (swim to cycle, and cycle to run), age,[45,94] and sex.[45,64,86] Of these factors, exercise duration appears to have the most significant influence on both the self-selected and the optimal pacing strategies selected by athletes during competition. Certainly, ultra-endurance events (>6 h)[175] induce greater neuromuscular fatigue than shorter events, possibly due to greater demands on metabolic substrates and psychological factors.[3] Despite the important role that exercise duration plays on pacing, there is currently no research which has extensively examined the influence of race distance on pacing in triathlon. Indeed, the majority of studies that have examined the distribution of pace within the triathlon have focused on the Olympic distance triathlon,[19,21,93,94,165,166] and only one study has investigated the cycle discipline of the Ironman.[5] Clearly, the abovementioned factors may influence the regulation of pace during triathlon to different extents. These factors are reviewed below, in the context of understanding the effectiveness of such strategies and providing recommendations for improved pacing.

2.3.1 Distance

Exercise duration appears to be one of the most important factors influencing both optimal and self-selected pacing.[17,27,63,65-68] Indeed, it is plausible that differences in race distance will have a significant influence on the mechanisms responsible for fatigue and thus athletes' pacing.[2] While a gradual reduction in speed (i.e. positive pacing) was observed in the Olympic[5,94,165] and Ironman distance triathlons,[5] the mechanisms responsible for such changes in pace are likely to vary. For instance, during shorter duration triathlon events (i.e. the sprint distance), the progressive reduction in pace may be associated with metabolite accumulation and accompanying neuromuscular fatigue. Indeed, the progressive reduction in speed during relatively short duration 200 m, 400 m[48] and 800 m[157] running events has been attributed to the accumulation of anaerobic metabolites, which in turn increases muscular acidity, impairing glycolysis[75] and muscular contractions.[46] However, during longer duration triathlons (i.e. half-Ironman or Ironman), fatigue is likely to be associated with reductions in muscle glycogen content[20,39,63,66,77,80] and neuromuscular activity.[2,58,103,106] For instance, reduced cycling time to fatigue and increased performance time during time trials were observed during cycling exercise without carbohydrate ingestion, as compared to carbohydrate supplementation.[39] Furthermore, a reduction in carbohydrate availability has also been shown to reduce cycling pace after ~2 h of prolonged exercise.[80] Supporting the reduction in neuromuscular activity during endurance exercise, St Clair Gibson et al.[58]

observed a progressive decline in EMG activity and mean power output of intermittent 4 km high intensity intervals during a 100 km cycling time trial.

Despite the different energy demands and physiological responses between triathlons of various distances, athletes of various calibre typically adopt a fast-start pacing regardless of race distance.[5,165] This fast start is likely to be caused by the high initial swim intensity required to achieve a good drafting position during the early portions of the swim discipline[165,166] (see *Section 2.3.2 Race dynamics and drafting in mass-start events*). Furthermore, data indicates that fast-start pacing may enhance oxygen kinetics and improve performance during short- to middle-distance (3-7 min) exercise tasks.[8,14,52] For instance, Bailey et al.[14] compared the effect of a fast-start, even-start and slow-start pacing strategy on 3 min cycling performance. The authors found superior performance with the fast-start (7% greater power output) which was attributed to a faster $\dot{V}O_2$ response. As such, it is possible that the adoption of a fast-start pacing strategy, especially during the swim discipline of shorter sprint triathlons, may enhance oxygen kinetics[27] and improve overall swim performance.[28] While the adoption of a fast-start pacing strategy minimises the time required to reach peak velocity and may improve performance during short explosive (≤ 2 min) sporting events,[3,34] the acceleration phase has limited influence on performance during longer endurance events. Instead, due to the prolonged nature of exercise in a triathlon (~1 h or more), the adoption of a fast-start pacing strategy could lead to sub-optimal distribution of energy resources and cause premature fatigue.[32,155] Under such circumstances, a more conservative pacing strategy which allows the conservation of glycogenic resources may be more ideal for overall performance.

While a fast-start pacing strategy is often observed during the beginning of triathlon (i.e. swim discipline), there is evidence to indicate that an even pacing, achieved by maintaining a constant velocity despite varying external (i.e. wind and altitude) conditions, may be ideal during endurance events such as the triathlon.[3,10,49,50,119] Within this context, endurance performance is compromised if an athlete's speed decreases below the average speed at any time throughout the event, even if they attempt to increase power output to make up for lost time during the final stages of the race.[51] This is because an increase in velocity requires a dramatic increase in energy expenditure to overcome the non-linear increase in resistive forces experienced.[139,174] Consequently, an even pacing results in the best possible balance of both propulsive and resistive forces thereby maximising overall performance during endurance events of varying distance. For instance, Le Meur et al.[93] observed that despite changes in gradient, the best runners during the 10 km run of an Olympic distance triathlon demonstrated a more even running pace and had a superior ability in limiting decrements in running speed during the later stages of the race. Likewise, Lambert et al.[87] investigated the pacing strategies adopted by 67 runners during a 100 km ultra-marathon running race and observed a tendency for the better (10 out of 67) performing runners to adopt a relatively even pacing during the first 50 km of a 100 km race. These runners also experienced the lowest reduction in running velocity during the second 50 km. It is possible that these runners have, to the best of their ability, attempted to adopt an even pacing strategy, but involuntarily slowed down due to significant metabolic[2,3,90,109,128] and/or psychological disturbances.[3,16,56,159] It is important to note that, although an even pacing may theoretically be optimal for performance during endurance exercise due to the balance of propulsive and resistive forces, this strategy may not be physiologically optimal. Indeed, large variations in power output to counteract external perturbations such as topography and wind *(discussed in Environmental factors below)* are required to maintain an even pacing strategy. Such changes in power output has been shown to increase physiological strain and reduce performance.[153] Under such circumstances, variations in speed to maintain a relatively even distribution of power output/energetic resources may likely be a more ideal strategy for athletes.

2.3.2 Race dynamics and drafting in mass-start events

Numerous factors associated with race dynamics may influence optimal and self-selected pacing in triathlon. The ability to conserve and maximise efficiency of one's energy is crucial for triathlon success. During mass-start events such as triathlon, athletes are often able to draft within a sheltered position behind another competitor.[68] This provides for an opportunity to conserve energy and plays an important role in both optimal and self-selected pacing.[159] For example, drafting behind a faster swimmer during the swim portion of a triathlon will conserve energy for the latter cycle and run disciplines, allowing an athlete to achieve a faster swim and overall performance time.[68] Certainly, drafting has been shown to improve swimming economy by reducing the drag force on the drafter (10 to 26%),[31,33,104] blood lactate concentration (31%), rating of perceived exertion (21%),[17] and oxygen consumption (5 to 10%).[17,33,38,110,116,136,147,148] The relatively fast speeds often observed at the beginning of triathlon events (especially for wave-starts or group starts) are therefore likely to be influenced by race dynamics. Indeed, starting at a swimming velocity faster than their mean speeds will allow athletes to achieve a strategic position behind the fastest swimmer, so as to conserve energy throughout the remainder of the swim, reduce the delaying effects of previous waves of swimmers, and allow them to be better positioned for the beginning of the cycle discipline.[94,165,166] For instance, during a 7-lap 40.2 km cycle draft legal World Cup triathlon, Vleck et al.[165] observed that male swim finishers who were not able to maintain a position within the lead swim group (within 13.6±8.5 s of the lead swimmer's finishing time) were unsuccessful in staying within the first two cycle packs by the end of lap one. Subsequently, these athletes had to cycle faster in laps two and three in order to "bridge the gap" by the end of lap three.

Similarly, drafting is extremely important to performance within the cycle discipline of triathlon. Drafting during cycling drastically reduces fluid resistance (i.e. aerodynamic drag)[68,69,72,73] and thus can conserve a considerable amount of energy. For example, in a simulated sprint distance triathlon, Hausswirth et al.[72] observed a reduction in oxygen uptake (-14%), heart rate (-7.5%) and pulmonary ventilation (-30.8%) when athletes were drafting 0.2 to 0.5 m behind a lead cyclist at an average speed of 39.5 $km \cdot h^{-1}$, compared with the non-drafting situation. Furthermore, the number of athletes present in the drafting pack may also influence the speed and energy utilisation, which has a significant influence on the subsequent run.[72] As such, the size and configuration of cycling packs as well as the tactical locations of athletes within a pack may considerably influence the distribution of exercise intensity within draft legal races. Rather than maintaining an even pacing, drafting in the cycle discipline likely induces a stochastic power profile due to acute tactical changes in pacing.[18,69] Indeed, Le Meur et al.[94] observed that, during a six lap 40 km cycle discipline of an elite Olympic distance triathlon, male athletes adopted an initial positive pacing during the first three laps, followed by a slight increase in speed during lap four, which was maintained until the end of the cycle discipline. In a separate 40 km elite Olympic distance cycle discipline, Vleck et al.[165] observed an entirely different pacing, where male athletes began with an increase in speed up to 50% of the distance (20.1 km), followed by decrements until 33.5 km, and increased thereafter till the finish. Collectively, these studies indicate that pacing during triathlons could be highly variable and rather than under the control of the individual, dependent on drafting and race dynamics. Indeed, the beneficial effects of drafting may limit an athlete to cycling in a pack, which is highly influenced by peer race tactics.[6,7]

Due to the importance of maintaining a position with the lead athletes during the cycle discipline, the pacing of top contenders during elite competitions is highly dependent on the pacing strategy of the leading athlete, who may attempt to maximise their lead, which may or may not be matched by other competitors. Therefore, pacing could be highly variable across the three disciplines. For instance, three studies[94,165,166] that have examined the pacing of elite athletes in draft legal races have collectively reported that these athletes typically adopt a positive pace during the swim, a variable pace during the cycle (characterised by fluctuations in speed) and a reverse J-shaped pace (explained below) during the run (Figure 2.1). A tactic commonly observed during elite races is the contribution of minimal effort during cycling in order to maximise run performance, which could partly explain the highly variable cycling pace.[94,165,166] Race dynamics may be further influenced by the strengths of the individual, who may adopt different pacing strategies in order to the maximise performance of a specific discipline. However, the influences of specific tactics and pacing strategies adopted by individual athletes on other competitors and race dynamics in triathlons are yet to be examined. Although elite athletes are permitted to draft during the cycle discipline of selected races, age-group triathletes are not.[21,93,94,165,166] For instance, in 'non-draft legal' events, athletes are required to maintain a specified distance behind the next competitor, and are given a specified time to pass the front athlete when overtaking. Specifically, a cycling distance of 7 to 12 m (draft zone) is maintained in the Ironman, and a passing time of 20 to 25 s enforced once entering the draft zone. The overtaken athlete then has the same specified time to drop back out of the draft zone. This difference in drafting ruling could significantly affect pacing during triathlon. Indeed, cycling during non-draft legal events is more similar to that of an individual time-trial, as reflected by the stability of power output during flat cycling in a triathlon race.[5,24] Under such conditions, race dynamics are likely to have less of an influence on cycling performance and thus athletes are likely to have a greater reliance on the intrinsic control over pacing. However, it is also important to note that despite the lack of drafting during the cycle discipline of some triathlon events, the race dynamics associated with mass start events is still likely to influence pacing. Indeed, non-drafting athletes are still required to be positioned near the leading riders to be in contention for a high finish place. Furthermore, regardless of drafting format, all athletes are permitted to draft during the swim and run disciplines of all triathlon events. Collectively, pacing during triathlon competition is likely to be dramatically influence by the actions and tactics of competitors, regardless of the specific drafting rules/regulations.

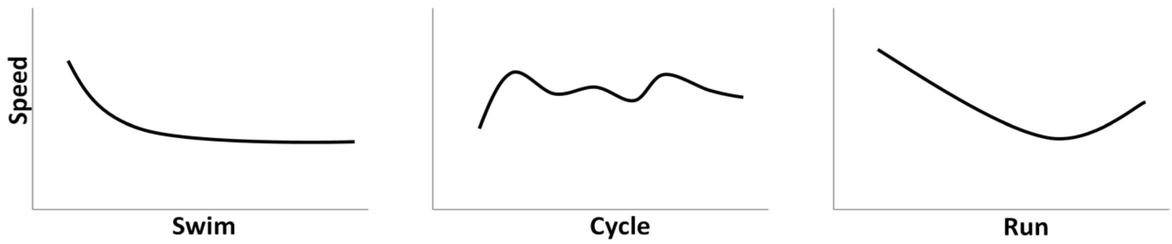

Figure 2. 1 Example of pacing adopted by elite athletes during a draft legal Olympic distance triathlon.

2.3.3 Environmental factors

While race dynamics are likely to increase the variability of exercise intensity within both draft legal and non-draft legal races, pacing could also be influenced by other external factors such as water currents, wind conditions,[5,11,57] topography,[12,21,57] environmental heat and humidity.[123] For example, a higher mean power output of 192±21 W was reported during women's world cup flat cycling races, as compared with 169±17 W observed during hilly races.[43] Conversely, power output during the Tour de France increased with increasing hill gradient. Specifically, average power outputs during flat, semi-mountainous and mountainous stages were 218±21 W, 228±22 W, and 234±13 W respectively.[169] It is important to note that when examining the pacing of athletes, the relationship between power output and speed is non-linear and therefore should not be used interchangeably, especially when external factors such as fluid resistance[11] and gravity[12] vary. Indeed, in an attempt to maintain an even pace, a variable power output is sometimes necessary to account for periods of high external resistance such as travelling uphill[12,13] or into a headwind.[11,13] For instance, Atkinson and colleagues[11,13] demonstrated in laboratory conditions that, when compared with a freely-paced trial, superior cycling performance was achieved when athletes increased power output uphill or into a headwind and decreased power output when external resistance was low (i.e. downhill and with a tailwind). However, no previous studies have examined the extent to which athletes adopt a varied distribution of power output in order to account for varying external conditions in actual triathlon competitions. Interestingly, a relatively even power output has been observed in well-trained triathletes during the cycle discipline of the Ironman[5] and half-Ironman events (unpublished data; Figure 2.2) despite fluctuating wind conditions. In this case, it is possible that maintaining physiological homeostasis, minimising neuromuscular fatigue and conserving metabolic reserves for the run may be more important during ultra-distance triathlons than the time saved from varying power output to counteract the effects of wind. Furthermore, the swim, cycle and run disciplines of triathlons are performed at different velocities and with dissimilar external resistances. Such differences in the resistance to locomotion will influence the degree of variation in energy expenditure necessary to adopt optimal pacing strategies.

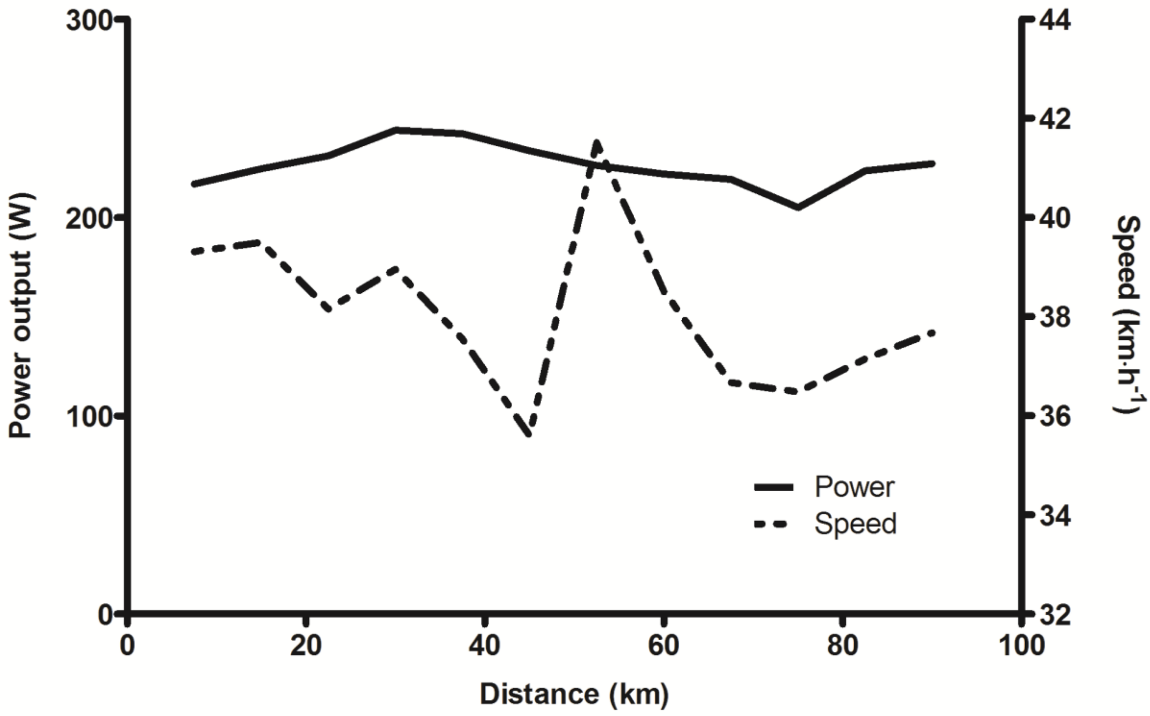

Figure 2. 2 Power output and speed of a well-trained triathlete during the cycle discipline of a half-Ironman event. Note the fluctuations in speed compared to a relatively even power profile.

During competitive triathlon events, it is possible that pacing may be further influenced by heat and humidity.[158,160] Peiffer et al.[123] observed an earlier decline in power output and subsequently lower average power output during a 40 km time trial at 32°C, as compared with 17°C, 22°C and 27°C. Although slightly different the pacing pattern observed were characterised by a gradual reduction in power followed by an increase towards the final stages of the trial.[123] Clearly, optimal pacing during triathlon in the heat will also depend on the abovementioned factors such as wind and topography, physiological characteristics, fitness and rate of athlete's heat dissipation. Further modeling research into the relationships between ambient temperature, power output, energy expenditure, drafting and external resistance is required to predict the optimal pacing strategies during different triathlon distances.

2.3.4 Transition

One of the challenges in triathlon is in successfully maneuvering the swim to cycle transition (T1) and cycle to run transition (T2). Indeed, the presence of a preceding swim before the cycle and the cycle before the run can negatively impact physiological stress and performance. For instance, Kreider et al.[84] observed a 16.8% reduction in power output during 75 min of cycling after 800 m swimming, compared with a control 75 min cycle without prior swimming. Similarly, Guzennec et al.[63] observed a significant increase in oxygen cost (51.2 versus 47.8 $mL \cdot kg^{-1} \cdot min^{-1}$) and heart rate (162 versus 156 bpm) during the 10 km run of an Olympic distance triathlon following cycling, as compared with a control run without prior cycling. Certainly, differences in muscle groups utilised,[18] energy expenditure and requirements between the swim to cycle transition[63,84,121] and cycle to run transition[25] may contribute to the complexity of pacing within triathlon. The sections below aim to illustrate the influence of T1 and T2 transitions on triathlon pacing in further detail.

2.3.4.1 Swim to cycle

The swim to cycle transition consists of changing from a sport that is upper body dominant to predominantly lower body, which may be difficult due to blood pooling in the upper extremities after swimming.[18] The detrimental effect of a prior swimming bout on subsequent cycling performance has been well documented.[37,38,63,84,120,121] Indeed, when preceded with a 1500 m swim (equal distance with an Olympic triathlon swim), an increase in energy cost (13% lower gross efficiency, 56% higher blood lactate concentrations, 9% higher heart rate, 5% higher $\dot{V}O_2$) was observed during the first 5 min of a 30 min cycle at

75% maximal aerobic power.[38] Nevertheless, the swim discipline within triathlon events is likely performed at a relatively high intensity, due to the importance of exiting the water in the lead group to form part of the first pack of cyclists, especially during draft legal races.[115,120,166] However, there is research to indicate that decreasing swim intensity decreases fatigue and improves overall triathlon performance.[121] Indeed, Peeling et al.[121] investigated the effect of swimming at 80-85%, 90-95% and 98-102% of the mean speed achieved during a control swim trial on subsequent cycle and run performance. They reported a faster cycling time when the swim was performed at 80-85% and 90-95%, as compared with 98-102%.[121] Further, a faster overall triathlon time was observed when swimming at 80-85%, as compared with 98-102%. This indicates that the pacing adopted during the swim of a triathlon not only affects subsequent cycling, but also has an influence on overall triathlon performance. As adopting a low swimming speed may be counter-productive to overall triathlon performance, especially during drafting events, improving swimming ability may be important for athletes to achieve a high swim finishing position without exceeding 90% of their maximal swim speed.[121]

2.3.4.2 Cycle to run

The negative effects of a preceding cycle bout on running performance is well known (for a review see Millet & Vleck, 2000[105]). These effects have been attributed to an increase in oxygen cost,[63,66,77,84] glycogen depletion,[63,66,77] muscle fatigue,[77] dehydration,[63,66,67] decreased pulmonary compliance, exercise induced hypoxemia,[29] muscle fatigue[66,101,172] and redistribution of muscle blood flow.[85] Novice athletes reportedly experienced loss of coordination[105] which is associated with changes in gait frequency (1.5-2.0 to 1-1.5 Hz in cycling and running, respectively), transitioning from a predominantly non-weight-bearing activity to one bearing two to three times of body mass[66,126] and shifting from primarily concentric contractions during cycling to eccentric contraction during running.[22] Therefore, it appears that careful pacing manipulation during the cycle discipline could benefit subsequent run performance. Indeed, it has been suggested that athletes may be able to alter power output and cadence during cycling in order to maximise subsequent running performance.[24,147,162,163] For instance, Bernard et al.[24] investigated the effect of pacing during a 20 km time-trial on subsequent 5 km running performance within the laboratory setting. The authors reported a significantly faster running performance after a constant intensity ride (1118±72 s) as compared with variable (1168±73 s) and freely chosen intensity (1134±64 s). These results indicate that an even cycling pace may be preferable during a sprint distance triathlon. In accordance with these findings, an increase in power output during the final stages of a 20 km cycling bout has been shown to be detrimental to 5 km running performance.[24] As such, during a World Cup Olympic triathlon, Le Meur et al.[94] observed a significant decrease in power output in both elite males (17%) and females (19%, $p<0.05$) from the first (lap 1) to last lap (lap 6), presumably an attempt to minimise fatigue and maximise subsequent running performance. Taken together, these studies indicate that, depending on the drafting nature and distance of the race, different combinations of pacing for specific disciplines of the triathlon are required for optimal performance.

It is plausible that the drafting nature of the race could affect pacing during triathlon transitions. During draft legal races, an increase in speed is sometimes observed during the swim to cycle transition[166] and cycle to run transition,[105,166] likely in attempt to achieve a prime position for the subsequent discipline. Indeed, there is data to indicate a positive relationship between transition time and finishing position of the cycle discipline.[105] However, there remains a paucity of research data which clarifies the effect of T1 and T2 on pacing during triathlon. There is, however, an abundance of research on the increase in speed during the final stages of a triathlon run. This sprint finish is widely referred to as an "end-spurt."[56,112,131,133] The end-spurt phenomenon is characterised by an increase in speed after 80-90% completion of the race when the athletes are supposedly most fatigued, and may be greater during draft legal races where race outcomes are more likely decided by a sprint finish. The end-spurt has been associated with an increased central drive, provided there is sufficient metabolic reserve[56] and pose no catastrophic risk to physiological homeostasis.[112,133] Yet, the maintenance of an overly large reserve capacity towards the end of the event could be evocative of ‘sub-optimal’ pacing, where a higher running velocity could have been maintained for a longer duration of the run discipline.[57,86,156,157] Therefore, the ability to manipulate run pacing such that energy stores are optimally utilised could highly influence triathlon performance. There is data to indicate that the run in a non-draft legal triathlon is performed without an end-spurt. Taylor et al.[152] compared pacing adopted during a sprint triathlon run, as compared with a control 5 km run, and found no differences in run pacing. Further, no increase in running speed was observed in the final kilometre. It is however important to note that laboratory simulated triathlons are usually performed as isolated trials and may not replicate the psycho-social factors and peer influence experienced during actual races. Further research is required to elucidate pacing strategies adopted during non-drafting triathlons.

