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The influence of a simulated Olympic distance cycle exercise on subsequent running economy and biomechanics in triathletes

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The Influence of a Simulated Olympic Distance Cycle Exercise on Subsequent Running Economy and Biomechanics in Triathletes

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ABSTRACT

The multidisciplinary sport of triathlon provides a good model for testing whether a secondary task can be negatively affected by a preceding task, especially when movement patterns are different. Research suggests that cycling exercise impairs subsequent running performance by altering a runner's economy and various mechanics (or technique-related) parameters. However, this is not an unambiguous finding. Furthermore, movement patterns are self-optimised during cycling and running to minimise the energy cost, yet the relationship between running mechanics and economy are not clear when different locomotor tasks are performed in succession.

Two research studies were conducted with the focus of describing and better understanding the influence of a prior cycle exercise on the economy and mechanics of running in 17, trained male triathletes. The first study aimed to investigate the differences in measures of running economy and other physiological and perceptual variables following a 60-min, simulated Olympic-distance cycling bout, compared to when cycling was not performed prior to running. Measures of running economy (i.e. aerobic energy cost, oxygen cost and the rate of oxygen consumption) and all other physiological (e.g. heart and ventilation rates) and perceptual descriptors (perception of exertion and effort) were significantly impaired ($p < 0.05$) following the cycling bout. It is likely that the generation of both peripheral and central fatigue during cycling contributed to these impairments, yet further investigation is required to enhance our understanding of the influence of a prior task on perceptual (or anticipatory) responses influencing the pacing strategies of subsequent running. Strong agreement existed between the three methods of calculating running economy, yet the number of participants identified as having an *impaired* running economy differed depending on the method used. Different conclusions may therefore be drawn as to the influence of prior cycling on subsequent running depending on the calculation method of economy used. It is recommended that aerobic energy cost be calculated to provide more specific information regarding the substrate utilisation, which is not accounted for when calculating oxygen cost and $\dot{V}O_2$.

The second study aimed to examine the differences in three-dimensional mechanical variables when running following a 60-min cycle exercise, compared to running

without prior cycling, and to assess the relationship between differences in running mechanical variables and running economy. Findings indicated significant differences ($p < 0.05$) between pre-and post-cycling running stride parameters (i.e. velocity, flight time, stride length, vertical oscillation of the centre of mass and landing of the foot relative to the centre of mass), lower body joint kinematics (knee flexion during the support and swing phases, and anterior pelvic tilt) and joint extension power of the knee. Interestingly majority of these differences replicated profiles typically associated with economical running techniques. Parameters of the ankle, hip, pelvis and trunk remained unchanged. The changes in flight time, knee flexion during the support phase and the lateral pelvic flexion were significantly associated with the changes in running economy, yet large individual differences existed. Runners identified in Study One as having an *improved* economy following cycling ($n = 6$), indicted a greater change in mechanical variables (although not statistically significant). Therefore, it is suggested that triathletes either self-optimised their kinematics in an attempt to maintain movement economy following cycling, or as an effective pacing strategy decreased their running velocity.

The results of this thesis confirmed a significant influence of a prior locomotor task (i.e. a cycling exercise) on the energy cost, perceptual responses and the biomechanics of a subsequent locomotor task (i.e. running) in most trained triathletes. However, 35% of the study cohort demonstrated an ability to run with better economy and presented with a trend towards lower increases in measured physiological and perceptual parameters. A single approach to identify an economical running technique, particularly when performed in immediate succession following a prior task, is therefore not adequate. Maintaining pre-cycling running mechanics might not be a main factor related to triathlon running performance as athletes appeared to self-optimise and adapt their running mechanics during the post-cycling condition, which was different to the pre-cycling, non-fatigued condition. It is recommended to make physiological testing procedures more task specific by including a cycling bout prior to running to assess and monitor individual adaptations, and to assist coaches in developing training to optimise this transition between cycling and running.

DECLARATION

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

i. incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;
ii. contain any material previously published or written by another person except where due reference is made in the text; or
iii. contain any defamatory material.

Signed: [redacted]

Date: 2/07/2018

USE OF THESIS

This thesis is dedicated to my loving family for encouraging me to be the best I can be.

Thank you for always believing in me.

In loving memory of my dearest grandparents and inspirational 'engel vriend':

Tina Strauss (17 February 1943 – 31 May 2015),

Hennie Strauss (3 September 1941 – 1 June 011),

Theuns Dercksen (7 July 1989 - 12 May 2012).