2.3.5 Biological sex

The influence of internal and external factors on pacing may differ between males and females, due to internal (physiological and morphological[95]) and external (participation rates[35]) differences between sexes (for a review, see Lepers et al.[95]). The physiological differences have been attributed to a 12 to 15% lower $\dot{V}O_{2max}$,[143] 5 to 10% lower hemoglobin concentration, and ~8% higher body fat percentage in elite females, as compared with elite males.[81,95,96] Le Meur et al.[94] observed that during a World Cup Olympic distance triathlon, females spent a greater percentage of total time (45%) above maximal aerobic power when cycling up hills, as compared with males (32%). Females also tended not to bridge gaps that were formed during the cycle section.[165] These results are in accordance with those previously reported in events based on a single mode of locomotion, such as a cross-country mountain bike World Championships.[6] It is speculated that the lower maximal aerobic power to weight ratio in females results in greater time spent on uphill sections of the race.[94] Since it has been previously shown that better cycling performance results from minimising time spent travelling uphill[13] and adopting a more even distribution of speed, it appears that females could benefit from improving uphill riding performance or MAP/weight ratio.[6,94] Collectively, research on the pacing differences in cycling/triathlon between sexes indicates that external factors such as topography and wind are likely to be more detrimental to performance in females than males.[6,43,86,94,161,165] As such, it is possible that drafting may benefit females more than males in triathlon and cycling performance. This could alter pacing strategies adopted based on the drafting nature of the race. Indeed, it has been found that males typically begin the swim[165] and cycle disciplines[94] of draft-legal Olympic races with a relatively more "aggressive" initial starting pace, as compared with females. However, despite the aforementioned physiological and morphological differences between sexes, and the weight bearing nature of running,[86,95] male and female triathletes typically adopt similar positive pacing during draft-legal Olympic distance triathlon runs.[93,94] To date, the benefit of this positive pacing remains unclear.[93,94]

It is possible that different pacing strategies could be observed with males and females during non-drafting triathlons, due to the various extents of influence of race dynamics[95] and peer influence (participation rates and depth of field)[35] between sexes. For example, the sex differences in participation are generally higher in non-drafting triathlons compared with draft legal elite races. This difference has been shown to account for more than one third of the differences in sex variations in marathon running.[78] Therefore, further research is warranted to elucidate the specific differences in influence of physiological, sociological and possibly psychological factors on pacing between sexes.

2.3.6 Age

The decline in endurance performance due to advancing age is well-known.[22,95,96,129,150] The sex gap for the age-related declines in endurance performance remains at 10 to 15% until 50 years of age, and progressively widens thereafter.[95,96] The gap between sexes for overall triathlon performance ranges from 12 to 18.2%,[95] however shows a similar widening between sexes after 55 years in the Olympic and Ironman triathlons.[96,127] Further, the duration of triathlon also influences the age-related declines in triathlon performance. Specifically, more pronounced declines have been observed during shorter distance triathlons, as compared with the Ironman.[95] The age-related decline in triathlon performance have been attributed to a reduction in $\dot{V}O_{2max}$,[95,150] muscle strength and mass, attenuation of repair and hypertrophy of skeletal muscles,[164] lower resting muscle glycogen content,[98] and a reduction in training volume and intensity.[95] As these factors play a critical role in fatigue development, it is plausible that ageing can influence the distribution of self-selected pace by triathletes of different age-groups. However, there is no research on the influence of age on pacing in triathlon to date. Nevertheless, previous research has demonstrated the effect of age on pacing during prolonged endurance exercise.[99] Specifically, March et al.[99] investigated the age-related changes in pacing of 319 finishers during a marathon and reported that women and older athletes adopted a relatively more even pacing as compared with men and younger athletes. Certainly, the complexity of triathlon and the increase in oxygen cost during running in a triathlon[63] indicates that pacing during triathlon could alter with age.

2.4 Influence of performance throughout individual disciplines on subsequent triathlon performance

Due to the influence of discipline-specific performance on overall pacing in triathlon, it is important to understand the relationships between performance in each discipline and overall race time. Indeed, the performance time of each discipline differs and thus can influence overall triathlon performance to different extents.[63,66,70,94,121,165,166] Therefore, the inter-disciplinary associations are highlighted below. Performance during the swim discipline of a triathlon is likely to be of greater importance within shorter distance triathlons (sprint and Olympic), as compared with longer distance triathlons (half-Ironman and Ironman). Indeed, it has been shown that the position achieved during the first 200-500 m in a 1500 m Olympic distance triathlon swim largely determines the final swim outcome.[94,165,166] Supporting this, a significant correlation (r=0.99 and 0.97 for males and females, respectively) was observed between the position attained at 350 m into a swim of 1500 m and final swim outcome during a World Cup Olympic distance competition.[94] In a separate World Cup race, the final swim position and velocity was reported to correlate with overall race position (r=0.44 and r=-0.52, respectively).[166] Further, there is evidence to indicate that the decreasing swim intensity could benefit subsequent cycling and therefore overall sprint triathlon performance.[121] This implies that the pacing strategy adopted during the swim of a triathlon not only affects subsequent cycling performance, but may also have a global influence on overall triathlon performance.

During longer half-Ironman and Ironman distances, however, the percentage contribution of swimming to total race time is considerably lower (~10% and ~20% during longer and shorter distances, respectively).[90] Hence it has been suggested that the swim portion in longer triathlon events are not tantamount to overall performance.[91] Further research is warranted to clarify the relationship between the swim discipline and overall performance in various triathlon distances in both draft legal and non-draft legal races are warranted.

In draft legal racing, athletes commonly complete the bike discipline in packs (pelotons). The effect of pacing and performance during cycling appears to affect overall performance more than swimming, due to the high possibility of overall winners belonging to the first finishing bike pack. Indeed, during draft legal Olympic distance triathlons, a higher correlation was observed between overall performance and the cycle (r= 0.52 to 0.74) compared with swim discipline (r=0.36 to 0.52).[94,165,166] Presently, there is a lack of research on the effect of pacing during swim and cycle bouts on subsequent running performance.[63,152] Further research is warranted to determine the pacing strategies required for optimal pacing in disciplines prior to the run in a triathlon.

The run discipline of a triathlon is completed last and following considerable energy expenditure in the swim and cycle discipline. Additionally, the full weight bearing nature of running[92,98] is likely to induce more muscular fatigue and damage when compared with swimming and cycling. Certainly, a decrease in running efficiency after a previous cycling bout[63,66] indicates higher metabolic costs and which is likely to induce fatigue and affect performance. This is especially critical in triathlons where energy efficiency could play a significant role in determining performance.[71] Thus, it seems reasonable to postulate that performance during the run discipline would have the greatest influence on overall race position. Indeed, the higher correlations have been reported between running performance and final race position (r= 0.71 to 0.99) when compared with other disciplines during the Olympic distance triathlon.[94,165,166] However, further research is needed to determine the relationships between the three individual disciplines and overall standings during other triathlon distances such as the sprint, half-Ironman and Ironman.

A reverse J-shaped pacing is commonly observed during the elite 10 km Olympic distance triathlon run.[93,94,165,166] The reverse J-shaped pacing is characterised by a fast-start, followed by a reduction in speed, and subsequent increase towards the end of the run (for a review, see Abbiss et al.[3]). It is currently unclear whether a reverse J-shaped pacing is optimal for the triathlon run. However, due to the importance of run performance relative to overall performance, it is highly likely that optimising run pacing could benefit triathlon performance. To date, only a single study has investigated the effect of manipulating run pace on overall triathlon performance. Hausswirth et al.[70] (2010) investigated the effect of altering the first run kilometre (by 5% slower, 10% slower and 5% faster than the mean speed during a control run) during a simulated Olympic distance triathlon in ten highly trained male triathletes. They reported significantly faster 10 km performance in the -5% condition, as compared with the +5% and -10% condition. A slower run performance observed in the +5% trial was attributed to the down-regulation of exercise intensity in a feed-forward manner controlled by the brain, to prevent catastrophic failure of the physiological systems.[70] Further, a faster start requires higher metabolic demands,[26,50,76,154] which could result in premature fatigue prior to the end of the race as demonstrated by the +5% run. As such, an even to slightly slower start, which resultantly elicits a more even overall run pace, may be ideal for an Olympic distance triathlon run. However, further research is required to determine the optimal run pacing strategies during other triathlon distances.

Although there is extensive amount of triathlon research, no studies have systematically investigated the effect of distance, age and sex on triathlon pacing. Further modeling research is required to establish the relationships between pacing during individual disciplines and overall performance across different triathlon distances.

2.5 Conclusion

The understanding of pacing in multi-sport events such as the triathlon is still poorly understood. The manipulation of pacing in triathlon is complex, due to the sequential swim, cycle and run disciplines, and is attributed to the accumulated fatigue between disciplines. Further, triathlon pacing could be influenced by a multitude of intrinsic and extrinsic factors including wind velocity, topography, influence of other competitors, transition, age, drafting, biological sex and duration of event. It appears that a reduced intensity in prior swimming and cycling could result in faster subsequent cycling and running performance, respectively. However, the optimal pacing strategies across the sprint, Olympic, half-Ironman and Ironman triathlons are currently unclear. Further research is required to establish the best possible pacing strategies to adopt across various triathlon distances.

CHAPTER THREE: STUDY 1

INFLUENCE OF RACE DISTANCE AND BIOLOGICAL SEX ON AGE-RELATED DECLINES IN TRIATHLON PERFORMANCE

3.1 Abstract

This study examined the effect of biological sex and race distance on the age-related declines in swimming, cycling, running and overall performances of the sprint, Olympic, Half-Ironman and Ironman triathlons. Individual discipline and overall performance time of the top 20% non-elite males (n=468) and females (n=146) were compared by categorising into four 10-year age-groups (20-29, 30-39, 40-49, 50+ years) and normalising to the mean performance time of the fastest age-group for each race. An earlier, larger and faster rate of decline (p=0.01) in performance with ageing was observed in females (≥30 years, 9.3%, 3.0% per decade respectively) and males (≥40 years, 5.9%, 2.2% per decade, respectively) for the longer events (half-Ironman and Ironman) compared with the shorter distances (sprint and Olympic, ≥50 years for both sexes). A greater magnitude of decline was observed in swimming for both sexes, especially in the longer events, when compared with cycling and running (12.8%, 5.6%, 9.3% for females, 9.4%, 3.7%, 7.3% for males, in the swim, cycle and run disciplines, respectively). These results indicate that both race distance and biological sex influence the age-related decline in triathlon performance and could aid athletes in optimising training programs to attenuate the age-related declines in performance across different

disciplines and distances. Specifically, older athletes may benefit from greater emphasis on swim training and factors that may influence performance during longer distance triathlons.

3.2 Introduction

In physically active individuals, endurance performance is maintained until approximately 35 years of age, followed by modest decreases (5-10% per decade) up to 50-60 years, and progressively steeper declines thereafter.[150,151] Associated with these changes, the age-related decline in endurance performance appears to differ depending upon the duration of activity.[81] Indeed, Lepers et al.[98] observed a greater age-related decline in top 10 male cycle and run performance for the Ironman triathlon (~9 h), compared with the Olympic distance triathlon (~2 h), which may reflect greater physiological and mechanical demands associated with ultra-endurance events.[98]

Irrespective of exercise duration, sociological (non-biological) and physiological differences between sexes typically results in endurance performance being 10-15% slower in females compared with males.[96] Furthermore, this difference between sexes has been shown to widen with age,[149] possibly due to a greater rate of muscle mass loss in females, especially beyond menopause.[124] To date, majority of studies examining the interaction of age and/or biological sex on endurance performance have focused on sports such as swimming,[41,145,173] cycling,[42,137] running,[150] rowing[138] and duathlon.[135] Tanaka and Seals[149] examined the sex and age-related decline during the US Masters Swimming Championships and observed a greater decline in females compared with males over both short- (50 m) and long- (1500 m) duration events. Conversely, Schumacher et al.[137] found no interaction in sex differences during world track cycling championships for 200 m, 1000 m, individual and team pursuit races. As such, it appears that the influence of sex on the age-related declines in endurance performance may differ depending on exercise duration and interaction of different modes of locomotion.

To date, few studies have examined the interaction between sex and age during multi-sport events such as triathlon.[45,83,96,146] Triathlon is a unique sport that allows for comparison of the age and sex effects between sequential disciplines (i.e. swim, cycle and run) and over various race distances/durations (~1 to 17 h, for a review, see Lepers et al.[95]). Research examining the Ironman triathlon has shown similar declines in performance between sexes until 55 years, after which females declined at a significantly faster rate.[96] Furthermore, sex differences within this study were found to be greatest in the run, followed by the cycle and swim disciplines (18.2%, 15.4% and 12.1%, respectively). Conversely, in a separate study, an earlier divergence in sex difference was observed in the Olympic distance (after 35 y), with a slight difference in the gap between males and females over the various disciplines (i.e. run- 17.1%; cycle- 13.4%; swim - 15.2%[45]). Collectively, these studies indicate that the age-related declines in triathlon performance between males and females may depend on both discipline and race distance.

It is also important to note that the sex and age differences in performance could be affected by the drafting nature of triathlons. Indeed, the conservation of energy through drafting could influence race tactics, especially within the cycle discipline, and may significantly impact race outcome.[68] Consequently, careful consideration should be made when comparing drafting and non-drafting races.[146] Since the cycle discipline of non-drafting races is performed more similarly to an individual time-trial,[5] such races may provide an ideal model to examine the age- and sex-related changes in triathlon performance.

To date, however, we are unaware of any studies that have extensively examined the effect of biological sex and race distance on overall and discipline-specific performance over the four standard triathlon distances during non-drafting races (sprint: ~1 h, Olympic: ~2 h, half-Ironman: ~5 h and Ironman: ~8-17 h). Elucidating the effect of these factors on triathlon performance could help to identify training strategies necessary to improve performance in ageing male and female athletes. Hence, the purpose of this study was to examine the influence of biological sex and race distance on the age-related declines in swimming, cycling, running and overall performances during the sprint, Olympic, half-Ironman and Ironman distance triathlons.

3.3 Methods

3.3.1 Participants

Completion times for the swim, bike and run and overall triathlon of non-drafting top age group male and female participants (≥18 y) in four standard distance triathlons were examined. The distances included a sprint (n=245 for males and 95 for females), an Olympic (n=265 and 80), a half-Ironman (n=905 and 335), and an Ironman (n=925 and 220) triathlon as described below. In order to examine differences in performance amongst the best performing athletes, only the top 20% of non-drafting overall finishers in each age group of both sexes were analysed (as opposed to a specific number of athletes to minimise the disparities caused by dissimilar participation rates between age groups). Prior to data collection, ethical clearance was obtained from the Edith Cowan University human research ethics committee, in accordance with the Australian National Statement on Ethical Conduct in Human Research.

3.3.2 Procedures

To ascertain performance times, official race transponders were worn by participants throughout each race, which transmitted a time signal through a radio-frequency timing system at specific locations determined by the race organisers. The locations included the end of the swim, bike and run leg in each race (described below). The swim, cycle, run and overall race results were downloaded from official competition websites following each event. Racing commenced at 0720 hrs (±68 min) in all conditions with an open water swim. The sprint triathlon consisted of a 750 m swim, 20 km cycle and a 5 km run. The cycle leg involved four laps of 5 km circuit (highest elevation of 6.68 m) while the run was an out and back course (highest elevation of 11.1 m). Mean completion race time was 82±10 min (results from http://www.bluechipresults.com.au/default.aspx?CId=11&RId=2068). The 1.5 km swim, 40 km cycle, 10 km run Olympic distance triathlon was completed in a time of 166 ± 19 min (http://www.bluechipresults.com.au/default.aspx?CId=11&RId=2064). The bike leg consisted of four laps of 10 km with a highest elevation of 6.59 m, and the run was three laps of 3.33 km with an elevation of 2.26 m. The mean completion time for the half-Ironman event (1.9 km swim, 90 km cycle, 21.1 km run) was 333±43 min (http://www.bluechipresults.com.au/Results.aspx?CId=11&RId=6032&EId=1). Following the swim, participants performed a two lap (45.05 km each) bike course with a highest elevation of 21.3 m, followed by a three lap (7.03 km each, elevation of 1.5 m) run. The Ironman event (3.8 km swim, 180 km cycle, 42.2 km run) was completed in 708±97 min (http://www.ironman.com/triathlon/events/asiapac/ironman/western-australia/results.aspx?rd=20111204). It was held in the same vicinity of the Busselton half-Ironman and includes a one loop swim, three loop bike ride (elevation change of 12.3 m) and 4 loop run (elevation change of 1.5 m).

3.3.3 Data processing

Based on the official timing system, the elapsed time for each discipline and entire course was determined for each of the participants in all distances (Table 3.1). To allow detection of meaningful differences, athletes were separated between sex (male and female) and into four 10 y age-groups (20-29, 30-39, 40-49, 50+ y inclusive). Since the minimum age of athletes in the sprint and Olympic distances was 20 y, all 18-19 y old participants in the half-Ironman and Ironman events in this study were included in the 20-29 y age group for analysis.

To allow meaningful comparisons between groups (i.e. biological sex, age group, race distance and disciplines) and to reduce the influence of environmental, topographical, distance factors and performance outliers, a ratio of the age-related decline in performance was calculated. The performance ratio is defined as the mean swim, cycle, run and overall performance time of each individual normalised to the mean performance time of the fastest age group in the respective sex, distance and race:

Performance ratio = Mean performance time of discipline by individual / Mean performance time of fastest age group for that discipline in the specific race.

The magnitude of decline (from 20 to 50+ y) was determined for the overall, swim, cycle and run performance ratio collectively over the four distances, and also for the shorter (sprint and Olympic) and longer (half-Ironman and Ironman) distances separately. As analysis showed no significant difference in performance ratio between the Sprint and

Olympic, or the half-Ironman and Ironman distances (Figure 3.1), the two shorter and two longer distances were combined for subsequent analysis to allow a distinct comparison of the distance effect on performance. The rate of decline in performance was calculated for each discipline and each race distance based on the linear relationship between age and the performance ratio of each decade. A linear relationship was determined for the shorter and longer distances separately. The percentage of time spent in each discipline relative to the overall race completion time (i.e. relative contribution time) was determined for each event. The standard deviation of the performance ratio for each discipline was compared to examine the variability in performance between disciplines.

Table 3. 1 Overall, swimming, cycling and running performance times for the top 20% of female (F) and male (M) in each age group at the sprint, Olympic, half-Ironman and Ironman distance triathlons. Values are expressed in minutes (mean±SD).

	Sprint (min)				Olympic (min)			
Age Category	Overall	Swim	Cycle	Run	Overall	Swim	Cycle	Run
F20-29	76.0±2.9	13.3±1.5	41.0±1.6	21.8±1.4	154.4±3.5	25.0±1.5	80.8±3.3	48.5±2.4
F30-39	77.9±3.5	14.6±1.4	41.5±2.4	21.7±1.5	157.2±6.4	29.3±2.9	78.2±2.3	49.7±4.3
F40-49	74.3±1.5	13.9±1.3	39.4±1.0	21.0±1.1	153.0±2.3	28.3±2.8	77.6±0.7	47.0±2.7
M20-29	67.9±2.0	12.5±1.4	36.2±1.7	19.2±1.3	142.2±4.3	26.8±2.2	72.0±2.6	43.4±3.2
M30-39	68.7±3.0	12.9±1.3	35.8±1.6	20.0±1.5	144.9±5.6	29.1±3.3	71.4±2.4	44.4±3.5
M40-49	68.8±1.6	13.1±0.9	35.8±1.3	20.0±0.8	147.0±4.2	28.3±1.8	72.1±3.0	46.6±3.1
M50+	71.3±1.3	13.5±1.4	37.1±1.5	20.6±1.0	146.5±4.1	28.8±2.9	72.6±2.9	45.0±3.3

	Half-Ironman (min)				Ironman (min)			
Age Category	Overall	Swim	Cycle	Run	Overall	Swim	Cycle	Run
F18-29	296.2±8.8	31.2±2.9	160.4±6.4	100.5±5.8	621.9±14.2	62.5±4.0	329.8±10.1	222.5±9.6
F30-39	309.6±13.5	33.5±3.5	164.9±6.6	106.5±8.0	644.9±22.9	66.5±6.4	335.1±14.3	236.2±14.0
F40-49	320.4±8.1	36.0±1.9	167.6±4.6	111.9±6.8	646.2±32.8	65.1±3.4	329.1±12.6	245.2±24.5
F50+	317.7±17.3	34.8±3.5	165.1±5.2	112.8±11.3	704.9±24.7	73.8±7.6	359.8±16.0	261.7±18.0
M20-29	274.0±11.6	29.6±3.3	148.0±7.3	92.8±9.3	577.0±20.7	58.0±5.4	304.5±13.4	209.0±15.3
M30-39	275.3±7.9	31.2±2.6	146.9±4.6	93.3±5.4	577.3±22.7	58.6±5.0	302.6±11.1	210.6±14.5
M40-49	284.8±11.2	31.6±2.8	150.1±6.9	98.6±7.5	615.4±32.7	62.4±7.3	315.2±18.3	230.0±19.3
M50+	289.9±10.4	32.1±3.0	153.4±6.8	99.9±5.9	615.7±26.7	65.2±5.3	317.0±11.9	225.7±14.8

3.3.4 Statistical analysis

All statistical tests were conducted using PASW Statistics (version 18.0, Chicago, Illinois). The magnitude of decline and performance ratio for the overall, swim, cycle and run of each age group were compared between distance, age groups and sex using a three-way analysis of variance (ANOVA). Comparisons between dependant variables were analysed using a two-way ANOVA followed by Gabriel's post-hoc. The relative time contribution of each discipline as a percentage of overall performance time (irrespective of sex) was compared between race distances using a one-way ANOVA. The standard deviation of the performance ratio of each discipline was compared using a one-way ANOVA. Games-Howell post-hoc test was used to determine where the differences lie. Significance was set at $p<0.05$. All results are expressed as mean±SD.

3.4 Results

The swimming, cycling, running and overall performance ratio of the top 20% male and females are presented in Figure 3.1. Collectively over the four distances, an earlier and greater magnitude of age-related decline (from 20 to 50+ y, $p=0.014$) was observed in overall performance of females (≥30 y, 8.4%) when compared with males (≥40 y, 5.6%). In the shorter distances, overall performance was maintained up to 49 y in both sexes, and the magnitude and rate of decline in overall performance were not significantly different between sexes (3.8%, 1.2% per decade for males, -1.6%, -0.80% per decade for females, respectively). In the longer distances, an earlier, larger and faster rate of decline ($p=0.01$) was observed in the females (≥30 years, 9.3%, 3.0% per decade, respectively), compared with males (≥40 y, 5.9%, 2.2% per decade, respectively).

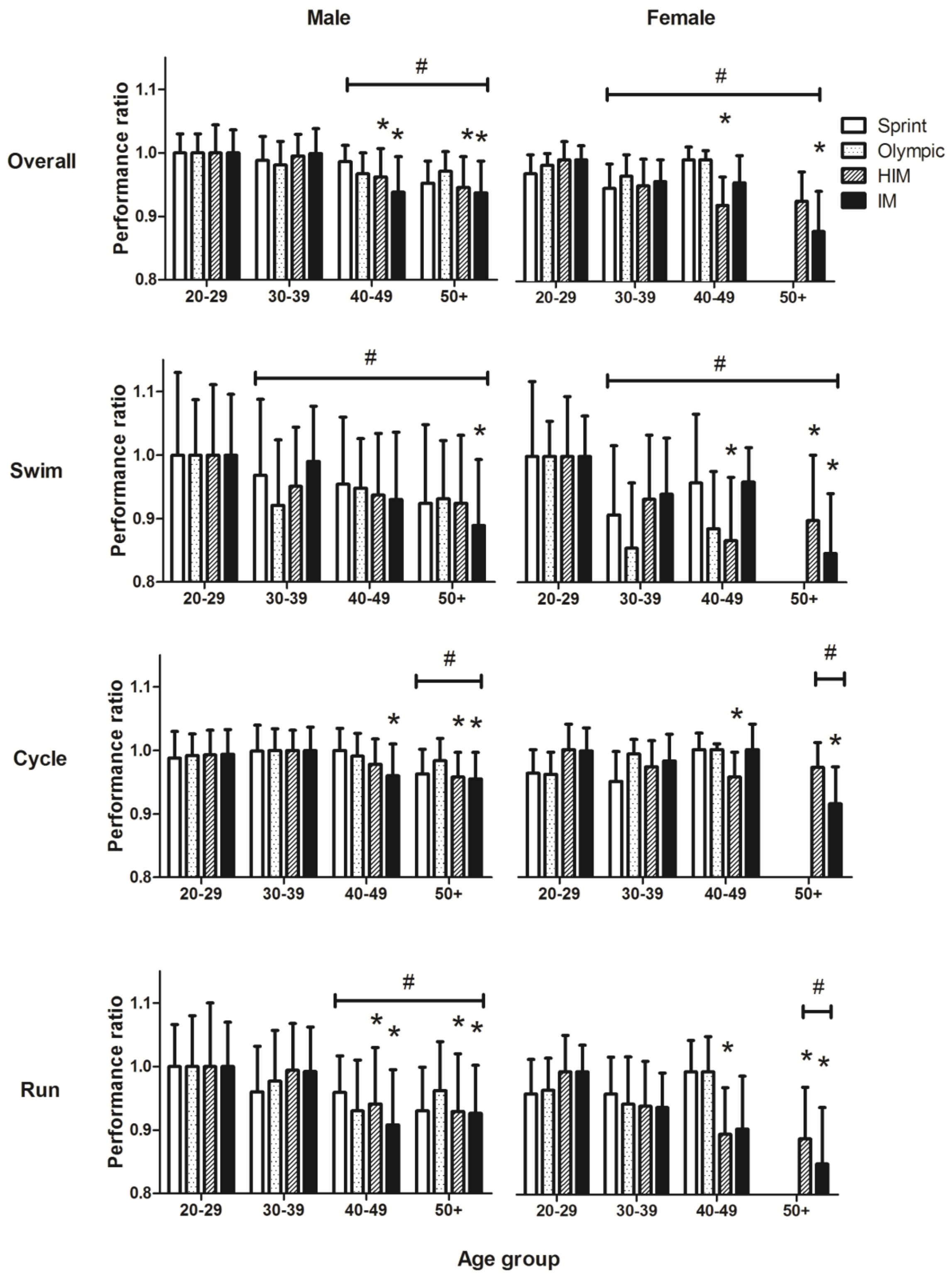

Figure 3. 1 Overall, swim, cycle and run performance for the top 20% male and female in each age group (20-29, 30-39, 40-49, 50+) for the sprint, Olympic, half-Ironman (HIM) and Ironman (IM) distance triathlon. #: significantly slower than younger age group. *: significantly slower than fastest age group in the respective distances.

Discipline-specific analysis revealed that, in the shorter distances, an initial age-related decline in swim performance was observed after 29 y for both males and females, and the magnitude of decline was similar between males (7.3%, p=0.011) and females (7.9%, p=0.01, Figure 3.1). No significant difference in decline during the cycling and running performance was observed between males (1.6% and 5.4% respectively) and females (-3.8% and -3.3% respectively) in the shorter distances. During the longer events, female performance decreased to a greater extent (12.8%, 5.6% and 9.3%, p=0.01) as compared with males (9.4%, 3.7% and 7.3%, p=0.01) across the swim, cycle and run discipline respectively. During the run discipline in the Ironman, the initial age-related decline in male performance was observed after 39 y (p=0.002), compared with 49 y in females (p=0.012).

Relative time contribution of the swim, cycle and run discipline towards overall performance time was not significantly different between sexes. The relative contribution of the swim discipline during the shorter distances, regardless of sex, was higher (18.7%), compared with the longer distances (10.6%, p=0.01). The relative time contribution for the run discipline significantly increased with each increasing race distance (28.6, 31.1, 34.5, 36.8%, p=0.01, for sprint, Olympic, half-Ironman and Ironman distance, respectively; Figure 3.2).

The standard deviation (indicating within group variability) of the normalised performance ratio in both males and females for each discipline increased significantly in the order of cycle < run < swim (Figure 3.1, p=0.038), however, no differences were observed between sexes for all disciplines.

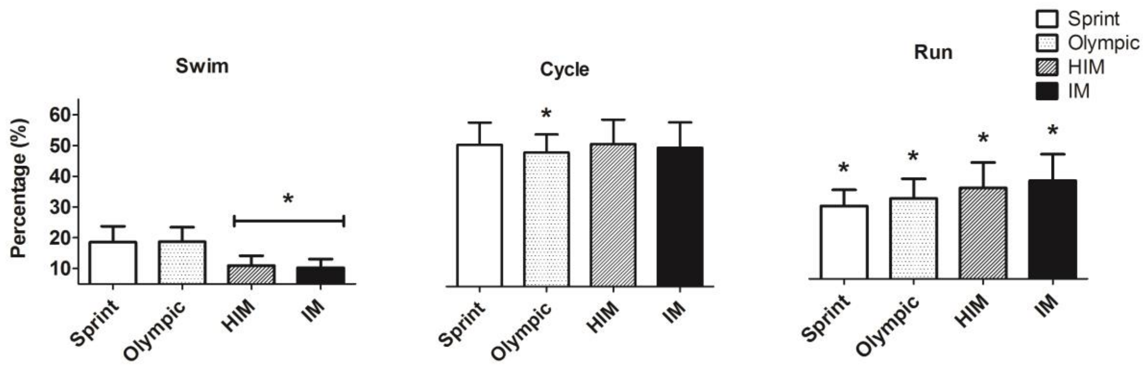

Figure 3. 2 Percentage of total time spent on each discipline (swim, cycle and run) during the sprint, Olympic, half-Ironman (HIM) and Ironman (IM) distance triathlon. *: significantly different from other distance/s.

3.5 Discussion

The present study examined the effect of biological sex and race distance on the age-related decline in swimming, cycling, running and overall performances during a sprint, Olympic, half-Ironman and Ironman distance triathlon in top 20% non-elite finishers. To the authors' knowledge, this is the first study to compare the effect of biological sex and age on age-related declines in triathlon performance across the four standard triathlon distances. The main findings are that: i) collectively, triathlon performance decreases with increasing age, however to a greater extent and faster rate in females during longer distance racing, ii) performance decline in all disciplines occurs at an earlier age in the longer (half-Ironman and Ironman) races as compared with the shorter (sprint and Olympic) distances in both sexes, and iii) swim performance decreases at an earlier age compared with cycle and run regardless of distance.

In this study, the decrease in overall triathlon performance with age was observed beyond 39 years in males and 29 years in females, with a marked decline in performance beyond 50 years for both sexes. Such age-related declines in performance have been attributed to a reduction in maximal aerobic capacity,[95,150] loss in muscle strength and muscle mass, reduced satellite cell content that is essential for the repair and hypertrophy of skeletal muscle,[164] declines in gluconeogenic and glyconeogenic capabilities,[125] and a reduced training "stimulus" with advancing age. [98,132] Furthermore, the greater age-related decline in overall triathlon performance observed in the females, compared with males, is associated with greater post-menopausal strength loss[81] and higher susceptibility to deteriorations in maximal aerobic capacity.[149,150] Indeed, the magnitude of decline in overall performance from age 20 to 50+ years across all distances was 8.4% for females, compared with 5.6% for males.

Non-biological factors such as participation rates could partly explain sex-related performance differences.[95] The attrition in participation numbers increases with age, especially in the female population.[95,96] As a result, the lower percentage of females compared with males (24% vs 76% respectively), could account for a higher variability in female performance, as indicated by a larger but insignificant increase in the standard deviation of performance ratios in females across all disciplines and overall performance. In an attempt to partly account for this, we examined only the top 20% of all male and female athletes in each age group rather than a predetermined sample size (e.g. the top 10 athletes). Importantly, it should be noted that the differences between male and female performance were not consistent across different race distances and triathlon disciplines.

The effect of distance on the age-related decline in performance was not apparent between the two shorter distances for overall, swim, cycle and run disciplines from 20 to 50+ years, with the fastest mean time for females in both distances observed from 40-49 years.

This novel finding is indicative of a protective effect against loss in functional muscle strength produced by the training load of the top 20% athletes, which could assist in maintaining exercise performance in the shorter events.[74] However, an earlier age-related decline was observed in both males (≥40 years) and females (≥30 years) during the longer half-Ironman and Ironman. Indeed, it has been shown that self-selected exercise intensity progressively decreases during endurance events lasting more than 4 h, attributed to the psychological and metabolic factors of neuromuscular fatigue.[3] In addition, the importance of optimising pre-exercise metabolic reserves and substrate utilisation during the event through manipulations of diet becomes increasingly crucial with longer race duration.[90,159] In older athletes, the reduction in muscle cross-sectional area which reduces overall muscle oxidative enzyme activity and muscle capillarisation,[134] coupled with a lower reliance on fat metabolism during moderate intensity exercise and lower resting muscle glycogen stores,[107] could help to explain the larger decrease in performance.

When examining performance within each discipline, the magnitude of decline for both sexes was greatest during the swim, followed by the run and then the cycle discipline across all distances (Figure 3.1). This pattern of decline among the different disciplines is similar to previous research on Olympic[45,98] and Ironman[96,98] distance triathlons. This observation could reflect the different physiological demands of the various disciplines. For instance, swimming requires high physical capacity and strength,[54] which is impaired with age due to sarcopenia. Similarly, the more rapid atrophy of fast twitch fibres, compared with loss of slow twitch fibres with age,[47] could be more debilitating to run than cycle performance due to the stretch shortening cycle in running. One could perceive more benefit from an emphasis on cycling, due to the relatively lower percentage of race time spent during swimming (~15%) and running (~33%), compared with cycling across distances (~52%,

Figure 3.2), as indicated, at least in part, by the smallest age-related decline in cycling among the 3 disciplines across distances and sex (Figure 3.1).

Interestingly, the initial decline in run performance for males was observed after 39 years, compared with 49 years in females. The later decline in females may be due to enhanced fat metabolism during exercise, thereby conserving carbohydrate stores.[82] Indeed, since running is the last discipline during a triathlon, conservation of carbohydrate stores would likely be more advantageous to run performance. Furthermore, post hoc analysis revealed that this sex bias in running performance was observed in the Ironman event, which is highly influenced by carbohydrate availability.[2] These results are in accordance with recent observations of elite females reducing the gap between sexes for the marathon run of the Ironman distance.[95] Further research is needed to examine the physiological factors that may be associated with the sex, distance and discipline specific biases observed in the age-related decline in performance.

The main limitation of this study was a lack of physiological data pertaining to participants (i.e. thresholds, aerobic capacity and anthropometrical data) to further elucidate the relationship between sex, age and performance in various triathlon distances. However, this is the first study to examine the age-related decline endurance exercise during various triathlon distances in both sexes, and offers novel data which could influence methods of training in triathlon. Furthermore, the large number of participants in this study increases the reliability and applicability of these results to the four standard triathlon distances.

In conclusion, triathlon performance in the sprint and Olympic distance is maintained up to 50+ years for both sexes, but decreases earlier during longer distance racing due to higher metabolic demands of the half-Ironman and Ironman events. This decrease is more apparent in females, and could be due to a greater decrease in maximal aerobic capacity and loss in muscle strength. A greater magnitude of decline was observed in the swim as compared with and cycle and run discipline across distances. These observations can have implications for athletes and coaches in developing training programs and race strategies to assist in attenuating the age-related decline in triathlon performance. Future studies providing in-depth race analysis and the physiological responses of athletes during various distances could further our understanding of the influence of sex and age on triathlon.

CHAPTER FOUR: STUDY 2

INFLUENCE OF AGE AND SEX ON PACING DURING SPRINT, OLYMPIC, HALF-IRONMAN AND IRONMAN TRIATHLONS

4.1 Abstract

The aim of this study was to investigate the influence of biological sex and age on the pacing strategies adopted by non-drafting top age group triathletes during the cycle and run disciplines of a Sprint, Olympic, half-Ironman and Ironman triathlon. Split times of the top 20% non-elite males (n=468) and females (n=146) were determined using official race transponders and a video capture system for pre-determined sections of the cycle and run disciplines of four triathlon distances. Indices of pacing were calculated to compare between sexes and age groups. Results of this study indicated that different pacing strategies were adopted between athletes of different age and sex over the various triathlon disciplines and distances. Females were more aggressive during the initial stages of the cycling discipline across all distances (sprint - 2.1% p=0.024; Olympic - 1.6%, p=0.011; half-Ironman- 1.5%, p<0.001; Ironman - 1.7%, p<0.001 higher relative to mean) compare with males. Younger athletes (20-29 y) tend to begin the run faster (2.0 to 3.0% faster than other age groups, p<0.029) during the sprint, Olympic and half-Ironman triathlons. These results indicate that different pacing strategies are adopted by non-drafting top athletes of different age and sex. Optimal pacing strategies may differ between sex and ages; therefore individuals may need to trial different strategies to develop their own optimal pacing profile for triathlon events of varying distances.

4.2 Introduction

The optimisation of pacing during triathlon is a challenging task, due to the difficulty in successfully negotiating different disciplines (i.e. swim, run and bike) as well as the overall event.[18] Previous research examining pacing in triathlon has focused on draft-legal Olympic distance triathlons[21,94,165] (~2 h), with only a single study examining cycling pacing during the longer non-drafting Ironman distance[5] (8-17 h). As such, the distribution of pace throughout the sprint (~1 h), half-Ironman (~5 h), and to an extent Ironman events are yet to be fully identified. It is likely that different pacing strategies could be adopted due to the influence of factors such as energy substrate demand and availability (muscle and liver glycogen), thermoregulation,[113] mental fatigue,[100] impaired muscle function and recruitment,[113] and the complex feed-forward cognitive control of the brain based on the expected duration of the event.[56,113,159]

Based upon previously published observations in Olympic distance triathlons, it appears that elite athletes typically adopt a positive pacing (characterised by a progressive decrease in power output/or speed) during the swim, cycle and run disciplines.[94,166] For instance, Le Meur et al.[94] observed a more pronounced decrease in the cycling speed for males (16.8%) compared with females during the first half of the cycling discipline in a World Cup Olympic distance triathlon. These results indicate that males may have adopted a more aggressive pacing strategy during the triathlon when compared with their female counterparts. Nevertheless, the draft-legal nature of these studies,[21,94,165] along with a greater number of overall male competitors is likely to have highly influenced the pacing strategies adopted. To date, we are unaware of any studies that have yet examined gender differences in pacing strategies during the other three common (sprint, half-Ironman and Ironman) triathlon distances.

Whilst studies have observed an age-related decline in male and female triathlon performance,[45,96,98] the influence of advancing age on pacing adopted during a triathlon has not been investigated. The decline in performance beyond 50-55 years of age[96,98] has been attributed to numerous physiological alterations, including reductions in muscle mass (sarcopenia), changes in muscle typology, lower resting muscle glycogen content, altered training and reduced training stimulus,[98] decrease in lactate threshold and reduced maximal oxygen uptake with advanced ageing.[96,97] Since all of these factors are associated with fatigue, they could, to various extents, influence the distribution of self-selected pace by triathletes of different ages.

Due to the lack of data elucidating the pacing strategies during non-drafting triathlon races of various distances in males and females across different age groups, the aim of this study was to examine the effect of biological sex and age on pacing strategies adopted during the cycle and run disciplines in the sprint, Olympic, half-Ironman and Ironman distance triathlons. Results of this study could help to optimise triathlon performance in athletes of varying age and biological sexes. It was hypothesised that a more pronounced decrease in speed (i.e. positive pacing) would be observed in older compared with younger athletes. It was further hypothesised that that males would adopt a relatively faster starting strategy when compared with females, for both the cycle and run disciplines across the four triathlon distances.

4.3 Methods

4.3.1 Participants and procedures

Speed during the bike and run sections of the top 20% age group male and female participants (≥18 y) in a sprint (n=245 and 95 for males and females, respectively), Olympic (n=265 and 80), half-Ironman (n=905 and 335) and Ironman triathlon (n=925 and 220) were examined (detailed description of participants and triathlons found in Chapter 3.3 of this study). All competing athletes were monitored, however, only the non-drafting top age group athletes were selected for data analysis due to the influence of drafting which is allowed in selected elite or "open" races which could dictate pacing. No guidelines were given to participants regarding pacing and diet intake prior to and during the race. All swims were performed in open water. Prior to data collection, ethical clearance was obtained from the Edith Cowan University human research ethics committee, in accordance with the Australian National Statement on Ethical Conduct in Human Research.

4.3.2 Data processing

Performance times were determined by means of official race transponders. Additional splits of equal distance were obtained with a video capture system (Sony HDRHC9, Japan) recording at 25 Hz. The number of splits was determined by the closest denomination from distance for each race. A total of five cycle splits (S1 to S5) were obtained for the sprint and Olympic distance, while six (S1 to S6) were determined for the half-Ironman and Ironman distance. During the run discipline, five splits were obtained for the sprint distance, while six were measured for the Olympic, half-Ironman (HIM) and Ironman distance. The location and distance between each point was determined by a global positioning system, with an accuracy of 2-3 m (5 Hz, Wi SPI, GPSports, ACT, Australia).

Ambient temperature, relative humidity, wind direction and speed for each race (Table 4.1) were obtained from the Bureau of Meteorology as an average of a 10-min period before 9:00 a.m. and/or 3:00 p.m.

Table 4. 1 Average ambient temperature, relative humidity and wind speed for the sprint, Olympic, half-Ironman and Ironman distance triathlons.

Distance	Measurement Time (h)	Temperature (°C)	Relative Humidity (%)	Wind Speed ($km \cdot h^{-1}$)
Sprint	0900	21.0	46	17
Olympic	0900	28.4	64	13
Half-	0900	14.7	72	19
Ironman	1500	20.8	44	9
Ironman	0900	17.3	70	26
	1500	23.5	43	22
Mean±SD		21.0±4.8	56.5±13.6	17.7±6.1

Based on the official timing and video capture system, the elapsed time for the respective splits during the cycle and run discipline and the entire course were determined for each participant in each race distance. The mean speed for each split was calculated as the distance covered divided by the completion time of each split. In order to examine pacing differences amongst the non-drafting top age group athletes and to account for the unequal sample sizes in each race distance, only the top 20% of overall finishers in each age and sex group were analysed. Participants were separated between sex and into 10 y age groups (20-29, 30-39, 40-49, and 50+ y) to allow the detection of meaningful differences. A pacing index (IP), calculated to allow comparisons between age and sex, was defined as the mean speed of each split normalised to the mean speed of the entire discipline for each individual.[98] IP allows direct comparisons between biological sexes and age separately, and was calculated as:

IP = Mean speed of split / Mean speed for entire discipline of the individual

4.3.3 Statistical analysis

Statistical tests were conducted using PASW Statistics (version 18.0, Chicago, Illinois). IP for each split were compared between sex and age groups using a multi-variate analysis of variance (MANOVA). Where significance was detected, a Tukey's post-hoc test was used to determine where the differences lie. Alpha level was set at $p<0.05$. All results expressed as mean±standard deviation (SD). No statistical comparisons were performed between race distances and disciplines due to: i) different participants between races, ii) dissimilar environmental conditions (temperature and wind speed/direction) which could alter pacing, and iii) inconsistent splits distances between races and mode of locomotion. However, appropriate comparisons between races and disciplines were made, where necessary.

4.4 Results

Comparison between sexes during the cycle discipline revealed a lower IP in males for S1 during the cycle discipline across all four triathlon distances (sprint - 2.1% difference, $p=0.024$; Olympic - 1.6% difference, $p=0.011$; HIM - 1.5% difference, $p<0.001$; Ironman - 1.7% difference, $p<0.001$, Figure 4.1). IP at S4 was lower for females when compared with males (1.5%, $p<0.001$). During running, a lower IP was observed in males for S1 (1.3%, $p=0.034$) during the sprint distance. However, a higher IP was seen in S5 (1.2%, $p=0.039$).

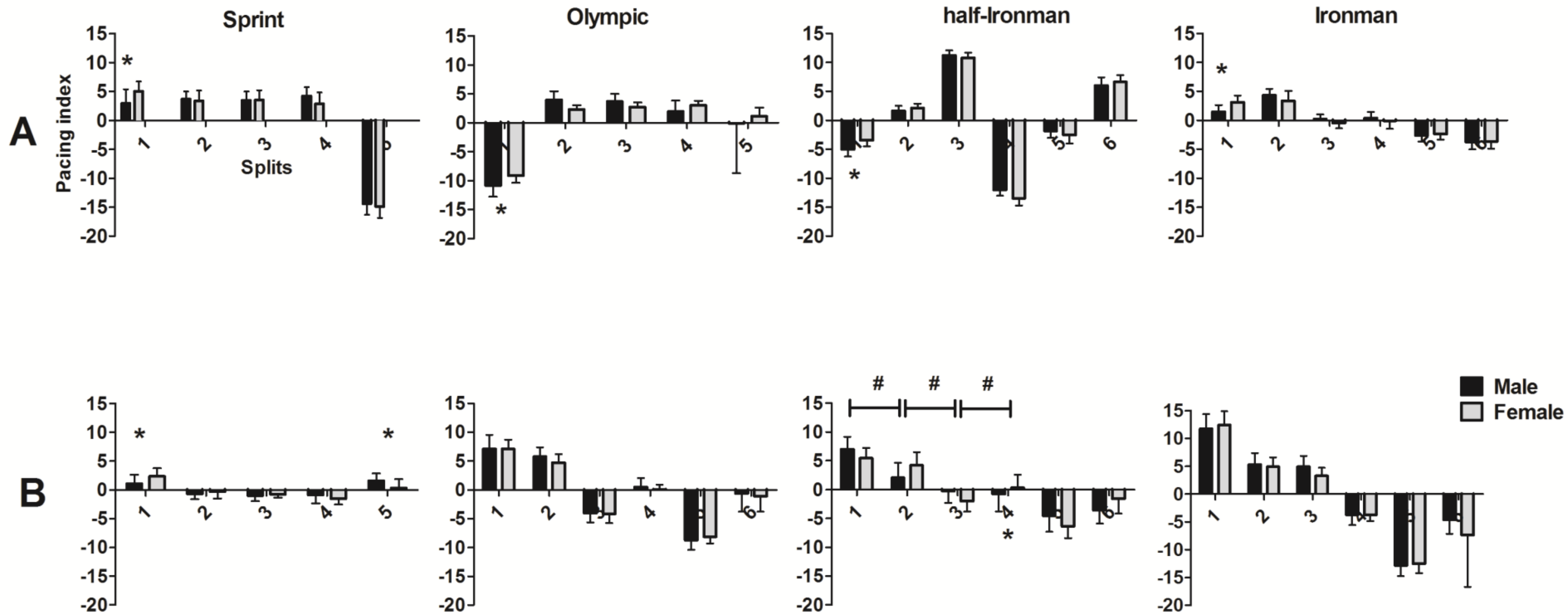

Figure 4. 1 Pacing index across splits for males and females during the cycle (A) and run (B) disciplines of a sprint, Olympic, half-Ironman and Ironman triathlon. *different for pacing index, #different for index of variability in speed, $p<0.05$.

Analysis of age-related changes showed an increase in IP in 50-59 y at S4 (3.0% higher than 20-29, $p=0.031$), followed by a decrease at the end of the cycle discipline (3.4% lower than 20-29 y, $p=0.036$) at S5 during the sprint distance cycle (Figure 4.2). During the HIM cycle, an initial age-related difference in IP was observed in 30-39 y, eliciting an IP closest to the mean at S3 and S4, compared with other age groups. Specifically, the IP was lower at S3 (1.0%, $p=0.009$ and 1.1%, $p=0.012$, compared with 20-29 and 50-59 y, respectively), followed by a higher IP at S4 compared with all other age groups (0.9%, $p=0.043$, 1.7%, $p<0.01$, 1.7%, $p=0.002$ compared with 20-29, 40-49, and 50-59 y, respectively). During the Ironman cycle, the 30-39 y age group demonstrated a lower (closest to the mean speed) IP at split 1, compared with 50+ y (1.4%, $p=0.029$). During the run, a higher IP was observed in 20-29 y in S1 for the sprint (3.0% higher than 50+,$p=0.008$), Olympic (3.2% higher than 40-49, $p=0.028$) and HIM (2.1% higher than 30-39, $p=0.01$) distance. No significant differences were observed between age groups for IP during the Ironman run.