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

LIST OF FIGURES

CHAPTER TWO

CHAPTER THREE

LIST OF ABBREVIATIONS AND DESCRIPTION OF TERMS

3-D	Three-dimensional
%Effort	Perception of effort on a scale of 0-100, 0% being no effort and 100% begin all-out effort
Anterior pelvic tilt/ APT	Maximal flexion angle of the pelvis that occurs at or just after toe-off.
AnkleHS	Ankle dorsiflexion angle at initial foot contact
AnkleTO	Ankle plantar flexion angle at toe-off
ANOVA	Analysis of variance
CoM	Centre of mass
$CoM_{vertical}$ / CoM_v	Vertical oscillation of the centre of mass
$CoM_{horizontal}$ / CoM_h	Horizontal distance from the centre of mass to the heel marker at initial foot contact with the ground
DXA	DXA, dual-energy x-ray absorptiometry
Contact time/ CT	Contact time, the time that the foot is in contact with the ground during the support phase (i.e. from initial foot contact to toe-off)
EMG	Electromyography
Flight time / FT	Flight time, the time from toe-off to the initial foot contact of the same limb during the swing phase
HR	Heart rate
Lateral pelvic tilt / Pelvic drop	Maximal lateral flexion angle of the pelvis that typically occurs during the stance phase, when the body's centre of mass is projected over the leg in contact with the ground, whilst the recovery leg is swinging through next to the stance leg.
MAP	Maximal aerobic power
Max	Maximum
Max hip extension	Maximal extension angle of the hip that occurs during the recovery phase at or just after toe-off.
Max hip flexion	Maximal flexion angle of the hip that occurs during the leg swing phase

Max knee flexion during stance	Maximal flexion angle of the knee during the support phase. Key position identified by the lowest knee angle during contact with the ground.
Max knee flexion during swing	Maximal flexion of the knee during the leg recovery phase i.e. the swing phase. Key position identified by the lowest knee angle during the leg swing phase.
Pelvic rotation	Maximal rotation angle of the pelvis that occurs during the recovery phase close to maximum hip flexion.
P_{max}	Power output at $\dot{V}O_{2max}$
PostRUN	Post-cycling running condition
PreRUN	Pre-cycling running condition
RER	Respiratory exchange ratio
RPE	Rating of perceived exertion, based on 6-20 Borg scale
rpm	Revolutions per minute
SD	Standard deviation
SL	Stride length
SR	Stride rate
Trunk flexion	Maximal trunk flexion angle during the stride that typically occurs during the stance phase just after initial foot contact
VE	Pulmonary ventilation
$\dot{V}CO_2$	Rate of carbon dioxide production
$\dot{V}O_2$	Rate of oxygen consumption, measured in $mL \cdot kg^{-1} \cdot min^{-1}$
$\dot{V}O_{2max}$	Maximal oxygen consumption

CHAPTER ONE - INTRODUCTION

1.1 OVERVIEW

This Masters dissertation contains two research studies with the underlying focus of describing and better understanding the influence of a prior rhythmic cycling activity on the economy, movement patterns and perceived effort (or level of exertion) of subsequent running. It is well known that an important aspect of any multidiscipline endurance sport such as triathlon, which involves consecutive swimming, cycling and running efforts, is the athlete's ability to transition between locomotor modes. The potential effect of this locomotor mode transition is particularly important during the cycling-to-running transition as the time taken to complete the running component is widely recognised to have the greatest correlation (r = 0.81-0.98, p < 0.01) with total race completion time. As a result, coaches specifically tend to include technical efforts of transitioning from cycling to running in the training practice. However, most physiological ergometer testing or monitoring procedures usually involve single sport assessment from a fresh start, without the inclusion of a prior locomotion mode. Furthermore, although running economy (an essential determinant of running performance) is thought to be heavily influenced by preceding cycling exercise, this is not a unambiguous finding. Therefore, the investigation of the influence of a triathlon-simulated cycling exercise on running economy and mechanics is important from a practical point of view to identify whether these parameters are negatively affected, and assist coaches in developing training to optimise this transition.