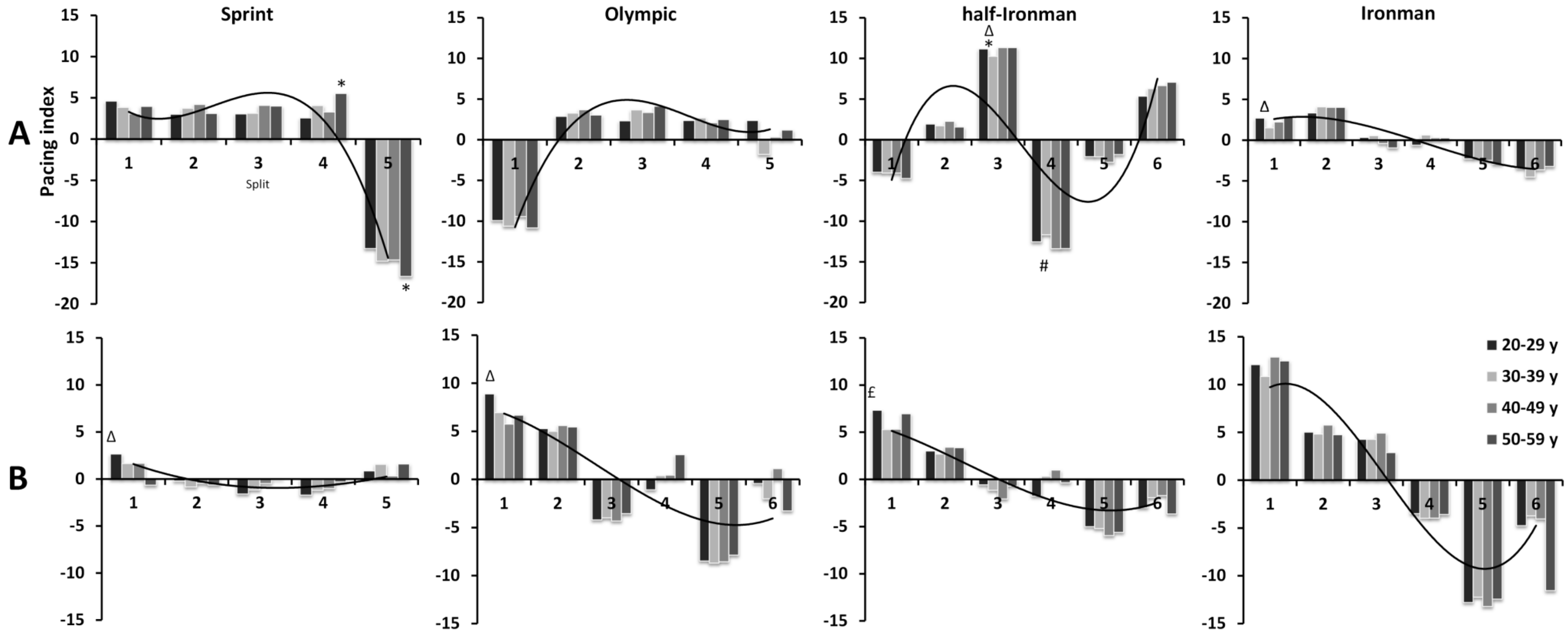

Figure 4. 2 Pacing index across splits for the 20-29 y, 30-39 y, 40-49 y, and 50+ y age group athletes during the cycle (A) and run (B) disciplines of a sprint, Olympic, half-Ironman and Ironman distance triathlon. *different from 20-29, [£]different from 30-39, ^different from 40-49, [Δ]different from 50-59, [#]different from all other age groups, $p<0.05$.Solid lines represent the polynomial trend (3[rd] power) for each split.

4.5 Discussion

The aim of this study was to investigate the effect of biological sex and age on pacing strategies adopted by the top 20% non-drafting age group triathletes during cycling and running in the sprint, Olympic, half-Ironman and Ironman distance triathlons. Indirect comparisons between distances have been made with caution due to the influence of external conditions such as wind and topography during different triathlon distances. The main finding of this study was that the distribution of pace differed between sexes and age groups over the various race distances and disciplines. Specifically, i) females commenced the cycle discipline at relatively faster speeds when compared with males throughout all four triathlon distances, ii) 30-39 y athletes demonstrated a more even cycling pacing during the half-Ironman (compared with all other age groups) and Ironman (compared with 50-59 y), iii) 20-29 y athletes started the run, during the sprint, Olympic and half-Ironman events, at relatively faster speeds when compared with all other age groups, and iv) pacing during the cycle and run discipline were different from the overall pacing adopted for the entire event.

The distinction of this study from past research is the non-drafting nature of the races. Cycle pacing during draft legal races is highly dictated by other competitors based on dynamic changes in tactical strategy[21,24] or attempts to bridge gaps with faster cycle packs.[94,165] Whilst non-drafting pacing could be influenced by the performance of other competitors, non-drafting races do not allow the formation of cycle packs, and as such are paced more similarly to an individual time-trial.[24] This could allow more intrinsic control over the pacing strategy adopted, hence a greater reflection of the individual responses to the physiological demands and psychological control involved during the race. The most striking result from our data is that the females adopted a more aggressive pacing strategy during the initial stages of the cycle discipline, compared with males. Indeed, a higher pacing index was elicited by females during the first split across all triathlon distances (Figure 4.1). This interesting observation diverges from past research examining draft-legal races,[94] and is contrary to popular belief that males pace more aggressively at the beginning of triathlon races. A fast-start pacing strategy as elicited by females is thought to be sub-optimal, since the relatively high-intensity likely leads to an increase in oxygen consumption, greater accumulation of intramuscular metabolites and an increase in rating of perceived exertion early in the race.[154] Instead, it is considered optimal during prolonged events if athletes are able to balance propulsive and resistive forces in order to adopt a relatively even pacing strategy.[3] Indeed, it has been shown that the top 10 runners of a 100 km running race adopted a relatively even pace, especially for the first 50 km.[87] Similarly, top athletes in an elite Olympic distance triathlon minimised decrements in running speed during the late stages of the 10 km run to maintain a more even pace, despite changes in elevation.[93] As the participants within this study were the most successful athletes within the event (i.e. the top 20% age group triathletes), it is possible that a relatively more aggressive start may be optimal for women, but a less aggressive start favourable for men.

In addition to a more even pacing strategy during the cycle discipline, males also adopted a more even pacing during the start (split 1) of the sprint distance run (1.3% closer to mean). This less aggressive start may be partly responsible for the "end-spurt phenomenon," characterised by speeding up towards the end of the race,[156] which was more apparent in males during the final split of the run (split 5, Figure 4.1). Indeed, a less apparent end-spurt was observed in females, who elicited a speed relatively closer to the mean during the final stages of the run (1.2% lower than males). The relatively faster start in females could have resulted in premature fatigue and impeded their ability to increase speed towards the end of the run and cycle disciplines. However, there is also evidence to indicate that the end-spurt phenomenon is indicative of 'sub-optimal' pacing, attributed to a conservation of reserve energy not efficiently distributed throughout the race.[57,156] The differences in pacing between sexes are possibly associated with a lower number of overall female competitors (24% of total participation) and therefore varied depth of field, thereby influencing motivation of the specific athletes examined.[95] As such, it is unclear whether these top male and female athletes paced optimally. More research is required to better understand the optimal pacing of males and female athletes and the factors that influence the selection of pace during triathlon.

During the sprint distance, older athletes were found to decrease speed to a greater extent during the final cycling section. Supporting this, an age-related difference was observed at split 5, where the pacing index of 50-59 y was 3.4% lower than the 20-29 y age group. This decrease in speed may have been associated with a conscious decision by older athletes to reduce intensity in order to minimise fatigue accumulation prior to the subsequent run. Indeed, previous data has shown that decreasing power output during the last 5 min of a 30 min cycle improved subsequent running performance.[147] Interestingly however, an increase in pacing before the final decrement in cycling speed was observed in the 50-59 y age group, where pacing index was 3.0% higher than the 20-29 y age group. The reason for this increase in speed is unclear, but may be to pre-compensate for time lost at split 5, when preparing for the subsequent run.

Despite relatively high winds during the cycle discipline of the half-Ironman and Ironman events (Table 4.1), 30-39 y athletes were able to maintain a relatively even pacing, compared with other age groups. For instance, the speed of the 30-39 y athletes remained closer to the mean during the tailwind section at split 3 (1.0% lower than 20-29 y) and the subsequent headwind section at split 4 (0.9% higher than 20-29 y) in the half-Ironman event.

Maintaining such an even distribution of pace during periods of varying external resistance (i.e. riding into a headwind or uphill) has been shown to benefit performance.[25,26] Indeed, it has been demonstrated that increasing power output on uphill sections of a course and reducing power output on downhill sections in attempt to minimise variations in speed results in meaningful improvements in performance.[11] It is possible that such strategies may have been partially responsible for the lower cycling time in the 30-39 y athletes, compared with other age groups. Unfortunately, it was not possible to measure power output or physiological characteristics of participants in the present study in order to further understand mechanisms responsible for differences in pacing between groups. It is plausible that unlike the 30-39 y athletes, older athletes in the present study were physically unable to increase power output during the headwind section of the half-Ironman and Ironman races, which therefore resulted in a more variable distribution of speed. Therefore, athletes need to consider the relationship between individual physiological characteristics and self-selected pacing strategies during triathlon competition, especially in events with varying external resistance.

Regardless of sexes, the 20-29 y age group adopted the most aggressive running pacing strategy during the initial stages of the sprint, Olympic and half-Ironman distance. Certainly, a higher pacing index was observed in 20-29 y for split 1 during the sprint (3.0% higher than 50+ y), Olympic (3.2% higher than 40-49 y), and half-Ironman (2.1% higher than 30-39 y) distance. Although positive pacing has been shown to be detrimental to run performance in an Olympic distance triathlon due to the central down-regulation of pace,[70] the positive pacing did not appear to negatively affect run performance in the 20-29 y age group. Further studies are required to investigate the effect of run start pacing on subsequent run performance during various triathlon distances.

The main limitation of this study was the inability to control for external conditions such as wind and topography, which could influence pacing. However, caution has been taken when comparing between distances within this study. Regardless, this is the first study to elucidate pacing adopted by top triathletes across the four popular triathlon distances and thus the findings of this study are highly applicable to these distances. A further limitation of this study is the lack of data on the training history of the participants and the monitoring of physiological response throughout exercise. Both of these factors are likely to influence pacing and thus further research examining mechanisms responsible for differences in pacing are warranted. Considering the large participant numbers included in this analysis, this study provides meaningful insight to the cycle and run pacing by top athletes of different sex and age groups across various triathlon distances.

The present study was designed to determine the effect of biological sex and age on pacing during the cycle and run disciplines in the sprint, Olympic, half-Ironman and Ironman distance triathlons. Results show that athletes of different ages and sex pace differently during various triathlon distances. Specifically, female triathletes were more aggressive during the initial phases of the cycling discipline across all distances, and the younger athletes were more aggressive during the initial stages of the run discipline in the sprint, Olympic and half-Ironman distances. Further, 30-39 y male athletes elicited a relatively even cycling pacing during longer distance triathlons, which likely results in lower times. These results could be useful to coaches and athletes, and should be considered when planning race/competition strategies.

CHAPTER FIVE: STUDY 3

PACING OF WELL-TRAINED TRIATHLETES DURING SWIM, CYCLE AND RUN DISCIPLINES OF SPRINT, OLYMPIC AND HALF-IRONMAN TRIATHLONS

5.1 Abstract

This study investigated the influence of distance on self-selected pacing during the swim, cycle and run disciplines of sprint, Olympic and half-Ironman distance triathlon races. Eight well-trained male triathletes performed the three individual races in <2 months. Participants' bikes were fitted with SRM to monitor speed, power output and heart rate during the cycle discipline. GPS was worn to determine speed and heart rate during the swim and run disciplines. An even swim pacing was observed across all distances. A more stochastic pacing was observed during the half-Ironman cycle (standard deviation of exposure variation analysis [EVA_{SD}]=3.21±0.61) as compared with the sprint cycle discipline (EVA_{SD}=3.84±0.44). Only 21% of the cycling time was spent more than 10% above the mean power output in the half-Ironman, compared with 44% and 38% during the sprint and Olympic distance triathlons, respectively. A negative pacing was adopted during the sprint distance run, compared with a positive pacing for the Olympic and half-Ironman. Results of this study indicate that pacing during triathlon is highly influenced by distance and discipline.

5.2 Introduction

Triathlon is a unique multi-sport event consisting of three different disciplines (swim, cycle, run) performed consecutively over a single race. The careful and continuous manipulation of effort (i.e. energy expenditure) is required to maintain a high speed throughout all three disciplines.[3,105] This continuous manipulation of effort and/or speed during an exercise task is defined as pacing. Although pacing is extremely important to triathlon performance, this area of research has received recent yet limited scientific attention.[93,94]

To date, much of the research on pacing during endurance exercise has been focused on single modes of locomotion such as cycling,[7,8,10,49,50,102] running,[87,99,130] swimming[154] or rowing.[53] For instance, Abbiss et al.[7] examined the pacing of elite female road cyclists during various cycling race formats (road race, criterium and time-trial). By way of exposure variation analysis (EVA), the authors quantified the cumulative time spent at certain predefined zones of cycling power output as well as acute time spent in each power zone. They reported a highly variable distribution of power output during the time trial (EVA_{SD}=2.81±0.33), but more even as compared with the criterium (EVA_{SD}=4.23 ± 0.31) and road race events (EVA_{SD}=4.81±0.96).[7] Previous studies that examined pacing within triathlon have focused on an individual discipline such as swimming,[121] cycling[5,21] or running.[87,93] To the best of the authors' knowledge, only two studies have investigated pacing during all three disciplines in a single triathlon race,[94,165] in which the pacing strategies adopted by elite male and female athletes during the draft legal Olympic distance triathlon were investigated. It is currently unclear whether the same pacing strategies are adopted by well-trained athletes during non-drafting races. Therefore, it is important to distinguish between drafting and non-drafting races, since pacing could be vastly different due to the considerable amount of energy conserved during drafting.[68,159]

Furthermore, previous studies examining pacing in triathlon have only examined individual triathlon distances such as the Olympic[19,70,93,94,165] and Ironman distance.[5] As it is likely that pacing strategies are different amongst various disciplines and race distances (e.g. sprint, Olympic, half-Ironman and Ironman), a systematic study comparing pacing during dissimilar triathlon distances performed by the same triathletes is required. Indeed, muscle glycogen depletion,[2,59] mechanical damage to muscle fibres,[36] increased body temperature over time[61] and reductions in neuromuscular activity[58] could influence performance to a greater extent during longer exercise durations, thus resulting in differences in pacing. For instance, St Clair Gibson et al.[58] examined the relationship between neuromuscular activity and pacing during a 100 km time-trial interspersed with 1- and 4-km high intensity intervals, and observed progressive decrements in power output with increasing distance during the 4-km intervals parallel with decreases in neuromuscular activity. In a triathlon specific setting, a progressive decline in power output during the cycle discipline of an Ironman[5] indicates that a more pronounced decrease in speed (i.e. positive pacing) may be observed during longer distance triathlons due to the abovementioned factors. In order to further understand the physiological constraints during various triathlon distances, it is necessary to compare the possible differences in pacing during triathlons of different distances.

Therefore, the purpose of this study was to investigate the influence of triathlon distance on pacing by well-trained triathletes by examining the speed, power output and heart rate elicited during separate sprint, Olympic and half-Ironman (HIM) triathlons. Due to the differences in factors such as energy demands and glycogen depletion between triathlon distances and individual disciplines,[63] it was hypothesised that an increasingly positive pacing would be observed during triathlons of increasing distance and that dissimilar pacing patterns would be observed between the three disciplines.

5.3 Methods

5.3.1 Participants

Eight well-trained male triathletes (current top 16.2% in their respective age groups, $\bar{x}\pm SD$ age: 40±7 y, body mass: 71.3±9.3 kg, height: 1.77±0.08 m, $\dot{V}O_{2peak}$: 60.1±4.8 $mL\cdot kg^{-1}\cdot min^{-1}$, MAP: 327.3±47.4 W), who had a triathlon racing history of >3 y, were recruited four weeks before the first of three triathlon races (completed in the order of sprint, Olympic, and half-Ironman). All participants were informed of the risks involved with the research and provided written informed consent. The study was approved by the Human Research Ethics Committee of the institution.

5.3.2 Procedures

Two to three weeks before the first race, participants performed a laboratory-based incremental cycle to exhaustion test on a cycle ergometer (Velotron, RacerMate Inc., Seattle, Washington, USA) to determine $\dot{V}O_{2peak}$. The ergometer was adjusted to replicate the participant's regular seat and handlebar position. During the incremental cycling exercise test, participants used their own pedals, cleats and cycling shoes. After a 10 min warm up at 150 W, power output increased subsequently by 30 W every 2 min until volitional exhaustion according to a modified version of previously published methods.[21] During the test, subjects were allowed to cycle at their preferred cadence, as the cycle ergometer maintains power output despite changes in cadence.[4] Exercise was terminated either by volitional exhaustion or when the pedal rate dropped below 60 rpm.[4] Throughout the test, a ParvoMedics metabolic measurement system (TrueOne 2400, ParvoMedics, Utah, USA) was used to measure and analyse expired air, which was continuously sampled and presented as an average over 15 s. The gas analysers were calibrated immediately before each test using a calibration gas mixture (Airgas Mid South, Tulsa, Oklahoma, USA) and a flow meter using a three-litre calibration syringe (Series 5530, Hans Rudolph Inc., Kansas City, USA). $\dot{V}O_{2peak}$ was determined according to previously published methods.[4]

All triathlons were completed in Western Australia consisting of, in order; a sprint (Telstra Triathlon Series, Hillarys, 0.75 km swim, 21.9 km cycle, 5 km run), Olympic (Coogee Beach, 1.5 km swim, 40 km cycle, 10 km run) and HIM (70.3 Busselton, 1.9 km swim, 90.1 km cycle, 21.1 km run) distances separated by 21 and 20 days, respectively. In order to maintain ecological validity, food and fluid intake was *ad libitum* during each race with no recommendations given as to the type or quantity of nutrient intake prior to or during the race. All swims were conducted in open water.

The sprint distance triathlon consisted of a 750 m swim, three laps of 7.31 km for the bike leg (highest elevation of 21 m) with an out and back lap of 5 km for the run (elevation of 11.1 m). Mean completion time for all finishers was 1 h 25±6 min to complete (results from http://www.bluechipresults.com.au). Overall completion time for the Olympic distance triathlon was 2 h 42±30 min. The swim was a 1-loop rectangular course of 1500 m, followed by four 10km laps of cycling, with an elevation of 6.59 m, and two 5 km lap run over an elevation of 2.26 m. Mean finishing time for the HIM was 5 h 41±41 min. Participants performed an out and back 1.9 km loop for the swim, two laps of 45.05 km for the bike discipline (21.3 m elevation), and a three lap (7.03 km each, elevation of 1.5 m) run.

During all races, participants wore portable global positioning units (Wi SPI, GPSports, ACT, Australia) sampling at 5 Hz throughout all races in order to determine velocity during the swim, cycle, and run disciplines. Heart rate was recorded at a frequency of 1 Hz with a compatible heart rate monitor (Polar Electro Oy™, Kempele, Finland). To determine power output during the cycling discipline, participants' bikes were fitted with a calibrated SRM power meter (Schoberer Rad Messtechnik, Jülich, Germany) set at a sampling rate of 1 Hz. Following completion of each race, performance times were retrieved from official websites or from the official organisers of the event. Ambient temperature, humidity (rh) and wind speed were obtained from the Bureau of Meteorology (www.bom.gov.au) within 2 h of the race start (Table 5.1). Pre-race hydration status was determined within 10 min of the race start by measuring urine osmolality (Advanced Instruments Inc, Massachusetts, USA) and urine specific gravity (Nippon Optical Works, Tokyo, Japan). No difference in hydration status was found between races.

Table 5. 1 Ambient temperature, relative humidity and wind speed for the sprint, Olympic and half-Ironman distance triathlon races.

Distance	Temperature (°C)	Relative Humidity (%)	Wind Speed (km·h^{-1})
Sprint	21.1	67	9
Olympic	19.3	66	6
Half-Ironman	21.8	67	13

5.3.3 Data processing

All split speeds were mean values for the entire split distance. Swim speed was divided into four equal distance splits (S1 to S4)[165] for each triathlon distance. Speed, power output and heart rate during the bike discipline were separated into six equal distances (S1 to S6)[94,165] for each triathlon distance. Power output was analysed using EVA according to previously published methods[7,123] in cycling pacing studies to determine the cumulative time and acute time spent at predefined exercise intensities. The predefined levels of power output during the cycle discipline were modified based on the above research. Specifically, six intensity zones/power bands (PB) were determined for each subject and race, based on the mean cycling power output (<-10% [PB1], -10% to -5% [PB2], -5% to mean [PB3], mean to 5% [PB4], 5% to 10% [PB5], and>10% [PB6]). In addition, EVA was also used to quantify the duration of time for which power output was kept within each predefined level of exercise intensity (i.e. acute time) without changing to another zone. In accordance with previous cycling pacing research by Abbiss et al.[7] and research by Passfield et al.[118] for accurate determination of time bands, the duration of each acute time band (based on the time to complete the cycle discipline in the sprint distance) was calculated to describe the continuous time spent in each specific zone of exercise intensity. The acute time bands (TB) were calculated as 0 to 1.875 s (TB1), 1.875 to 3.75 s (TB2), 3.75 to 7.45 s (TB3), 7.45 to 14.95 s (TB4), 14.95 to 29.95 s (TB5) and 29.95 to 3000 s (TB6), based on the typical time required to complete a sprint cycle time-trial. The standard deviation of the EVA matrix (EVA_{SD}) was determined to assess the quantity of time spent in a certain zone of exercise intensity. A greater EVA_{SD} implies more time spent within a specific intensity zone and therefore greater monotony or lesser variations in intensity observed. During the run discipline, speed and heart rate were separated into five splits of equal distances (S1 to S5), decided as the best denomination between triathlon distances.

5.3.4 Statistical analysis

Overall completion times, mean speeds, mean heart rate, mean power output (W) of the cycling discipline and EVA_{SD} were compared between the three races using a one-way repeated measures analysis of variance (ANOVA). Power output, split speeds (km·h^{1}), split heart rate (bpm) and time spent at individual power bands for each split was compared between races using independent variable repeated measures two-way ANOVA. If a significant interaction was present, Tukey's post-hoc analyses were performed to delineate differences. All data was expressed as mean±SD. Alpha level was set at $p < 0.05$.

5.4 Results

5.4.1 Overall and swim performance

Participants in the current study were the top 12.3, 14.0 and 16.2% of overall finishers within the sprint, Olympic and HIM distance races, respectively. Mean overall speed, power output and HR are shown in Table 5.2. No differences in mean swim speed were observed between distances and between splits. Overall cycle and run speeds were higher in the sprint (36.4±2.0 and 14.8±0.7 km·h^{-1} for the cycle and run, respectively) compared with the Olympic (35.7±1.3 and 13.3±1.4 km·h^{-1} for the cycle and run, respectively), and in the Olympic compared with the half-Ironman distance (34.8±1.5 and 12.1±1.4 km·h^{-1} for the cycle and run, respectively). Similarly, power output and cycle heart rate was higher during the sprint (263.3±37.9 W and 159.0±9.6 bpm for power output and cycle heart rate, respectively) compared with the Olympic (246.8±33.7 W and 156.1±8.3 bpm for power output and cycle heart rate, respectively), and in the Olympic distance compared with the half-Ironman distance (241.6±29.6 and 150.6±10.1 for power output and cycle heart rate, respectively). Run heart rate was higher in the sprint distance (168.4±9.1 bpm) compared with the Olympic (160.1±7.4 bpm) and half-Ironman distance (158.8±6.2 bpm). No difference in run heart rate was observed between the Olympic and half-Ironman distances.

Table 5. 2 Mean overall performance speed, power output and heart rate during the sprint, Olympic and HIM events.

	Completion time (min)	Swim speed ($km \cdot h^{-1}$)	Cycle speed ($km \cdot h^{-1}$)	Power output (W)	Cycle HR (bpm)	Run speed ($km \cdot h^{-1}$)	Run HR (bpm)
Sprint	74.1±5.6*#	4.1±0.2	36.4±2.0 *#	263.3±37.9*#	159.0±9.6*#	14.8±0.7*#	168.4±9.1*#
Olympic	142.5±8.0#	3.9±0.1	35.7±1.3#	246.8±33.7#	156.1±8.3#	13.3±1.4#	160.1±7.4
HIM	299.4±18.2	3.8±0.1	34.8±1.5	241.6±29.6	150.6±10.1	12.1±1.4	158.8±6.2

*significantly different from Olympic distance #significantly different from HIM distance. $p<0.05$

5.4.2 Cycle discipline

During the cycle discipline, a decrease in power output was observed after the initial split (S1 to S2) across all distances. This decrease was most pronounced during the sprint (14.24 W, p=0.003) as compared with the Olympic (6.72 W, p=0.035) and HIM distance (6.76 W, p=0.038, Figure 5.1). Heart rate was significantly higher (9.7bpm, p=0.01) across all sections after S2 in the sprint compared with the HIM (Figure 5.2).A higher EVA_{SD} (3.84±0.44) was observed in the sprint cycle when compared with the HIM (3.21±0.61, p=0.018), indicating more even power distribution during the sprint distance (Figure 5.3).No differences were observed between the EVA_{SD} for the Olympic distance (3.65±0.90) and other distances. A significantly greater percentage of time was spent in power band 6 during the sprint (43.8±2.9%) and Olympic (37.7±11.1%) distance as compared with the HIM distance (20.9±4.1%; p=0.002 and p=0.039 respectively). Conversely, a significantly lesser percentage of time was spent in power band 2 during the sprint (5.9±1.2%) and Olympic distance (8.0±5.1%) when compared with the HIM distance (13.6±5.1%; p=0.034, p=0.045 respectively).

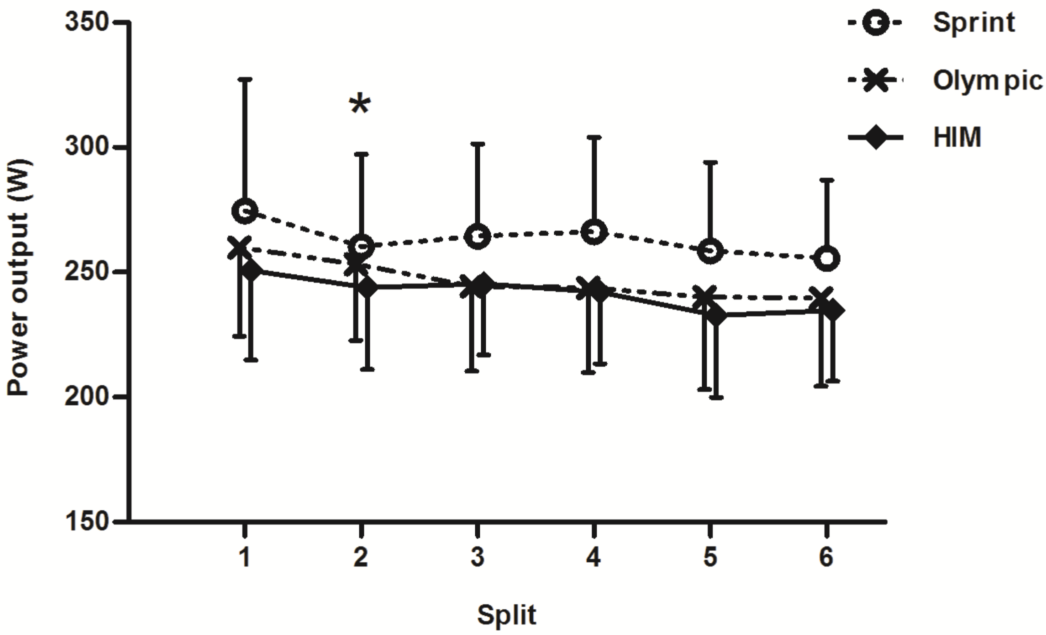

Figure 5. 1 Power output during the cycle discipline of the sprint, Olympic and HIM triathlons.*significantly different from previous split for all distances. $p<0.05$

5.4.3 Run discipline

Running speed increased from start to finish during the sprint (0.89 km·h^{-1}), however, decreased during the Olympic (1.32 km·h^{-1}) and HIM (1.65 km·h^{-1}, Figure 5.4). During the sprint distance, a final increase in running speed was observed at S4 to S5 (0.39 km·h^{-1}, p=0.031). However, a decrease was observed during the final splits of the Olympic (S3 to S5, 0.89 km·h^{-1}, p=0.013) and half-Ironman (S4 to S5, 1.22 km·h^{-1}, p=0.021). Initial running HR increased during the run in the sprint distance at S4 (170.9±8.0 bpm), as compared with S3 for Olympic (159.6±7.4 bpm), and S2 for HIM (157.8±6.3 bpm).

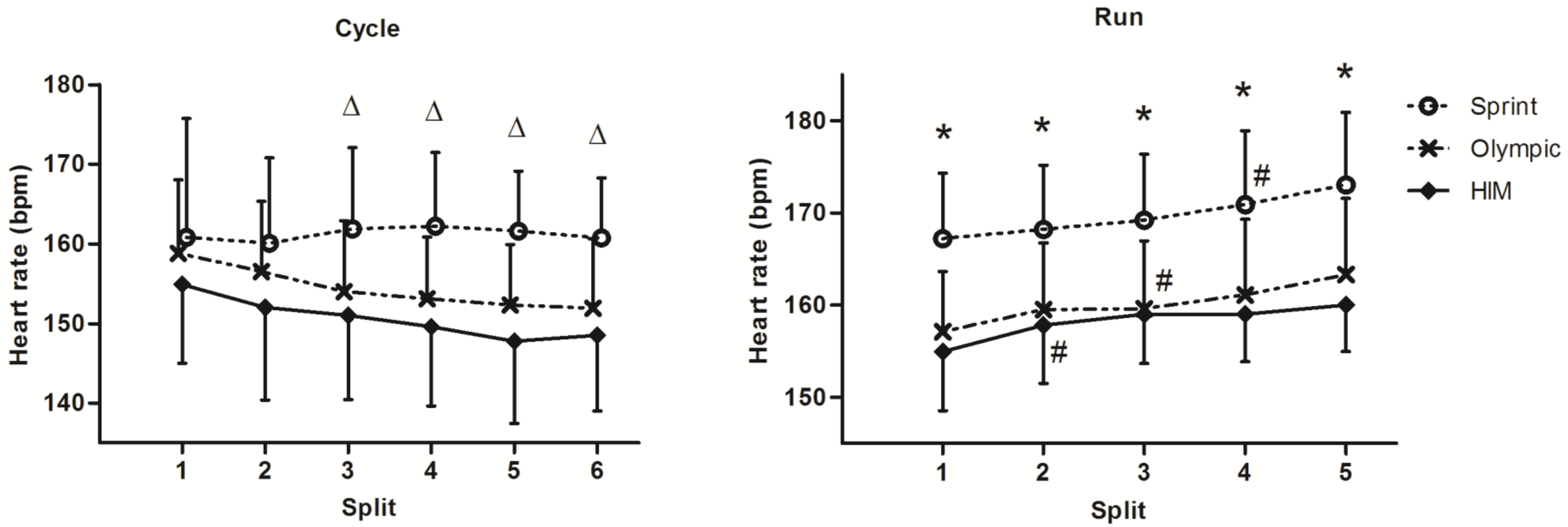

Figure 5. 2 Heart rate during the cycle and run disciplines of the sprint, Olympic and HIM triathlons. $^{\Delta}$significantly higher than HIM. *significantly higher than Olympic and HIM. $^{\#}$significantly higher than previous split. $p<0.05$

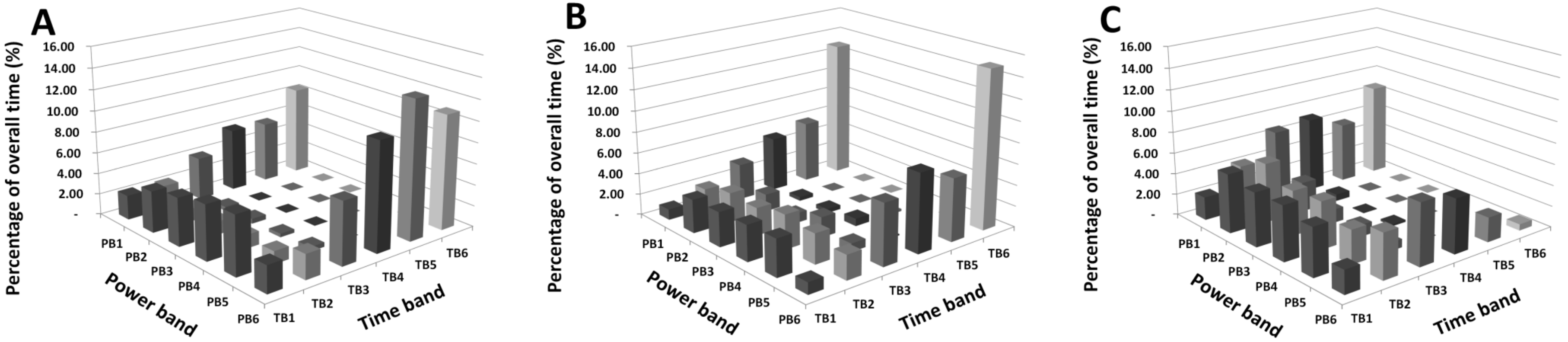

Figure 5. 3 Frequency distribution of power output during the cycle disciplines of the sprint (A), Olympic (B) and HIM(C) triathlons using exposure variation analysis.

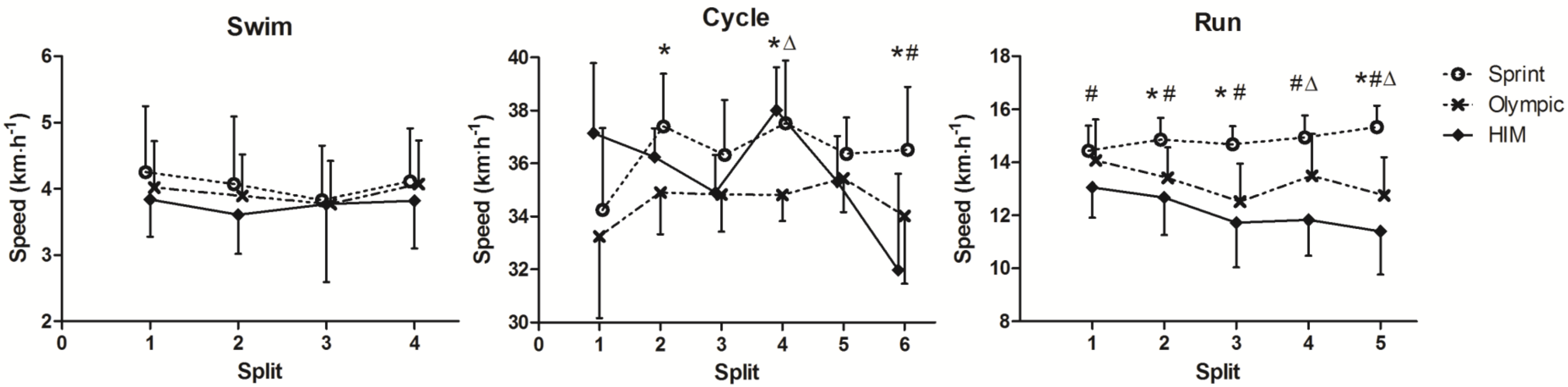

Figure 5. 4 Speed during the swim, cycle and run disciplines of the sprint, Olympic and HIM triathlons. *significantly different between sprint and Olympic distance. #significantly different between sprint and HIM. $^{\Delta}$significantly different between Olympic and HIM.

5.5 Discussion

This study examined the pacing of a group of 8 well-trained age group triathletes for the swim, cycle and run disciplines in a sprint, Olympic and half-Ironman triathlon race. This was the first study to compare pacing across the three triathlon races performed by the same athletes. The main findings of this study were that the triathlon race distance/duration influenced pacing in the cycle and run. More specifically, it was observed that i) swim intensity and pacing was comparable between different triathlon distances, ii) similar pacing were observed between the sprint and Olympic distance cycle disciplines, iii) a more variable cycling pace was adopted during the half-Ironman as compared with the sprint distance, and iv) similar positive run pacing were observed between the Olympic and half-Ironman distances, compared with negative pacing during the sprint. These results are in contrast with our hypothesis, as only the run discipline elicited an increasingly positive pacing with increasing distance.

The results of this study indicate that triathlon distance did not influence the swim pacing strategy adopted by well-trained triathletes for a sprint, Olympic and half-Ironman race (Figure 5.4). Certainly, no differences were observed in mean swim speed between distance and between splits across distances. Athletes adopted an even pacing strategy during the swim for all distances, with minimal deviations from the mean speed, which may be the ideal strategy during endurance exercise.[3,5] It is possible that the athletes were attempting to maintain a consistent swim intensity that optimises both swim and subsequent discipline performance.[121] Indeed, it has been shown that an even swim pacing appears to be "less physically stressful" compared with positive pacing, due to lower blood lactate concentration and perceived exertion following 200 m of breaststroke swimming.

Variations in pacing adopted between triathlon distances were more apparent within the cycle and run disciplines as compared with the swim discipline. A relatively variable pacing was observed during the cycle discipline of the half-Ironman, however, a relatively even pacing was observed during the sprint and Olympic distances (Figure 5.4). This could be partly attributed to external conditions such as wind velocity,[11] topography,[12] and influence of other competitors.[56] Indeed, the results from this study indicate that the strongest wind conditions during the half-Ironman (13 $km \cdot h^{-1}$) may be the main contributing factor to eliciting a variable pacing, as compared with wind conditions during the sprint (9 $km \cdot h^{-1}$) and Olympic distance (6$km \cdot h^{-1}$). To account for this, we quantified pacing by monitoring cycling power output and heart rate during the three triathlons. Specifically, similar positive power profiles (Figure 5.1) which paralleled cycle heart rate (Figure 5.2) were observed across distances. This indicates that, despite differences in wind conditions between distances (Table 5.1), athletes might be more concerned with maintaining an overall even power output in order to conserve energy and maintain physiological homeostasis, rather than dynamically manipulating power such that speed is sustained for a faster time. However, the data indicates that athletes made attempts to adopt an even pace during the shortest sprint distance as shown in Figure 5.1. The relatively high initial power output (S1) compared with the relatively low starting speed (relative to mean, Figure 5.4) during the sprint distance could be an attempt to maintain an even pace despite external perturbations (wind or topography) to achieve an even pacing strategy.

Interestingly, power output was less stochastic during the sprint as compared with the half-Ironman cycle discipline. Certainly, a higher EVA_{SD} was observed during the sprint cycle (3.84±0.44) than the HIM (3.2±0.61, $p=0.018$), indicative of a lower frequency of acute changes in power output (Figure 5.1). These athletes may have adopted a more stochastic pacing strategy during the HIM, frequently altering between cycling intensities in an attempt to conserve energy, change cycling position or alter muscle recruitment. Further, the observed differences invariability of cycling power output could be influenced by multiple factors, including wind and topography. As a result, further research is needed to understand if this difference is caused by race distance or variables subjective to race conditions.

Despite the relatively similar power output profile between distances, an extended amount of time was spent at higher exercise intensities during the cycle discipline of the sprint and Olympic distances, whereas a higher percentage of time was spent at lower power outputs, or "soft-pedalling" during the half-Ironman. Specifically, exposure variation analysis revealed 44% and 38% of total cycling time spent more than 10% above the mean power output during the sprint and Olympic distance triathlons respectively, as compared with 21% during the half-Ironman distance (Figure 5.3). In addition, a lower percentage of time was spent between -5% to -10% below the mean power output during the sprint (6%) and Olympic (8%) as compared with the half-Ironman (14%). Collectively, these results indicate that athletes employed more similar cycling power output profiles during the two shorter distances, as compared with the half-Ironman.

While the cycling pacing during the Olympic distance was more similar to the sprint distance, the run pacing of the Olympic distance was more comparable to that of the half-Ironman. Indeed, a positive pacing was observed during the Olympic and half-Ironman runs, while a negative pacing was adopted for the sprint distance run (Figure 5.4). Certainly, longer endurance exercise induces greater neuromuscular fatigue,[2] reductions in muscle glycogen content[66] and reduced neural drive,[106] which could result in the gradual decrease in speed during the two longer distances. Supporting this, an apparent heart rate drift was observed during the longer Olympic and half-Ironman, but not during the sprint distance run (Figure 5.2). The increase in heart rate during the sprint run was paralleled with an increase in running speed, which likely indicates a more conscious approach to the adoption of a negative pacing strategy. Further, it has been shown that adopting a positive pacing strategy during the Olympic distance run could be sub-optimal. Hausswirth et al. (2010) investigated the effect of starting speed during the first 1 km of the 10 km run in an Olympic distance triathlon, and demonstrated that a 5% slower start (relative to mean speed) during the first 1 km resulted in superior run performance, as compared with -10% and +5% starting speed. It is currently unclear whether a negative run pacing strategy would be beneficial towards sprint and half-Ironman triathlon performance. Hence, it appears that the current pacing by well-trained age group athletes could be improved.

In conclusion, the present study showed differences in the influence of distance on pacing during specific disciplines within triathlon. More specifically, swim pacing does not appear to be affected by distance from the sprint through to the half-Ironman distance. The maintenance of speed during the cycle discipline may be of priority during the shorter sprint and Olympic triathlon, however, the preservation of energy stores may be more important during longer distance half-Ironman racing. Results from this study also indicate that a more even, less aggressive run start pacing may benefit athletes during the Olympic and half-Ironman distance runs. This underscores the need for athletes to trial different pacing strategies based on race distance, fitness, discipline-specific strengths and race conditions. Future studies could examine the effect of pacing manipulations on performance during various triathlon distances and disciplines, as optimal pacing strategies may differ depending on distance and discipline.

CHAPTER SIX: STUDY 4

POSITIVE SWIM PACING IMPROVES SUBSEQUENT SPRINT DISTANCE TRIATHLON PERFORMANCE IN WELL-TRAINED ATHLETES

6.1 Abstract

The purpose of this study was to investigate the effect of three swim pacing strategies on subsequent performance during a sprint distance triathlon. Nine well-trained male triathletes completed five experimental sessions, including a graded running exhaustion test, a 750 m swim time-trial (STT), and three sprint distance triathlons. The swim of the sprint distance triathlons were work matched but pacing was manipulated to be either positive (i.e. speed gradually decreasing from 92 to 73% STT), negative (i.e. speed gradually increasing from 73 to 92% STT) or even (constant 82.5% STT). The remaining disciplines were completed at a self-selected maximal pace. Speed over the entire triathlon, power output during the cycle discipline, rating of perceived exertion (RPE) for each discipline and heart rate during the cycle and run were determined. Faster cycle and overall triathlon times were achieved with positive swim pacing (30.5±1.8 and 65.9±4.0 min respectively), as compared with the even (31.4±1.0 and 67.7±3.9 min respectively) and negative (31.8±1.6 and 67.3±3.7 min respectively) pacing strategies. Positive swim pacing elicited a lower RPE (9±2) than negative swim pacing (11±2). No differences were observed in the other measured variables. A positive swim pacing strategy significantly improves subsequent sprint distance triathlon performance possibly due to a lower sense of fatigue and perception of exertion during the early stages of the cycle discipline.

6.2 Introduction

Triathlon is a multi-sport event that consists of sequential swim, cycle and run disciplines. The manipulation of pacing during triathlon is crucial to performance but complex due to the importance of optimising energy expenditure throughout the three different locomotion modes. Although the effect of cycling on subsequent running performance is well documented, the majority of these studies lack an initial swim discipline, which may inaccurately reflect the metabolic demands and pacing during a triathlon.[23,62,120,163] Certainly, Kreider et al.[84] has shown that, as compared with a control cycle bout, cycling power output during 75 min of cycling was reduced by 16.8% after an 800 m swim.

The effect of swim pacing seems to have a more profound effect on short distance triathlon, as compared with the longer distances.[85,91,121] For instance, Peeling et al.[121] has demonstrated that swim intensity during a sprint distance triathlon could affect overall race performance. Specifically, these authors investigated the effect of swimming at a constant 80-85%, 90-95% and 98-102% of the mean speed attained during a control 750 m swim time-trial (STT) on subsequent sprint distance triathlon performance, and reported the fastest overall triathlon time following the 80-85% intensity swim, as compared with 98-102%. Conversely, Laursen et al.[91] found no negative effects of a prior 3000 m swim on subsequent 3 h cycling performance. It is likely that the shorter sprint distance swim performed at a higher intensity (1.21 $m \cdot s^{-1}$ versus 0.95 $m \cdot s^{-1}$ in the 750 and 3000 m swim respectively) requires higher metabolic demands, which could be detrimental to subsequent cycling and running performance.[121]

Due to the importance of swim pacing during the sprint distance triathlon, it is plausible that successful manipulations in swim pacing could produce beneficial outcomes for overall race performance. For example, research has shown that a fast-start pacing strategy improves performance during 2 min kayak[27] and both 3[14] and 5 min cycle performance[8] which has been attributed to faster $\dot{V}O_2$ kinetics. However, no such performance improvements were observed with a fast-start strategy during longer 6 min cycle performance,[9] 400 m freestyle STT[139] or 20 km cycle time trial.[1] Indeed, there is evidence to indicate that an even pacing may be optimal during prolonged exercise lasting more than two minutes.[3,49] In addition to exercise duration,[157] differences modes of locomotion may require various pacing to exploit optimal performance. Certainly, the complexity of triathlon provides an interesting model for pacing manipulation, due to the importance of optimal energy distribution over each individual discipline and the entire event.

Therefore, the purpose of this study was to investigate the effect of a positive (relatively fast-start), negative (relatively slow start) and even pacing strategy during the swim discipline on subsequent sprint distance triathlon performance. It was hypothesised that an even pacing strategy would result in superior overall sprint triathlon performance, compared with the positive and negative swim pacing strategies.

6.3 Methods

6.3.1 Participants and procedures

Nine well-trained male triathletes ($\bar{x}$ ±SD: $\dot{V}O_{2max}$ = 63.7±3.6ml·kg^{-1}·min^{-1}, age=26.7 ± 8.2y, mass=71.8±10.3 kg, height=1.78± 0.07 m) performed an incremental running test, a 750 m STT, and three randomised sprint distance triathlons (750 m swim, 20 km cycle, 5 km run). Each exercise bout was performed at the same time of day, one week apart. Intensive exercise was avoided for a minimum of 24 h prior to each session. All swims were performed in a six lane, 25 m outdoor pool at a water temperature of 28 °C. Mean daily temperature and humidity were 24.2±1.0 °C and 63±4 % respectively. Cycling was performed on the TacX bicycle trainer (TacXFortius, Wassenaar, Netherlands) shown to be valid (r=0.99 compared with the PowerTap for the measurement of power output) and reliable (r=0.99 for test-retest reliability) according to previously published methods.[122] Participants own race bicycle and racing setup was used for all sprint distance triathlons. All runs (except the incremental running test) were performed on a 2-loop out and back course on flat tarmac surface, totaling 5 km in distance. Participants were informed of the possible risks involved and provided written informed consent in accordance with the Edith Cowan University Human Research Ethics Committee, in accordance with the Australian National Statement on Ethical Conduct in Human Research.

A fast-ramp incremental run test to exhaustion on a motorised treadmill (Trackmaster, JAS Fitness Systems, Kansas, USA) was performed to determine $\dot{V}O_{2max}$. Participants commenced this test with a 5 min warm-up at 10 $km{\cdot}h^{-1}$, followed by 1 $km{\cdot}h^{-1}$ increments every minute until 16 $km{\cdot}h^{-1}$, and subsequently 2% increases in gradient every minute thereafter until volitional exhaustion. Expired air was analysed using the Parvo-Medics metabolic measurement system (TrueOne 2400, ParvoMedics, Utah, USA) and averaged over 15 s. Calibration of the gas analyser was performed immediately before and verified after each test using a calibration gas mixture (Airgas Mid-South, Tulsa, OK, USA). The systems flow-meter was calibrated with a 3-L calibration syringe (Series 5530, Hans Rudolph Inc., Kansas City, USA). $\dot{V}O_{2max}$ was determined as: i) the plateau of $\dot{V}O_2$ consumption (two highest consecutive 15 s samples), ii) heart rate within 10 beats·min^{-1} of age predicted maximum, iii) a respiratory exchange ratio (RER) of >1.1, and iv) volitional fatigue.[4]

Following the incremental running test, participants performed a 10 min familiarization time-trial on the TacX bicycle trainer (TacXFortius, Wassenaar, Netherlands).