Anecdotal evidence suggests that triathletes typically report an incoordination and an inability to maintain a consistent rhythm during the run when it immediately follows the cycling discipline (Gottschall & Palmer, 2000; Millet, Millet & Candau, 2001; Rendos, Harrison, Dicharry, Sauer & Hart, 2013). It is likely that both movement pattern interference and the metabolic and neuromuscular fatigue induced by cycling contribute to an impairment in running economy, and possibly an alteration in running mechanics (Bernard et al., 2003; Gottschall & Palmer, 2002; Le Meur et al., 2012). In contrast, however, other studies have shown little or no effect of preceding cycling on the economy or mechanics of subsequent running (Bentley, Millet, Vleck & McNaughton, 2002; Bonacci, Saunders, Alexander, Blanch & Vicenzino, 2011; Millet et al., 2001; Walsh, 2015). These findings are difficult to reconcile and are indicative

of our lack of understanding of the effects of cycling exercise on the energetics of running. Some reasons for these contradictory findings might include differences in methodological protocols between studies, the use of data averaging techniques that may mask individual differences through the analysis only of group-level data, and the validity of different techniques used to quantify running economy. Moreover, a detailed three-dimensional kinematic and kinetic (lower body joint powers) analysis, rather than the more common two-dimensional analysis (often limited to specific lower-limb joints), is required in order to obtain information relating to individual differences between triathletes, particularly for those showing substantial changes in running economy following cycling.

In response to these issues, two controlled experimental studies were completed in the present dissertation. The first study was conducted to describe the relative influence of a simulated Olympic-distance cycling exercise on running economy and other variables relating to physiological and psychological perceptual responses (e.g. heart and ventilation rates, perceived effort and exertion), when compared to running without prior cycling exercise in a group of trained triathletes. The study included an assessment of the validity of the use of the rate of oxygen consumption ($\dot{V}O_2$, in $mL \cdot kg^{-1} \cdot min^{-1}$) and the oxygen cost (in $mL \cdot kg^{-1} \cdot m^{-1}$) as measures of running economy by comparing it to the calculated aerobic energy cost ($J \cdot kg^{-1} \cdot m^{-1}$) and providing information regarding metabolic substrate utilisation, which is not commonly reported in triathlon research. The second study was aimed to describe the influence of cycling exercise that replicates the cycling leg (i.e. duration and intensity) of an Olympic distance triathlon on running technique and its relationship to running economy. This study quantified the temporal running stride parameters and three-dimensional joint kinematic and kinetic (lower body joint power production) patterns before and after a bout of cycling exercise. Importantly, the relationship between the changes in running kinematics and the changes in running economy before and after cycling were also explored in Study Two. Additionally, this testing allowed a description of the differences in kinematic and kinetic patterns between triathletes who do or do not show substantial changes in running economy.

1.2 BACKGROUND INFORMATION AND LITERATURE REVIEW

The energetics of complex movements, including those occurring in lower limb locomotion such as walking, running and cycling, have been extensively studied and is one of the key requirements for an understanding of human motion (Cavagna, 1975; Di Prampero, 1986; Saibene & Minetti, 2003). The interaction between the energetic cost of lower limb locomotion, defined as the total energy consumed by the muscles, and the movement strategy used to cause locomotion (resulting from the coordinated action of muscles exerting forces to produce movement of body segments) is essential in understanding movement efficiency (Cavagna, 2010; Saibene & Minetti, 2003). For instance, movement *efficiency* can be obtained from the ratio of the mechanical work done to the metabolic energy cost of the task (Cavagna & Kaneko, 1977; Di Prampero, 1986; Mian, Thom, Ardigò, Narici & Minetti, 2006). Movement *economy,* on the other hand, refers to the metabolic energy demand for a given speed or distance covered, which is only part of the work performed, and is typically measured during submaximal and steady-state locomotion at a given workload (Daniels, 1985; Saunders, Pyne, Telford & Hawley, 2004). The processes that result in better use of oxygen and energy expenditure relative to a given workload will enable an athlete to consume less $\dot{V}O_2$ for a given workload. This includes the ability to minimise any counterproductive or wasteful movements that will allow athletes to move faster at a given distance, or longer at a constant velocity (Barnes & Kilding, 2015b; Daniels, 1985). In order to develop strategies that optimise the performance (i.e. increase velocity or decrease time) in an energetically demanding activity such as running, it is important to understand the factors that influence movement economy.