Prior to any experimental trials, all participants performed a maximal effort self-paced 750 m STT. Mean swim speed for the subsequent triathlon swims were calculated based on the mean speed achieved during this STT.[121]

The swim disciplines of the three sprint distance triathlons were performed with even, negative and positive pacing strategies, while the mean speed achieved across the entire swim remained constant. The negative and positive pacing strategies were based on slow-start and fast-start pacing strategies respectively, where magnitude was calculated based on the range of deviations in swim speed observed during an actual competitive sprint distance triathlon event (data from Chapter 5). During the even pacing strategy, participants swam at a constant 82.5% of the initial STT. Based on similar previous research, an intensity of 82.5% has been shown to significantly improve subsequent cycling and sprint distance triathlon performance.[121] Negative and positive pacing strategies were completed with up to 9.5% change in speed from the mean. Specifically, the negative-pacing swim began at 73% of the STT pace, and increased consistently (2.5% of STT change in speed per 100m) to 92% by the finish. The positive-pace swim began at 92% of the STT speed, and finished at 73% by completion. Visual signals were provided during the swimmers breaths to control pace. Following the swim, participants immediately moved onto a bicycle ergometer (TacXFortius, Wassenaar, Netherlands) with compatible simulation software, located ~10 m from the swim finish, allowing quantification of instantaneous power output and speed throughout the 20 km cycle section of the sprint distance triathlon. On completion of the cycle discipline, athletes commenced the 5 km run. Running speed was determined by a GPS watch (910XT, Garmin, US) worn on the wrist. Participants were instructed to complete the cycle and run disciplines as quickly as possible at a self-selected pace, and were provided only with distance feedback.

An overall RPE for each discipline was obtained at the conclusion of each discipline. Heart rate (HR) was determined throughout exercise using a Polar S810i (Polar Electro Oy™, Kempele, Finland) for accuracy. Identical exercise clothing was worn for every session. A training and dietary log was maintained throughout the experimental period. Nutrition and hydration were *ad libitum* for all trials.

6.3.2 Data Processing

Power output during the cycle, in addition to HR and speed during the cycle and run disciplines were divided into 10 equal splits (S1 to S10). Each split during the cycle discipline represented 2 km, while each split during the run represented 500 m.

6.3.3 Statistical analysis

RPE and completion times for swim, cycle, run and overall sprint triathlon performance were compared between pacing strategies using one-way repeated measures analysis of variance (ANOVA). Power output and heart rate was compared between conditions with a separate repeated measures two-way ANOVA. Where a significant interaction effect was observed, a Tukey's post-hoc test was used to identify where differences occurred. All data was expressed as mean±SD unless otherwise specified. The alpha level was accepted at $p<0.05$.

6.4 Results

A faster overall sprint triathlon performance time was achieved during the positive (65.9±4.0 min) as compared with the even (67.7±3.9 min, p=0.034) and negative (67.3±3.7 min, p=0.041) swim pacing trials (Figure 6.1). By design, no differences in swim performance times were observed between trials (Figure 1).

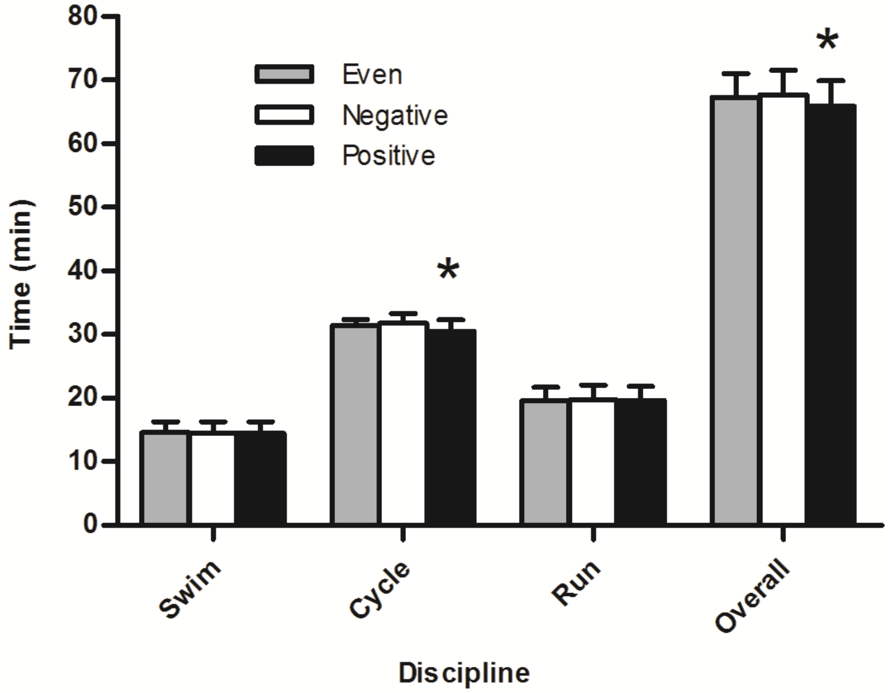

Figure 6. 1 Time to completion for the swim, cycle, run disciplines and overall triathlon for the even, negative and positive swim pacing strategies. *significantly lower than other conditions.

A faster cycle time was achieved during the positive pacing trial (30.5±1.8 min) as compared with the even (31.4±1.0 min, p=0.018) and negative (31.8±1.6 min, p=0.011) pacing strategies. Cycling power output was consistently higher (9.8 to 14.1 W, p<0.046, Figure 6.2A) in the positive pacing trial from S2 to S5, as compared with the negative pacing trial. Furthermore, power output was higher in the positive pacing at S2 (9.8 W, p=0.048) and at S6 (15.1 W, p=0.039, Figure 6.2A), as compared with the even pacing trial. No differences in running times or pacing were observed between the three pacing strategies (Figure 2B). No differences in HR were observed in cycling and running during the different pacing strategies (Table 6.2). A lower RPE was observed during the positive (8.9±2.2), as compared with negative pacing swim (11.4±1.8, p=0.014, Table 6.1). No differences in RPE were observed during the cycle and run disciplines.

Table 6. 1 RPE during the swim, cycle and run disciplines of the even, negative and positive swim pacing strategies.

Swim pacing	Swim	Cycle	Run
Even	10±2	15±2	18±1
Negative	11±2	16±1	19±1
Positive	9±2*	16±2	18±1

*****significantly different from negative pacing.

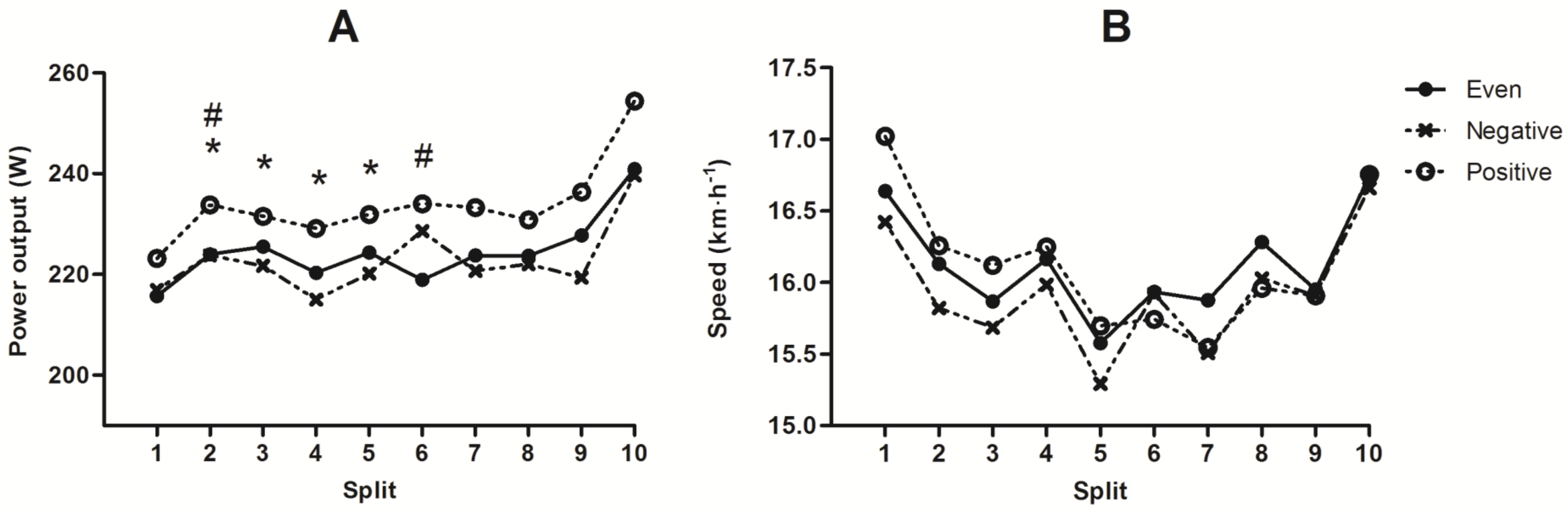

Figure 6. 2 Power output during the cycle discipline (A) and run speed (B) in even, negative and positive pacing strategies. *positive pacing faster than negative pacing #positive pacing faster than even pacing.

Table 6. 2 Heart rate during the cycle and run disciplines of the even, negative and positive pacing strategies.

	Pacing	Split 1	Split 2	Split 3	Split 4	Split 5	Split 6	Split 7	Split 8	Split 9	Split 10
Cycle	Even	141±14	149±13	151±13	152±11	153±11	153±10	154±10	154±9	155±10	160±10
	Negative	142±15	151±10	153±11	152±11	153±12	155±11	154±11	153±12	156±11	159±11
	Positive	140±10	153±10	155±10	156±9	156±10	157±11	157±10	158±11	15912	161±11
Run	Even	167±8	170±6	171±6	171±6	173±5	172±6	172±5	172±5	174±6	175±6
	Negative	170±12	172±11	173±9	174±9	174±9	175±9	175±8	174±9	175±9	177±7
	Positive	168±9	174±8	176±8	176±8	176±7	177±6	175±6	175±6	179±5	180±6

6.5 Discussion

The purpose of this study was to investigate the effect of swim pacing strategy on subsequent cycle and run performance in a simulated sprint distance triathlon. The main findings of this study were: i) swim pacing strategy influences overall triathlon performance during a sprint distance triathlon, ii) a lower swim RPE could result in superior cycling and overall triathlon performance, and iii) similar cycle and run pacing patterns were adopted despite different preceding swim pacing strategies.

This study demonstrated superior cycle and overall triathlon performance during a sprint distance triathlon when adopting a positive swim pacing strategy, as compared with negative and even swim pacing strategies, with matched total work expenditure during the swim. In the current study, 6 out of 9 participants elicited the fastest triathlon time with a positive pacing swim. In accordance with previous research, a fast-start pacing strategy has been show to improve performance during middle distance (2-5 min) events. Indeed, Bailey et al.[14] reported a 7% greater mean power output during a 3 min cycling bout with a fast-start strategy as compared with slow-start and even pacing strategies. The greater power output was attributed to faster $\dot{V}O_2$ kinetics at the start of exercise, therefore sparing anaerobic energy reserves for later in the task. Although the duration of exercise in the current study was considerably longer (66 to 68 min), it is possible that a relatively faster start could have elicited a meaningful, rapid $\dot{V}O_2$ response during the initial stages of the swim.

Conversely, it has also been demonstrated that the relatively high intensity of a fast-start could lead to an increased RPE early in the race, in addition to an increased oxygen consumption and faster accumulation of intramuscular metabolites during endurance exercise.[154] In such cases, an even pacing has been shown to be optimal. The support for even pacing is derived from mathematical models,[40,51,108] which propose that endurance performance is compromised whenever an athlete's locomotive speed drops below their "fatigue threshold" or "critical power"[3] at any time during the race. However, these mathematical models may not be optimal for triathlon, as the maintenance of a maximal sustainable effort during the swim may be detrimental to triathlon performance. Indeed, Peeling et al.[121] have demonstrated that swimming at a lower 80-85% of the mean speed achieved during the control swim elicited superior sprint distance triathlon performance, as compared with swimming at 90-95% and 98-102%. It is therefore plausible that the gradual reduction in speed (92% to 73% of control swim) with the positive pacing strategy at a submaximal intensity led to faster $\dot{V}O_2$ kinetics without the detrimental effects of a fast-start pacing. This pacing strategy is similar to actual races where the swim tends to start at a relatively higher intensity due to the need for an athlete to avoid crowd congestion.

It is important to note that, despite the matched total work expenditure during the swim, a higher cycling power output was elicited after the positive pacing swim during the earlier stages of the cycle discipline, compared with the negative and even pacing strategies (Figure 6.2A). This could be due to a lower RPE after completion of a positive pacing swim (9±2) as compared with the negatively paced swim (11±2, Table 6.1). It is likely that the lower sensation of muscle activity and power generation during the final half of the positive pacing swim elicited a lower sense of fatigue,[55] compared with the even and negative pacing swims. As RPE has been validated as a reliable instrument for evaluating whole body exertion and has been suggested to be influenced by various cardiorespiratory and peripheral signals,[65] the lower RPE following the positive pacing swim may have improved subsequent cycling performance. Further, cycling power output following the negatively and evenly paced swims may have been reduced by a central buffering process to prevent premature exhaustion.[44] Collectively, these results indicate a lower swim intensity and perceived exertion (especially at completion of the swim) could benefit subsequent cycle performance.

Despite the differences in swim pacing between the three sprint distance triathlons here, similar pacing were adopted during the subsequent cycle and run disciplines within each trial. Specifically, a relatively even speed/power pacing was adopted during the cycle discipline, followed by an increase in speed during the final stages. Interestingly, an increase in speed is regularly observed in draft-legal Olympic distance triathlons during the cycle to run transition,[105,166] likely in an attempt to gain a strategic advantage for the run. However, the same pacing strategy was employed in the current study despite the lack of drafting or peer influence. It is possible that the participants perceived this pacing strategy to be beneficial for overall sprint triathlon performance. Subsequently, a parabolic U-shaped pacing was observed during the run across all triathlons, with no difference in running speed observed between trials for all splits, despite a higher absolute workload during the positive pacing cycle discipline. It appears that a lower RPE following the positive pacing swim could have provided a psychological advantage during subsequent cycling performance, without causing metabolic disturbances that are detrimental for the subsequent run.

In conclusion, this study demonstrated the influence of swim pacing strategy on subsequent triathlon performance. Specifically, a sub-maximal positive swim pacing strategy improves subsequent cycling and overall triathlon performance. The higher initial cycling power output during the positive swim pacing strategy could be attributed to a lower RPE at the conclusion of the swim. Further research should examine the effect of pacing manipulation during different distances and different disciplines.

CHAPTER SEVEN: GENERAL DISCUSSION

The regulation of pacing during multi-sport events such as the triathlon is complex, due to the importance of pacing not only over the entire race distance, but also during the individual swim, cycle and run disciplines. Pacing during triathlons can be influenced by a multitude of factors such as exercise distance/duration,[98] race dynamics,[16,69,156] environmental factors,[11,12,18,34,148] transitions,[18] age,[45,94] and sex.[45,64,86] As such, success in triathlon performance depends on the careful manipulation of pace such that available energy substrates are optimally distributed throughout the duration of exercise. Despite this, there are limited studies investigating performance and pacing of triathletes in various sex and age groups during the three disciplines as well as over the entire race distance. Furthermore, the optimal pacing strategies in various triathlon distances have not been established. To help further understand the factors regulating pacing in triathlon, the purpose of this thesis was to examine the pacing strategies adopted by triathletes of different age and sex over various triathlon distances. It was hoped that by understanding the factors regulating pacing in triathlon, optimal pacing strategies could be developed to improve performance in triathlon. The major findings from this thesis were that: i) an earlier, larger and faster rate of decline in performance with ageing was observed in females and males for the longer events (half-Ironman and Ironman) compared with the shorter distances (sprint and Olympic), ii) various pacing strategies are adopted by non-drafting top athletes of different age and sex, iii) pacing strategies during triathlon is highly influenced by distance and discipline, and iv) a positive pacing swim improves subsequent sprint triathlon performance.

The age- and sex-related differences in triathlon performance and pacing are poorly understood. Identifying the effect of these factors on triathlon is necessary in improving the performance of ageing male and female athletes. The purpose of the first two studies was to delineate the performance and pacing strategies adopted by top triathletes across the four standard triathlon distances (sprint, Olympic, half-Ironman and Ironman). The results from Study 1 showed that the age-related declines in triathlon performance is in accordance with previous research on the age-related declines in endurance performance.[95,150] Specifically, a marked decrease in triathlon performance appeared after 50 years for both sexes, with a greater rate from 20 to 50+ years in females (8.4%) as compared with males (5.6%) across distances. This sex-related difference could be attributed to a greater reduction in maximal aerobic capacity,[95,150] loss in muscle strength and muscle mass[164] in females, and could also be partly due to the lower female participation rates.[95] Further analysis revealed that the age-related declines in longer (half-Ironman and Ironman) triathlons were earlier, higher and larger in females (≥30 years, 9.3%, 3.0% per decade respectively) as compared with males (≥40 years, 5.9%, 2.2% per decade, respectively). Certainly, endurance events lasting >4 h induces greater neuromuscular fatigue due to psychological and metabolic factors.[3] Studies on the female population needs to be performed to determine the specific effect of morphological changes on performance and identify strategies in attenuating the early decline in triathlon performance. When comparing between disciplines, it was found that a greater magnitude of decline was observed in swimming for both sexes, especially in the longer events, when compared with cycling and running (12.8%, 5.6%, 9.3% for females, 9.4%, 3.7%, 7.3% for males, in the swim, cycle and run disciplines, respectively). These results could have implications for training and racing; athletes of different age and sex could modify their training to improve discipline-specific and distance-specific performance. Particularly, athletes may need to improve their swim performance accordingly whilst finding an optimal balance with the other disciplines through individual trialing and training volume manipulations.

Due to the large variations in performance across age-groups and sexes, it is likely that the pacing strategies adopted by athletes of different age-groups and sexes may vary during triathlons of various distances. However, previous research examining pacing in triathlon has focused on the draft-legal Olympic distance triathlons (~2 h),[21,94,165] with only a single study examining cycling pacing during the longer non-drafting Ironman distance (8-17 h).[5] Hence, the distribution of pace throughout the sprint (~1 h), half-Ironman (~5 h), and to an extent Ironman events across different age-groups and sexes are yet to be fully understood. Despite this, no research has examined the effect of sex and age on the pacing strategies adopted during various triathlon distances. Therefore, the purpose of Study 2 was to elucidate the pacing strategies adopted by top age group triathletes during the sprint, Olympic, half-Ironman and Ironman distance triathlons. Results from Study 2 indicated that the distribution of pace differed between sexes and age-groups over the various race distances and disciplines. Specifically, females were more aggressive during the initial stages of the cycling discipline across all distances (sprint - 2.1%, Olympic - 1.6%, half-Ironman- 1.5% and Ironman - 1.7% higher relative to mean) compared with males. Younger athletes (20-29 y) tend to begin the run faster (2.0 to 3.0% faster than other age-groups, $p<0.029$) during the sprint, Olympic and half-Ironman triathlons. Hence, age, sex and/or fitness may influence self-selected and possibly individual optimal pacing strategies during triathlons of various distances. This could be a result of inexperience, as triathlon has been one of the sports which have shown a great increase in participation numbers over the last twenty years. Consequently, many age-group athletes could be ill-informed about superior training methods and pacing strategies to adopt during competition. As such, athletes from this population could attempt a more even pacing strategy to possibly improve performance.

While Study 2 provided indication that distance is a major contributing factor to the selection of pacing strategy, it is unclear whether the same top performing triathletes would pace differently during triathlons of different distances. Indeed, exercise duration has been shown to be one of the primary factors influencing both optimal and self-selected pacing.[17,27,63,65-68] Therefore, Study 3 was developed in order to elucidate the pacing strategies, power output and heart rate of a group of top performing age-group triathletes during the swim, cycle and run disciplines of three triathlons of various distances (sprint, half-Ironman and Ironman). The results of Study 3 showed that dissimilar pacing strategies were adopted during the three triathlon disciplines within a triathlon, and further differences in pacing were evident between distances. Despite this, athletes appeared to swim at a similar speed and pace across all distances. Comparatively, a more variable pacing was observed during the cycle discipline. Athletes appeared to be more willing to alter power output in order to overcome the external resistive forces (i.e. wind[11] and topography[12]) during the shorter sprint distance (EVA_{SD}=3.84±0.44) triathlons, as compared with the half-Ironman distance (EVA_{SD}=3.21±0.61). A more stochastic power profile was adopted during the longer half-Ironman triathlon due to a higher percentage of time spent at lower power outputs, or "soft-pedalling." It is likely that during the longer half-Ironman event the athletes were more concerned with maintaining a relatively even power output in order to conserve energy and delaying neuromuscular fatigue. During the run, a negative pacing strategy was adopted during the sprint distance run, compared with positive pacing for the Olympic and half-Ironman. It appears that the run pacing strategies adopted by top performing age-group triathletes are currently sub-optimal and could be improved. For instance, even the top athletes could be over-conservative during the short sprint distance run, and under-conservative during longer Olympic and half-Ironman distances. Thus it is imperative that individual athletes continuously monitor their race pace in order to improve pacing in triathlons.

Based on the results of Study 3, it is clear that different pacing strategies are required to perform optimally during different disciplines and triathlon distances. Interestingly, Study 3 demonstrated that top triathletes swam at similar speeds and pacing patterns regardless of race distance, and therefore it is plausible that these athletes did not adopt an optimal swim pacing strategy for performance for the respective distances. Indeed, Peeling et al.[121] previously demonstrated that swim intensity influenced subsequent sprint distance triathlon performance. Therefore, it is likely that altering the swim pacing strategy could affect triathlon performance. Within this context, the primary purpose of Study 4 was to investigate the influence of different swim pacing strategies on subsequent sprint triathlon performance. The main finding of Study 4 was that a positive swim pacing strategy produced superior overall sprint triathlon performance (65.9±4.0 min) as compared with an even (67.7±3.9 min, $p=0.034$) or negative swim pacing strategy (67.3±3.7 min, $p=0.041$). Despite a matched total work expenditure during the swim, a lower RPE and higher cycling power output was observed after the positive pacing swim (9±2 and 233.8 W respectively) as compared with the even (10±2 and 224.5 W) and negative (11±2 and 222.8 W) pacing strategies. A lower RPE could have reflected a lower sense of fatigue[55] and whole body exertion,[65] which may be responsible for the subsequent improvements in cycling performance. It is also likely that a relatively faster start could have elicited a meaningful, rapid $\dot{V}O_2$ response during the initial stages of the swim. The results of this study could be applied during a sprint distance triathlon by starting at a relatively higher swim speed and decreasing throughout the remainder of the swim to possibly improve overall sprint triathlon performance.

7.1 Directions for future research

The main findings from the series of studies in this thesis are as follows: i) the age-related declines in triathlon performance varies with sex and race distance, ii) different pacing strategies are adopted by top performing triathletes of various age-groups and sex, iii) the current pacing and power output distribution of top triathletes may be sub-optimal and are highly dependent on triathlon distance, and iv) a positive swim pacing strategy produces superior sprint triathlon performance, compared with an even or negative swim pacing strategy. While these findings elucidate the efficacy of current pacing strategies adopted by triathletes of various sex and age across different triathlon distances, the results also highlight the need for further research in triathlon pacing.

The pacing strategies adopted by top triathletes varies with sex, age and race distance (Study 1 and 2). However, it is unclear whether these top athletes adopted optimal pacing strategies. More research is required to clarify the physiological responses of males and female athletes in order to identify the optimal pacing strategies and the factors that influence the selection of pace during triathlon. Such research will help sports practitioners in refining training programs, developing further investigations and race strategies.

Pacing in triathlon appears to be highly influenced by the race distance or duration (Study 3). It was revealed that pacing differed depending on the specific distance and discipline, and the inability to maintain an even pacing strategy throughout disciplines is evident with increasing race distance. However, it was unclear as to the extent to which external factors such as wind velocity [11] and topography [12]influenced pacing, especially during the cycle discipline. Hence, further studies are required to clarify the magnitude influence of external perturbations on pacing during triathlons of different distances.

The influence of swim pacing strategy during the sprint distance triathlon was examined in Study 4. This study revealed that a positive swim pacing strategy elicited superior triathlon performance, as compared with an even or negative swim pacing strategy. We believe this was due to increased $\dot{V}O_2$ kinetics from a faster start, and relatively lower sense of fatigue during the initial stages of the cycle discipline after a positive pacing swim. Further research is required to identify the optimal pacing strategies for other disciplines and distances. It is also possible that these strategies may differ depending on the age and sex of the athlete.

7.2 Conclusion

The series of studies in this thesis has shown that the age-related declines in pacing and performance in triathlon differs between sex and age. Furthermore, race distance can significantly the pacing strategies of well-trained athletes. During the short sprint distance triathlon, a submaximal positive swim pacing strategy can improve sprint triathlon performance. Such findings are of practical significance to coaches and athletes, as it highlights the differences in triathlon pacing with age, sex and race distance, as well as providing an improved pacing strategy for the sprint distance triathlon. Further research is necessary to gain a greater understanding of, and to develop optimal pacing strategies for athletes of different age and sex, and in triathlons of different distances.

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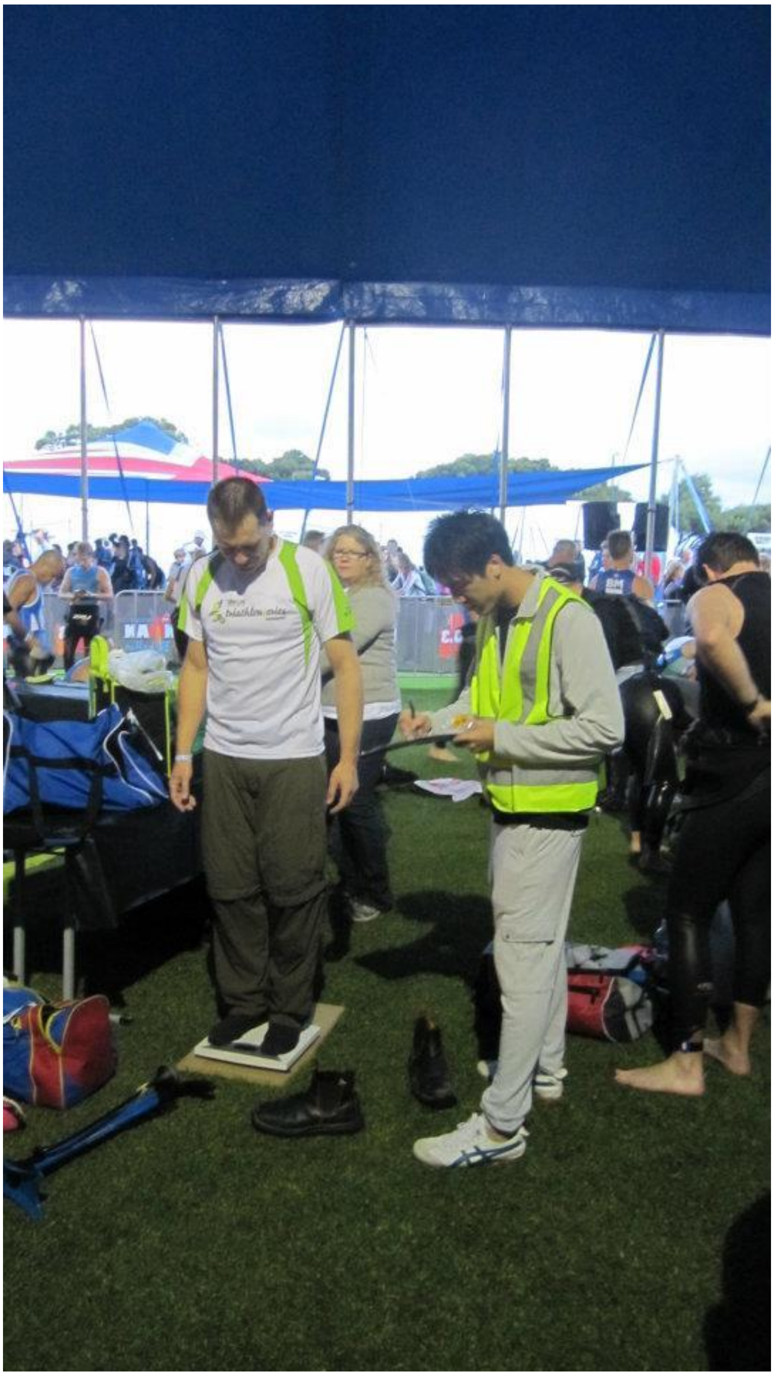
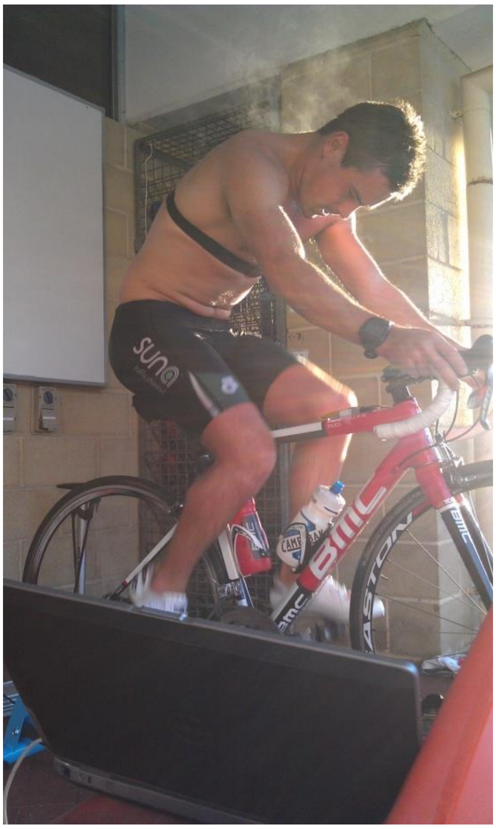
APPENDICES

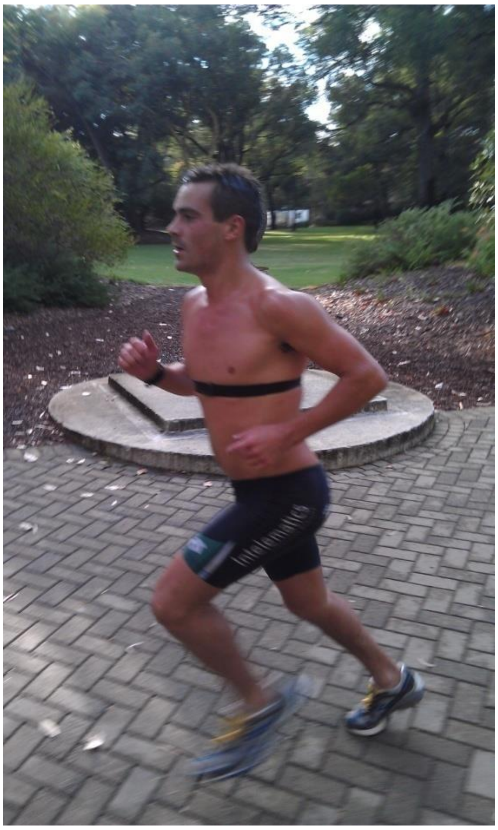
Appendix A



Appendix B



Appendix C



Appendix D

HUMAN RESEARCH ETHICS COMMITTEE
For all queries, please contact:
Research Ethics Officer
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: 6304 2170
Fax: 6304 5044
E-mail: research.ethics@ecu.edu.au

OFFICE OF RESEARCH
AND INNOVATION

270 Joondalup Drive,
Joondalup
Western Australia 6027
Telephone 134 328
Facsimile: (08) 9300 1257
CRICOS 00279B

ABN 54 361 485 361

4 September 2012

Mr Sam Goh
54A Cornell Parade
Joondalup WA 6027

Dear Sam

ETHICS APPROVAL

Project Code:	**6144**	
Project Title:	**Understanding and optimising pacing strategies during various standard distance triathlons in age group triathletes**	
Chief Investigator:	Mr Sam Goh	
Supervisors	Dr Chris Abbiss Dr Jeremiah Peiffer Professor Ken Nosaka	
Approval Dates:	*From:* 25 January 2012	*To:* 1 April 2013

I am happy to confirm that this application was reviewed by members of the Human Research Ethics Committee (HREC) and ethics approval was granted.

The proposal complied with the provisions contained in the University's policy for the conduct of ethical human research. In granting approval, the HREC determined that the research project met the requirements of the National Statement on Ethical Conduct in Human Research.

All research projects are approved subject to general conditions of approval. Please see the attached document for details of these conditions, which include monitoring requirements, changes to the project and extension of ethics approval.

We wish you continued success with your research project.

Yours sincerely

Kim Gifkins
RESEARCH ETHICS OFFICER

Appendix E

INFORMATION LETTER FOR PARTICIPANTS

Pacing strategy and physiological profile of age group triathletes during three standard distance triathlon events

Chief investigator: Sam Wu
School of Exercise and Health Sciences
Edith Cowan University
270 Joondalup Drive, Joondalup WA 6027
Phone: 0405760989 Email: s.goh@ecu.edu.au

Thank you for expressing interest in this study. Your participation in this study requires you to have been placed in the top 20% of the selected triathlon distance/s. This information letter provides you with information on the study that you may participate in as a subject. Please read through the following information carefully, and feel free to clarify any doubts with the investigator/s if necessary.

Purpose of the Study

The purpose of this study is to examine the self-selected pacing strategy of triathletes, corresponding power output and heart rate to model the physiological profile of age group triathletes during three standard distance triathlons.

Background

Triathlon success is largely dependent on an athlete's ability to generate continuous power output, sufficient to overcome resistive forces experienced (i.e. hydrodynamic drag during the swim; gravity and aerodynamic resistance during cycle and run). The distribution of this power output is referred to as the pacing strategy and is an integral aspect of triathlon performance. Since the physiological demands of each race distance is varied, different pacing strategies may be required to complete each distance in an optimal time. To date, the relationship between absolute speeds, power output and heart rate in age group triathletes during triathlon races of varied distances is still unclear. Results from this study will help to identify the relationship between speed and individual effort levels (as represented by power output and heart rate) during the selected triathlon distances.

Description of the Study

This study consists of 1 lab session and 2 triathlon races. The lab session will be held at the Exercise Physiology Laboratory (Building 19, Room 150) of Edith Cowan University **prior** to the first race. In this session, you will perform an incremental **cycle** test to exhaustion on an ergometer. Several measurements will be taken before, during and after exercise. The following 2 sessions will require the completion of **three standard triathlons** at the respective venues to the best of your ability. Measurements will be taken prior to and following the event.

Lab session (1.5 hrs)

You will be measured for body fat composition using dual energy X-ray absorptiometry (DEXA). This procedure is the gold standard and determines your body fat content. The radiation experienced during this procedure is insignificant (0.2-0.37μSv) when compared with daily natural background radiation levels (10μSv) (Njeh et al. 1999).

You will then proceed to complete the cycle test to exhaustion. The cycle ergometer will be adjusted to replicate your seat and handlebar position. Therefore, we require you to bring your race bicycle. You will be using your **own pedals, cleats and cycling shoes**. You will start cycling at a comfortable 100 W for 6 min. Workload will be increased by 30 W every 2 min thereafter until you feel you can't pedal any longer. We do however encourage you to continue cycling for as long as you possibly can. We will be monitoring you closely throughout the test. This test usually takes 20 - 30 min. Throughout the test, a mouthpiece will be in place to monitor respiratory oxygen and carbon dioxide content to determine your individual ventilatory thresholds and maximal aerobic capacity.

2nd to 4th session

These sessions requires your participation and completion of 3 standard distance triathlons to the best of your ability. Prior to race day, your race bicycle will be fitted with the SRM power meter (by a bike shop). On both race days, you will be required to come **an hour** before race start to allow pre-race measurements. This will include body mass, blood electrolyte and glucose content. The latter will be obtained from a single prick of your fingertip. You will also be fitted with a GPS unit and a heart rate monitor.

We will not interfere with your race in any way during the event. You will follow your own nutrition plan.

Immediately following completion of the race, we ask that you report for post-race body mass, electrolyte and glucose content measurements and strip-down of equipment.

Requirements

You will be required to report to the laboratory with your race bicycle and complete the field races as explained above. It is required that you have been placed in the top 20% of the selected triathlon distance/s. You will be asked to maintain your normal dietary practices and to refrain from training and strenuous activity in the 24 hr period prior to testing. A food diary will be asked from you for a period of 3 days prior to testing.

Possible Risks

As with any type of physical activity, there exists the possibility of muscle strain and ligament sprains. Due to the nature of the maximal aerobic tests, participants may experience breathlessness or nausea. However, the criteria for subject recruitment include only participants who have an adequate training background, which should lower these risks. It is also required that you are healthy at the time of testing. All testing sessions will be supervised by a First Aid/CPR qualified personnel. Safety procedures for physical exercise testing will be followed as previously conducted in our laboratory.

Confidentiality

All results will be kept confidential. Personal identity will not be revealed in any publication. Participants' names will not be used in any reports and/or scientific journals. Data will only be directly available to the primary investigator, which will be stored electronically for a period of 5 years and will be password protected.

Participation

Participation in this study is strictly voluntary. If you decide to withdraw your consent at any time, you will not be prejudiced in any way. You are free to withdraw your consent and may discontinue your involvement in the project at any time.

Contact

In the event that you have any queries, please do not hesitate to contact us.

Supervisors

Name -	Dr. Chris Abbiss	Dr. Jeremiah Peiffer	Prof. Ken Nosaka
Email -	c.abbiss@ecu.edu.au	j.peiffer@murdoch.edu.au	k.nosaka@ecu.edu.au
Phone -	6304-5740	9360-7603	6304-5655

If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Human Research Ethics Officer
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170 Email: research.ethics@ecu.edu.au

Appendix F

Informed Consent Form

Project Title

Pacing strategy and physiological profile of age group triathletes during three standard distance triathlon events

Researcher contact details

Sam Wu, MSc, CSCS
School of Exercise and Health Sciences.
270 Joondalup Drive, Joondalup,
WA 6027, Australia.
Phone: (08) 6304 2242.
Email: s.goh@ecu.edu.au

Statement indicating consent to participate

I confirm the following:

I have been provided with a copy of the Information Letter, explaining the research study

I have read and understood the information provided

I understand what is required from my participation in this study.

I have been given the opportunity to ask questions and I have had any questions answered to my satisfaction

I am aware that if I have any additional questions I can contact the research team

I understand that participation in the research project will involve:

1 lab session including an incremental cycle test to exhaustion

3 actual triathlon races completed to the best of my ability

Measurements of blood electrolyte, glucose content and body mass.

Wearing of a GPS unit and heart rate monitor

I understands that I am free to withdraw from further participation at any time, without explanation or penalty

I freely agree to participate in the project

I understand that my information provided will be kept confidential, and that my identity will not be disclosed without consent

I agree to take part in this study and for the results obtained to be published without disclosure of my name or other identifying information.

Signed ……………………………………………….

Name………………………………………. **Date**……………

Signed by member of research team ………………………………………………….

Appendix G

INFORMATION LETTER FOR PARTICIPANTS

Effect of a modified swim pacing strategy on Sprint triathlon performance

Chief investigator: Sam Wu
School of Exercise and Health Sciences
Edith Cowan University
270 Joondalup Drive, Joondalup WA 6027
Phone: 6304-2242 Email: s.goh@ecu.edu.au

Thank you for expressing interest in this study. Your participation in this study requires you to have been placed in the top 20% of a sprint distance triathlon with a finishing time <1h10min. This information letter provides you with information on the study that you may participate in as a subject. Please read through the following information carefully, and feel free to clarify any doubts with the investigator/s if necessary.

Purpose of the Study

The aim of study is to establish an optimal pacing strategy for age group triathletes to produce the fastest overall performance time during a sprint distance triathlon race.

Background

Success in triathlon is dependent on the triathlete’s ability to adopt an optimal pacing strategy that is most suitable for the distance of the event. As such, previous studies have attempted to manipulate pacing strategies in an attempt to enhance triathlon performance. However, no studies have sought to determine the best discipline (i.e. swim, bike, run) to enhance performance through the manipulation of pacing strategies. Results from this study will aid in developing develop an optimal pacing strategy to improve overall triathlon performance during a standard distance triathlon.

Description of the Study

This study consists of 1 lab session, 1 swim trial and 3 simulated triathlon trials. The 1^{st} lab session will be held in the **Exercise Physiology Laboratory (Building 19, Room 150) of Edith Cowan University (ECU, address below)**. In the 1^{st} session, you will perform an incremental **running** test to exhaustion on a treadmill. The following 4 trials will require the completion of **one swim trial** and **three simulated sprint triathlons** at the **School of Sport Science, Exercise and Health, University of Western Australia (UWA, address below)**, each one week apart. Several measurements will be taken before, during and after exercise for all sessions.

1^{st} lab session (1.5 hrs)

$\dot{V}O_2max$

You will then proceed to complete a run test to exhaustion on a treadmill, therefore please bring your **running gear**. You will start running at a comfortable pace of 10 kmh^{-1} which begins warm-up. Subsequently, speed will be increased by 1kmh^{-1} every 2 minutes until 16kmh^{-1}, followed by 1% increments in gradient every minute thereafter until you feel you cannot continue running. We do however encourage you to continue running for as long as you possibly can. We will be monitoring you closely throughout the test. This test usually takes 12-20 min. Throughout the test, a mouthpiece will be in place to monitor respiratory oxygen and carbon dioxide content to determine your individual ventilatory thresholds and maximal aerobic capacity.

Familiarisation

You will be asked to perform a 5 min familiarisation (easy, low intensity) on the TacX bicycle trainer in a time trial format to be accustomed to cycling on the trainer. As you will be using your own race bicycle, please remember to bring your **cycling gear**. Also please remember to bring your race gear, nutrition, hydration and post-race nutrition.

2nd to 5th session

In sessions 2 – 5, a simulated triathlon trial will be performed at UWA in 1 of the 4 following conditions:
Control swim trial
ii,iii,iv) 3 modified triathlon trials

All swims will be performed in a 25 m (26.5°C) pool, and cycling on the TacX bicycle trainer fitted with your own race bicycle. Running will be performed on an outdoor track and path near the pool. The control swim trial will be performed to the best of your ability, with no modifications to the pacing strategy. In the modified pacing strategy trials, changes in speed will be made to the swim discipline. The remainder of the modified trials will be completed at your self-selected pace (as quickly as possible). You will be provided with constant feedback as to laps completed during the swim, distance covered and time elapsed during the bike and the run.

Throughout all trials, you will be wearing a portable GPS unit and a heart rate monitor. Nutrition during the triathlon trials will be kept constant for all sessions.

Requirements

You will be required to report to the Edith Cowan University laboratory or The University of Western Australia laboratory with your race bicycle and gear for all sessions as explained above. It is required that you have completed a sprint distance triathlon in <70min and are currently training. You will be asked to maintain your normal dietary practices and to refrain from training and strenuous activity in the 24 hr period prior to testing. A food diary will be asked from you for a period of 3 days prior to testing.

Possible Risks

As with any type of physical activity, there exists the possibility of muscle strain and ligament sprains. Due to the nature of the maximal aerobic tests, participants may experience breathlessness or nausea. However, the criteria for subject recruitment include only participants who have an adequate training background, which should lower these risks. It is also required that you are healthy at the time of testing. All testing sessions will be supervised by a First Aid/CPR qualified personnel. Safety procedures for physical exercise testing will be followed as previously conducted in our laboratory.

Confidentiality

All results will be kept confidential. Personal identity will not be revealed in any publication. Participants' names will not be used in any reports and/or scientific journals. Data will only be directly available to the primary investigator, which will be stored electronically for a period of 5 years and will be password protected.

Participation

Participation in this study is strictly voluntary. If you decide to withdraw your consent at any time, you will not be prejudiced in any way. You are free to withdraw your consent and may discontinue your involvement in the project at any time.

Contact

In the event that you have any queries, please do not hesitate to contact us.

Supervisors

Name -	Dr. Chris Abbiss	Dr. Jeremiah Peiffer	Prof. Ken Nosaka	Dr. Pete Peeling
Email -	c.abbiss@ecu.edu.au	j.peiffer@murdoch.edu.au	k.nosaka@ecu.edu.au	ppeeling@wais.org.au
Phone -	6304-5740	9360-7603	6304-5655	93878166

If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:

Research Ethics Officer
Human Research Ethics Officer
Edith Cowan University
270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170 Email: research.ethics@ecu.edu.au

Appendix H

Informed Consent Form

Project Title

Effect of a modified swim pacing strategy on Sprint triathlon performance

Researcher contact details

Sam Wu, MSc, CSCS
School of Exercise and Health Sciences.
270 Joondalup Drive, Joondalup,
WA 6027, Australia.
Phone: (08) 6304 2242.
Email: s.goh@ecu.edu.au

Statement indicating consent to participate

I confirm the following:

I have been provided with a copy of the Information Letter, explaining the research study

I have read and understood the information provided

I understand what is required from my participation in this study.

I have been given the opportunity to ask questions and I have had any questions answered to my satisfaction

I am aware that if I have any additional questions I can contact the research team

I understand that participation in the research project will involve:

1 lab session including an incremental running test to exhaustion

1 swim trial and 3 simulated sprint triathlons

Wearing of a GPS unit and heart rate monitor

I understands that I am free to withdraw from further participation at any time, without explanation or penalty

I freely agree to participate in the project

I understand that my information provided will be kept confidential, and that my identity will not be disclosed without consent

I agree to take part in this study and for the results obtained to be published without disclosure of my name or other identifying information.

Signed……………………………………………

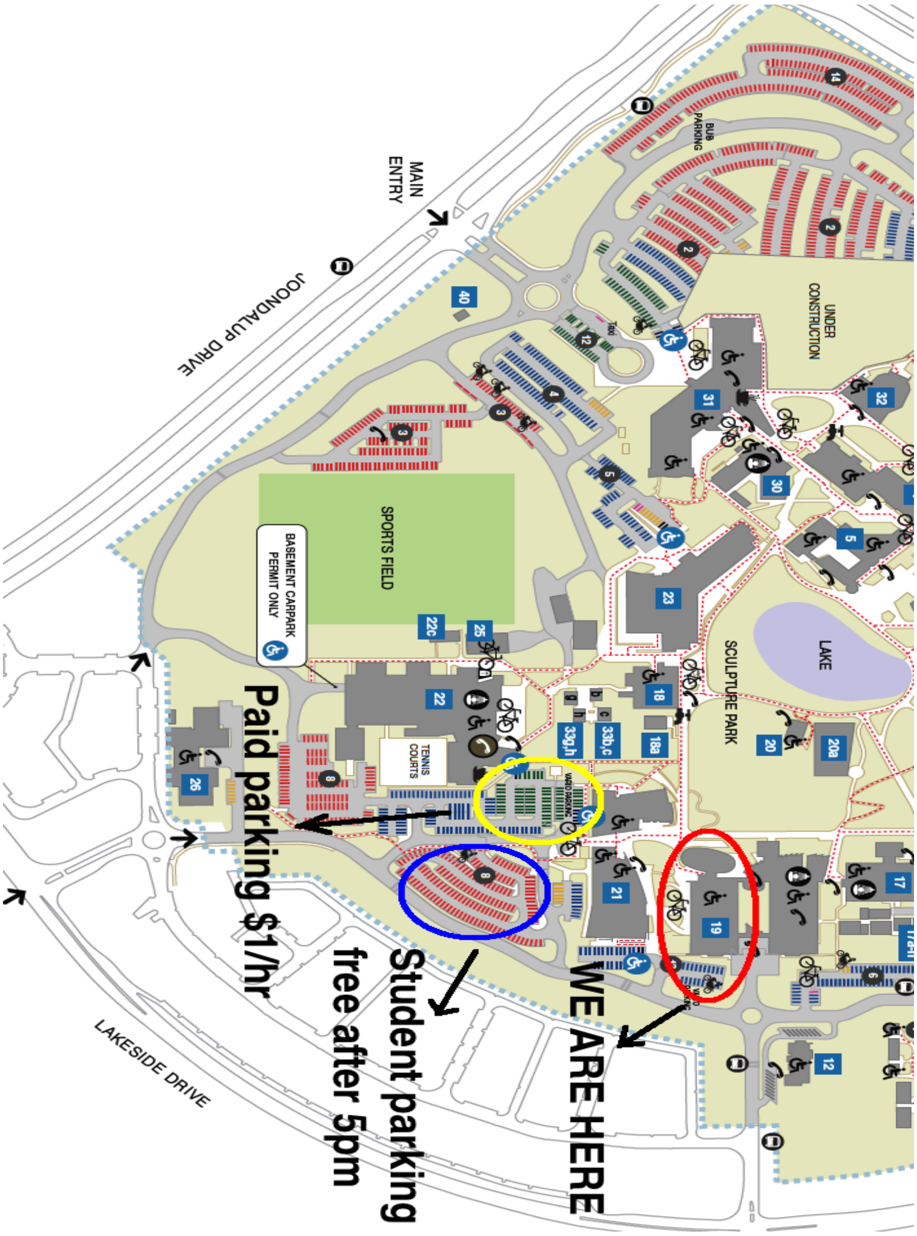
Name……………………………………. **Date**……………

Signed by member of research team ………………………………………………….