Previous research has demonstrated that athletes typically (probably subconsciously) self-select movement patterns during tasks such as cycling, running and various upper body activities that minimise energy cost and thus improve movement efficiency (Cavanagh & Williams, 1981; Saibene & Minetti, 2003; Vercruyssen & Brisswalter, 2010). For example, it has been shown that a spontaneous walking speed is chosen that is very close to an 'optimal' walking speed where the energy cost is at a minimum and where the 'optimal' stride frequency corresponds closely to the freely chosen stride frequency (Cavagna, Mantovani, Willems & Musch, 1997; Hunter & Smith, 2007). However, as the speed of the locomotion increases, so does

the cost of walking. Alternative strategies are therefore required to minimise the energy cost, resulting in the walking gait changing to a running gait, particularly if the walking speed increases above approximately 2 $m{\cdot}s^{-1}$ (Saibene & Minetti, 2003). Similarly, whilst running at a given speed, optimal combinations of stride length and stride frequencies are adopted that are least metabolically taxing and appear to be self-determined. If the task or the speed of locomotion were to change, modifications to the given combinations will be required to minimise the metabolic energy cost (Saibene & Minetti, 2003; Willems, Cavagna & Heglund, 1995). It has been proposed that the efficient movement patterns self-selected by runners either come from an innate, fine-tuning process of self-optimisation or from the effective process of energy optimisation through an adaptation to years of training (Hunter & Smith, 2007; Moore, 2016; Williams & Cavanagh, 1987).

Alternatively, tasks that require a person to deviate from their preferred movement pattern may reduce locomotion economy by increasing energy expenditure for a given speed or power output (Hunter & Smith, 2007; Saibene & Minetti, 2003). Williams and Cavanagh (1982) demonstrated an increase in $\dot{V}O_2$ at a given running speed when the self-selected stride lengths were altered by ±20%. Similarly, Cavagna and colleagues (1997) indicated that when the freely chosen step frequency was altered during running, the stiffness of the bouncing limb-body system changed in an attempt to match the new frequency; which could can be done through alterations in muscle activities and limb-joint configurations. This indicates that in order to maintain movement efficiency, movement patterns may be modified either consciously or subconsciously by tuning the step frequency to the natural frequency of the bouncing system (Cavagna, 2010; Cavagna et al., 1997).

To date, little is known of the factors influencing movement economy and how it may be complicated by prior exercise in a multidisciplinary sport such as triathlon. Triathlon involves the completion of three consecutive modes of locomotion (swim, cycle and run) over a variety of distances (see Table 1.1), of which the Olympic distance (1.5 km swimming, 40 km cycling and 10 km running) is the most common event (Millet & Vleck, 2000). The ability to reduce the transition time between modes of locomotion and thus maintain a high average speed throughout the race is essential for successful triathlon performance (Bentley et al., 2002; Vercruyssen, Suriano, Bishop, Hausswirth & Brisswalter, 2005). Due to its high correlation (r =

0.81 to 0.98) with overall performance time, and anecdotal reports within the literature, the run leg is widely recognised as the most important section of the race (Cejuela, Perez-Turpín, Cortell & Villa, 2008; Figueiredo, Marques & Lepers, 2016; Le Meur et al., 2009). Research conducted on triathletes of various levels of performance has suggested that cycle exercise impairs subsequent running performance by altering a runner's economy (Bonacci, Vleck, Saunders, Blanch & Vicenzino, 2013; Hausswirth, Bigard & Guézennec, 1997; Hue, Le Gallais, Chollet, Boussana & Prefaut, 1997). In fact, an increase in the $\dot{V}O_2$ and oxygen cost of up to 16.9% has been reported in well-trained and recreational triathletes when compared to running without prior cycling, especially during the first few minutes of the run following cycling (Bentley et al., 2002; Bonacci et al., 2010; Pialoux, Proust & Mounier, 2008). Efficiency during the running leg is therefore a critical factor influencing overall performance and any adverse effects resulting from the previous cycling leg need to be minimised (Hausswirth et al., 1997; Millet, Vleck & Bentley, 2009).

Table 1.1 Details of the most common triathlon event distances.

Distance	Swim (km)	Bike (km)	Run (km)
Sprint	0.75	20	5
Short/ Olympic	1.5	40	10
Middle/Half Ironman	1.9	90	21.1
Long/ Ironman	3.8	180	42.2

Although the precise factors responsible for these alterations in running economy are unclear, the repetitive cyclic movement patterns of cycling and locomotor pattern interference, and/or fatigue are suggested as likely contributors (Bentley et al., 2002; Chapman, Vicenzino, Blanch, Knox, et al., 2008; Lepers, Theurel, Hausswirth & Bernard, 2008). In agreement, several studies (as well as anecdotal evidence) indicate that triathletes report impairment in their coordination, or awkwardness, when running immediately after cycling. They also report a greater perceived exertion and experiencing difficulty in following a consistent rhythm to maintain a constant pace during the early stages of the run (Bonacci et al., 2013; Chapman, Vicenzino, Blanch, Dowlan & Hodges, 2008; Lepers et al., 2008; Rendos et al., 2013). Any movement pattern interference caused by the prior cycle exercise could possibly lead to an inability of the triathlete to immediately adapt to the different

locomotor pattern of the run within the first few minutes (Chapman, Hodges, Briggs, Stapley & Vicenzino, 2010; Gottschall & Palmer, 2002).

This perceived loss of coordination might be explained by the findings of studies investigating the influence of sequentially-performed tasks (Classen, Liepert, Wise, Hallett & Cohen, 1998; Keele, 1968; Rubinstein, Meyer & Evans, 2001). It has been clearly observed that a preceding task (whether language, maths, memory or locomotor task) can affect the execution speed of a subsequent task, leading to a reduction in performance (Giannouli, 2013; Proios & Brugger, 2004). Interestingly, Classen and colleagues (1998) indicated that the motor cortex is able to retain specific kinematic aspects of recently practiced movements and it that may take up to 20 min to adapt to a new, consecutive task. These authors performed an experiment in which unidirectional thumb movements were evoked through transcranial magnetic stimulation (TMS) of the motor cortex. Participants then performed volitional thumb movements in the opposite direction for 30 min, after which the motor cortex was again stimulated using TMS. The results showed that the thumb movement direction was sustained in the direction of the recent practice for several minutes before returning to the original evoked direction over time. It is therefore evident that maintenance of a previously practised movement pattern may occur, possibly leading to a reduced ability to interrupt a task in progress and shift from one strategy to another (Giannouli, 2013). This phenomenon is often referred to as perseveration, whereby a person will involuntarily continue a movement pattern after performing a rhythmic activity for an extended period of time (Proios & Brugger, 2004; Ramage, Bayles, Helm-Estabrooks & Cruz, 1999), i.e. the preponderance for use of one movement pattern perseveres even after a new motor pattern is chosen for use.

Perseveration has mainly been presented through simple experimental finger tapping tasks or simulating locomotor lower limb movement patterns (Classen et al., 1998; Gurfinkel, Levik, Kazennikov & Selionov, 1998; Keele, 1968), yet little reference has been made to the interference of successive gross movement patterns or locomotion as observed in multidiscipline sport. In an attempt to investigate the influence of prior cycling cadence on subsequent running, Gottschall and Palmer (2002) suggested that perseveration could likely be a mechanism causing some of the unintentional movement pattern changes observed in running immediately following cycling. They found that average running speed and stride frequency were substantially greater

after cycling at faster cadences than after cycling at slower cadences. As the participants' heart rates during cycling and running were equivalent to those in the controlled cycling and running conditions respectively, the authors suggested that the neural firing rates during running were affected by prior cycling neural control. Moreover, a change in muscle activity during running has also been demonstrated to be dependent on the preceding cycle demands. This perception supports the findings of Heiden and Burnett (2003), indicating greater differences in muscle activation levels and durations during a subsequent 2-km run following a 40-km cycle exercise compared to following a 10-km run condition. Furthermore, Chapman and others (2008) concluded that some elite level triathletes were able to adapt or modify their kinematics and muscle recruitment strategies (measured in tibialis anterior) in order to maintain mechanical efficiency. Whilst these studies provide valuable insight into the movement pattern alterations caused by prior cycle exercise, running economy was not measured, making it difficult to ascertain whether these changes affected the cost of running.