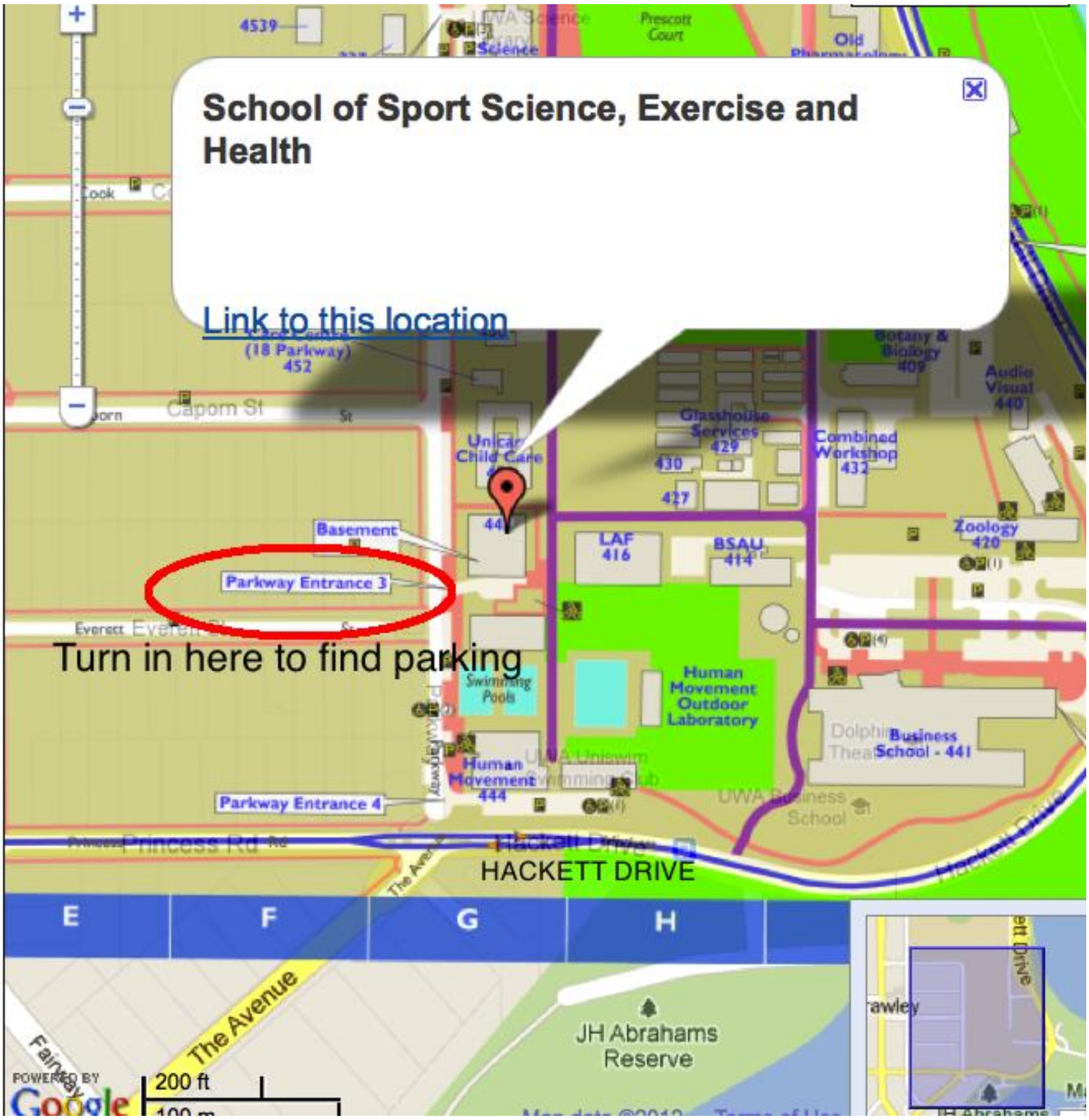
ECU - Exercise Physiology Laboratory, Building 19, Room 150, Edith Cowan University

270 Joondalup Drive

Joondalup WA 6027



UWA - School of Sport Science, Exercise and Heal3h, University of Western Australia Exercise Science Building Parkway Entrance #335 Stirling Highway Crawley Perth Western Australia 6009



Appendix I

Pre-exercise Medical Questionnaire

The following questionnaire is designed to establish a background of your medical history, and identify any injury and/ or illness that may influence your testing and performance.

Please answer all questions as accurately as possible, and if you are unsure about anything please ask for clarification. All information provided is strictly confidential.

Personal Details

Name:____

Date of Birth (DD/MM/YYYY):___________________   Gender: Female/ Male

PART A

1. Are you a male over 45 yr, or female over 55 yr or who has had a hysterectomy or are postmenopausal?

Yes   No

If YES, please provide details

2. Are you a regular smoker or have you quit in the last 6 months?   Y   N   ________________

3. Did a close family member have heart disease or surgery, or stroke before the age of 60 years?	Y	N	Unsure	________________
4. Do you have, or have you ever been told you have blood pressure above 140/90 mmHg, or do you current take blood pressure medication?	Y	N	Unsure	________________
5. Do you have, or have you ever been told you have, a total cholesterol level above 5.2 mmol/L (200 mg/dL)?	Y	N	Unsure	________________
6. Is your BMI (weight/height^2) greater than 30 kg/m^2?	Y	N	Unsure	________________

PART B

1. Have you ever had a serious asthma attack during exercise?	Y	N	________________________
2. Do you have asthma that requires medication?	Y	N	________________________
3. Have you had an epileptic seizure in the last 5 years?	Y	N	________________________
4. Do you have any moderate or severe allergies?	Y	N	________________________
5. Do you, or could you reasonably, have an infectious disease?	Y	N	________________________

6. Do you, or could you reasonably, have an infection or disease that might be aggravated by exercise?	Y	N	______________________

PART C

1. Are you currently taking any prescribed or non-prescribed medications?

	Y	N	______________________

2. Have you had, or do you currently have, any of the following?

			If YES, please provide details
Rheumatic fever	Y	N	______________________
Heart abnormalities	Y	N	______________________
Diabetes	Y	N	______________________
Epilepsy	Y	N	______________________
Recurring back pain that would make exercise problematic, or where exercise may aggravate the pain	Y	N	______________________

PART C cont’d

Recurring neck pain that would make exercise problematic, or where exercise may aggravate the pain	Y	N	______________________
Any neurological disorders that would make exercise problematic, or where exercise may aggravate the condition	Y	N	______________________
Any neuromuscular disorders that would make exercise problematic, or where exercise may aggravate the condition	Y	N	______________________
Recurring muscle or joint injuries that would make exercise problematic, or where exercise may aggravate the condition	Y	N	______________________
A burning or cramping sensation in your legs when walking short distances	Y	N	______________________
Chest discomfort, unreasonable breathlessness, dizziness or fainting, or blackouts during exercise	Y	N	______________________

PART D

Have you had flu in the last week?	Y	N	______________________
Do you currently have an injury that might affect, or be affected by, exercise?	Y	N	______________________

*Is there any other condition not previously mentioned that may affect your ability to participate in this study?

Y N ______________________________

Medical Questions that are directly related to the research techniques:

Have you ever been told by a medical Practitioner, or do you think it is likely, that you have a blood clotting disorder? [a]   Y   N   ____________

Are you currently taking any supplements (e.g. aspirin, fish oil supplements) or blood thinning drugs that might affect blood clotting?[b]   Y   N   ____________

If a participant answers YES to any question with a:

Superscript 'a': Refer to GP or specialist before participation

Superscript 'b': Refer to GP if the subject has taken aspirin daily for the past week, regularly takes >4000 mg per day of fish oil supplements (or EPA and DHA at similar levels through another source) or takes another blood thinning medication at any dose (e.g. Warfarin).

Declaration (to be signed in the presence of the researcher)

I acknowledge that the information provided on this form, is to the best of my knowledge, a true and accurate indication of my current state of health.

Participant

Name:_________________________ Date (DD/MM/YYYY):_______________

Signature:_____________________________

Researcher:

Signature:______________________________

Date (DD/MM/YYYY):_________________

____

Parent/ Guardian (only if applicable)

I, ____, as parent / guardian of Mr/ Miss ____, acknowledge that I have checked the answers provided to all questions in the medical questionnaire and verify that they are correct to the best of my knowledge.

Signature: _____________________________________

Date (DD/MM/YYYY): __________________________

Practitioner (only if applicable)

I, Dr ____ have read the medical questionnaire and information/ consent form provided to my patient Mr/Miss/ Ms_____________________________________, and clear him/ her medically for involvement in exercise testing.

Signature:_____________________________________

Date (DD/MM/YYYY):_________________________

Appendix J

Diet Records

DIETARY FOOD RECORD INSTRUCTIONS

- Please record dietary intake for 3 days.

- Follow the guidelines for recording foods, beverages, and supplements provided with this packet.

HELPFUL HINTS:

ALL foods and beverages (INCLUDING WATER) that are consumed should be recorded.

Be very specific in your description of the type, the preparation method, and the amount of each food/beverage you consume.

Use the label on foods to help you determine portion sizes.

Save labels from packages and return them with your food record forms (this will greatly assist and enhance our analysis of your true nutrient intake).

Use nutrient descriptors (e.g., low-fat, fat-free, light, reduced calorie, etc.) and brand names (e.g., Kraft, Nabisco, Planters, etc.) to describe foods.

Record food/beverage consumption after each meal/snack instead of waiting until the end of the day.

MEATS/CHEESES

Description: Include description of the type, cut, and preparation method.

Portion Sizes:

List <u>cooked</u> (not raw) amounts of meats.

Determine amounts by weighing when possible.

170g of cooked meat is equivalent to approximately a deck of cards or the palm of your hand.

*Listed below are examples of how to document foods

100g. Skinless, boneless, chicken breast-roasted

100g. Ground beef round-fried

100g. Deli turkey breast slices

100g Atlantic cod-baked

100g. Sirloin steak-grilled

1/2 cup cubed beef stew meat

1 slice ham, 3" x 4" x 1/4" (7.5cm x 10cm x .6cm)

1 oz colby cheese

1 piece cheddar cheese, 3" x 2" x 1" (7.5cm x 5cm x 2.5cm)

STARCH/BREAD

(CEREALS, BREADS, PASTAS, RICES, BEANS)

Description: Include a complete description of the starch/bread including preparation method and brand name if applicable.

Portion Sizes:

List <u>cooked</u> (not raw) amounts of starch/bread products.

Generally, a measuring cup will suffice for cereals, rice’s, pastas, and beans.

½ cup brown rice (Uncle Bens)

2 slices rye bread-toasted

2 cups spaghetti noodles-boiled

1½ cups dry cereal (Cheerios)

1 cup oatmeal (Quaker Oats)-microwaved

8 animal crackers

Blueberry muffin, small

½ cup canned baked beans

1 corn tortilla, 6" across

FRUITS/VEGETABLES

Description: Include description of fruit/vegetable and whether it was fresh, frozen, or canned.

Include preparation method (e.g., steamed, fried, etc.)

Portion Sizes:

For whole pieces of fruit or vegetables, you may use small, medium, or large.

For many fruits/vegetables, cups may be used also.

1 medium Granny Smith apple

½ of a large tomato-fresh

5 small strawberries-fresh

½ cup canned pineapple-canned in water

1 cup frozen peas-steamed

¾ cup frozen mixed vegetables

3 spears steamed broccoli

2 medium raw carrots

COMBINATION DISHES

For standard mixed dishes, it is generally acceptable to list the type of dish without trying to list the ingredients separately. If the food is modified (e.g., low-fat), indicate this and try to describe how the food was modified. Provide enough detail to explain the composition of the dish. For tossed salad, list the individual ingredients paying careful attention to salad dressings and other caloric-dense toppings (bacon bits, cheese, ham, chopped egg, etc.).

1 cup bean chili w/o meat
3 slices thin crust large cheese pizza with pepperoni-frozen
½ cup potato salad
1 cup tuna casserole
1 cup macaroni and cheese (Kraft)
1 slice angel food cake
2 cups tossed salad
- 2 cups lettuce greens
- 3 slices cucumber
- 3 slices tomato
- 1 T shredded cheddar cheese
- 1 T shredded carrots
- 2 T fat-free Italian dressing

BEVERAGES/FLUIDS

Description: Include **ALL BEVERAGES INCLUDING WATER** complete description of the beverage

Portion Sizes: Use mls, liters, cups, or tablespoons.

200ml regular coffee, brewed
375ml Diet Coke
1 cup 2% milk
500ml unsweetened iced tea
125ml red table wine
200ml orange juice (from concentrate)
2 T light olive oil

MISCELLANEOUS

Remember to list all condiments and additions to foods and beverages, such as cream, sugar, butter, lemon, salad dressing, artificial sweeteners, catsup, etc.

3 T low-fat French salad dressing
2 tsp black raspberry jam
1 packet Sweet'n Low
1 T cream (half and half)
2 tsp margarine spread (Country Crock)
3 T fat-free ranch salad dressing (Kraft)

Date:______________ Name: _______________________________

Time	FOOD/BEVERAGE DESCRIPTION	AMOUNT	Total kcal (from label)

Comments:

Appendix K

Open Access Journal of Sports Medicine

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Open Access Full Text Article

REVIEW

Factors influencing pacing in triathlon

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Abstract: Triathlon is a multisport event consisting of sequential swim, cycle, and run disciplines performed over a variety of distances. This complex and unique sport requires athletes to appropriately distribute their speed or energy expenditure (ie, pacing) within each discipline as well as over the entire event. As with most physical activity, the regulation of pacing in triathlon may be influenced by a multitude of intrinsic and extrinsic factors. The majority of current research focuses mainly on the Olympic distance, whilst much less literature is available on other triathlon distances such as the sprint, half-Ironman, and Ironman distances. Furthermore, little is understood regarding the specific physiological, environmental, and interdisciplinary effects on pacing. Therefore, this article discusses the pacing strategies observed in triathlon across different distances, and elucidates the possible factors influencing pacing within the three specific disciplines of a triathlon.

Keywords: cycle, endurance, multisport, pacing strategy, run, swim

Introduction

Triathlon is a unique sport that consists of consecutive swim, cycle, and run disciplines completed over a variety of distances. The origin of triathlon is unclear; however, the first officially organized Ironman triathlon was conducted in Hawaii in 1978 with only 12 participants.[1] Over the last 30 years, the popularity of this sport has increased tremendously, driving the emergence of other shorter (ie, sprint, Olympic, half-Ironman) and longer (ie, double to 20× Ironman) distances as well as other formats (ie, off-road) of triathlons.[2] Of these, the most popular standard triathlon distances include the sprint (swim: 0.75 km, cycle: 20 km, run: 5 km, ~1 hour), Olympic (swim: 1.5 km, cycle: 40 km, run: 10 km, ~2 hours), half-Ironman (swim: 1.9 km, cycle: 90 km, run: 21.1 km, ~4–5 hours), and Ironman (swim: 3.8 km, cycle: 180 km, run: 42.2 km, 8–17 hours). Due to the large variations in distances, and thus exercise duration, the metabolic demands and physiological responses during such races could vary greatly.[3,4]

It is well accepted that the distribution of speed, work, or energy expenditure throughout an exercise task is extremely important in optimizing performance.[5–7] This pattern of energy expenditure or distribution of speed is known as "pacing" and, although often used interchangeably, differs slightly to the term "pacing strategy", which refers to a conscious strategy or plan to manipulate effort. Indeed, it has been proposed that the distribution of speed throughout an exercise task may be partially regulated on a subconscious level[8] and is, therefore, presumably disjointed somewhat from the athletes' pre-race strategy or plan. Within this context, energy expenditure

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Appendix L

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RESEARCH ARTICLE **Open Access**

Influence of race distance and biological sex on age-related declines in triathlon performance. Part A

Sam SX Wu[1]✉, Jeremiah J Peiffer[2], Jeanick Brisswalter[3], Wing Y Lau[1], Kazunori Nosaka[1], Chris R Abbiss[1]

Abstract

This study examined the effect of biological sex and race distance on the age-related declines in swimming, cycling, running and overall performances of the sprint, Olympic, Half-Ironman and Ironman triathlons. Individual discipline and overall performance time of the top 20% non-elite males (n=468) and females (n=146) were compared by categorizing into four 10-year age-groups (20-29, 30-39, 40-49, 50+ years) and normalising to the mean performance time of the fastest age-group for each race. An earlier, larger and faster rate of decline (p=0.01) in performance with ageing was observed in females (≥30 years, 9.3%, 3.0% per decade respectively) and males (≥40 years, 5.9%, 2.2% per decade, respectively) for the longer events (half-Ironman and Ironman) compared with the shorter distances (sprint and Olympic, ≥50 years for both sexes). A greater magnitude of decline was observed in swimming for both sexes, especially in the longer events, when compared with cycling and running (12.8%, 5.6%, 9.3% for females, 9.4%, 3.7%, 7.3% for males, in the swim, cycle and run disciplines, respectively). These results indicate that both race distance and biological sex influence the age-related decline in triathlon performance and could aid athletes in optimising training programs to attenuate the age-related declines in performance across different disciplines and distances. Specifically, older athletes may benefit from greater emphasis on swim training and factors that may influence performance during longer distance triathlons.

Keywords: sprint triathlon; Olympic triathlon; half-ironman triathlon; ironman triathlon; gender

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Introduction

In physically active individuals, endurance performance is maintained until approximately 35 years of age, followed by modest decreases (5-10% per decade) up to 50-60 years, and progressively steeper declines thereafter (Tanaka and Seals 2003, 2008). Associated with these changes, the age-related decline in endurance performance appears to differ depending upon the duration of activity (Joyner 1993). Indeed, Lepers et al. (2010) observed a greater age-related decline in top 10 male cycle and run performance for the Ironman triathlon (~9 h), compared with the Olympic distance triathlon (~2 h), which may reflect greater physiological and mechanical demands associated with ultra-endurance events (Lepers et al. 2010).

Irrespective of exercise duration, sociological (non-biological) and physiological differences between sexes typically results in endurance performance being 10-15% slower in females compared with males (Lepers and Maffiuletti 2011). Furthermore, this difference between sexes has been shown to widen with age (Tanaka and Seals 1997), possibly due to a greater rate of muscle mass loss in females, especially beyond menopause (Phillips et al. 1993). To date, majority of studies examining the interaction of age and/or biological sex on endurance performance have focused on sports such as swimming (Donato et al. 2003; Stefani 2006; Zamparo 2006), cycling (Dore et al. 2005; Schumacher et al. 2001), running (Tanaka and Seals 2003), rowing (Seiler et al. 1998) and duathlon (Rust et al. 2013). Tanaka and Seals (1997) examined the sex and age-related decline during the US Masters Swimming Championships and observed a greater decline in females compared with males over both short- (50 m) and long- (1500 m) duration events. Conversely, Schumacher et al. (2001) found no interaction in sex differences during world track cycling championships for 200 m, 1000 m, individual and team pursuit races. As such, it appears that the influence of sex on the age-related declines in endurance performance may differ depending on exercise duration and interaction of different modes of locomotion.

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Appendix M

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RESEARCH ARTICLE **Open Access**

Influence of age and sex on pacing during Sprint, Olympic, Half-Ironman and Ironman triathlons. Part B

Sam Shi Xuan Wu[1]✉, Jeremiah J Peiffer[2], Jeanick Brisswalter[3], Wing Y Lau[1], Kazunori Nosaka[1], Chris R Abbiss[1]

Abstract

The aim of this study was to investigate the influence of biological sex and age on the pacing strategies adopted by non-drafting top triathletes during the cycle and run disciplines of a Sprint, Olympic, half-Ironman and Ironman triathlon. Split times of the top 20% non-elite males (n=468) and females (n=146) were determined using official race transponders and a video capture system for pre-determined sections of the cycle and run disciplines of four triathlon distances. Indices of pacing were calculated to compare between sexes and age-groups. Results of this study indicated that different pacing strategies were adopted between athletes of different age and sex over the various triathlon disciplines and distances. Females were more aggressive during the initial stages of the cycling discipline across all distances (sprint - 2.1% p=0.024; Olympic - 1.6%, p=0.011; half-Ironman- 1.5%, p<0.001; Ironman - 1.7%, p<0.001 higher relative to mean) compare with males. Younger athletes (20-29 y) tend to begin the run faster (2.0 to 3.0% faster than other age-groups, p<0.029) during the sprint, Olympic and half-Ironman triathlons. These results indicate that different pacing strategies are adopted by non-drafting top athletes of different age and sex. Optimal pacing strategies may differ between sex and ages; therefore individuals may need to trial different strategies to develop their own optimal pacing profile for triathlon events of varying distances.

Keywords: Gender, ageing, cycling, running, pacing strategy

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Introduction

The optimisation of pacing during triathlon is a challenging task, due to the difficulty in successfully negotiating different disciplines (i.e. swim, run and bike) as well as the overall event (Bentley et al. 2002). Previous research examining pacing in triathlon has focused on draft-legal Olympic distance triathlons (~2h, Bernard et al. 2009; Le Meur et al. 2009; Vleck et al. 2008), with only a single study examining cycling pacing during the longer non-drafting Ironman distance (8-17 h, Abbiss et al. 2006). As such, the distribution of pace throughout the sprint (~1 h), half-Ironman (~5 h), and to an extent Ironman events are yet to be fully identified. It is likely that different pacing strategies could be adopted due to the influence of factors such as energy substrate demand and availability (muscle and liver glycogen), thermoregulation (Noakes et al. 2005), mental fatigue (Marcora et al. 2009), impaired muscle function and recruitment (Noakes et al. 2005), and the complex feed-forward cognitive control of the brain based on the expected duration of the event (Noakes et al. 2005; St Clair Gibson et al. 2006; Tucker and Noakes 2009).

Based upon previously published observations in Olympic distance triathlons, it appears that elite athletes typically adopt a positive pacing strategy (characterised by a progressive decrease in power output/or speed) during the swim, cycle and run disciplines (Le Meur et al. 2009; Vleck et al. 2006). For instance, Le Meur et al. (2009) observed a more pronounced decrease in the cycling speed for males (16.8%) compared with females during the first half of the cycling discipline in a World Cup Olympic distance triathlon. These results indicate that males may have adopted a more aggressive pacing strategy during the triathlon when compared with their female counterparts. Nevertheless, the draft-legal nature of these studies (Bernard et al. 2009; Le Meur et al. 2009; Vleck et al. 2008), along with a greater number of overall male competitors is likely to have highly influenced the pacing strategies adopted. To date, we are unaware of any studies that have yet examined gender differences in pacing strategies during the other three common (sprint, half-Ironman and Ironman) triathlon distances.

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