In addition to the possible locomotor pattern interference induced by cycling contributing to the loss of running economy and incoordination typically reported by triathletes during the early stage of the run, neuromuscular and metabolic fatigue are also probable causes (Heiden & Burnett, 2003; Lepers, Millet & Maffiuletti, 2001). It is well known that fatigue is an important determining factor of performance and influences not only physiological characteristics, but also the forcefulness of muscular contractions (Nicol, Komi & Marconnet, 1991). Indeed, Lepers and colleagues (2001) and Theurel and Lepers (2008) found that 30 min of prolonged cycling at 70-80% maximal aerobic power was sufficient to induce significant neuromuscular fatigue, as indicated by a reduction in maximal voluntary contraction torque and muscle activation levels in the knee extensors. Cycling at high and variable intensities (~1 h to 1 h 15 min) (Bernard et al., 2003; Le Meur et al., 2011), as observed in Olympic distance races, could potentially increase the metabolic load during cycling, which could increase the development of neuromuscular and metabolic fatigue prior to commencing the run (Bentley et al., 2002; Etxebarria, Anson, Pyne & Ferguson, 2014). Moreover, fatigue induced by the preceding swim and cycle phases in a triathlon have also been shown to alter leg stiffness and, consequently, the efficiency of energy storage and recoil during subsequent running

(Candau et al., 1998; Tartaruga et al., 2012). Fatigue caused by prolonged cycling is often associated with a reduced metabolic efficiency exemplified by an increased minute ventilation, cardiac output, blood lactate accumulation and muscle glycogen depletion, which could be related to the increase in the subsequent energy cost of running (Hausswirth & Lehénaff, 2001; Hue et al., 1997; Kyröläinen et al., 2000). Therefore, the physiological and biomechanical ability to cope with the high energy demands of cycling and to efficiently utilise oxygen for energy production whilst maintaining a high average running velocity might be compromised through cycling-induced neuromuscular and metabolic fatigue.

Nevertheless, and irrespective of the cause (i.e. movement pattern interference or neuromuscular metabolic fatigue induced by cycling), the majority of the available evidence suggests prior cycling has an impact on subsequent running ability. These results are supported through laboratory-based findings where significant alterations in several running biomechanical parameters have been observed following cycling when compared to running without prior cycling (Bernard et al., 2003; Bonacci et al., 2010; Rendos et al., 2013). In particular, significant changes in running velocity, stride rate, knee and ankle angle at foot strike and trunk position, typically within the first 5 min of running following cycle exercise, have been observed. The majority of the aforementioned studies investigating running mechanics following cycling have used treadmill-based testing protocols but did not account for the energetic cost differences between overground vs. treadmill running, which may be done by setting the treadmill at a 1% incline (Jones & Doust, 1996). Another limitation of previous studies is the use of running velocities that are less than those likely achieved during Olympic distance triathlon competition. Thus, whilst previous researchers have suggested that movement pattern alterations caused by prior cycling are likely to contribute to the increase in energy cost (Bonacci et al., 2010; Hausswirth et al., 1997), the amount to which the consistency and magnitude of biomechanical alterations influence the changes in running economy are inconclusive.

The relationship between mechanical factors and the energy cost of running has been demonstrated in numerous studies of distance running (Barnes & Kilding, 2015a; Saunders et al., 2004; Tartaruga et al., 2012; Williams & Cavanagh, 1987), yet no single mechanical factor has been shown to underpin the changes in running economy. A number of physiological, biomechanical and neuromuscular factors

appear likely to influence energy cost in well-trained and elite runners (Dallam, Wilber, Jadelis, Fletcher & Romanov, 2005; Kyröläinen, Belli & Komi, 2001). A combination of biomechanical variables has been shown to explain up to 81% variability in the rate of $\dot{V}O_2$ in distance running studies, as confirmed by Tartaruga and colleagues (2012) in 16 national-level distance runners. These authors and others (Folland, Allen, Black, Handsaker & Forrester, 2017; Kyröläinen et al., 2001; Moore, 2016), alluded to the fact, that although a relationship between mechanical and metabolic variables was established, the interactions were complex and highly individual. Mechanical variables that have been shown to be closely related to running economy include, but are not limited to, vertical oscillation distance and velocity of the centre of mass, foot-ground contact time, stride length and stride frequency, vertical and horizontal ground reaction forces and the work done during foot-ground contact (Cavanagh & Kram, 1989; Folland et al., 2017; Kyröläinen et al., 2001). Their effect on running economy is then also influenced by the ability of the muscles and tendons to store and release elastic energy, and thus to minimise the energy lost during foot-ground contact (Saunders et al., 2004; Tartaruga et al., 2012). This illustrates that although a number of biomechanical factors have been identified to influence movement economy, complex and controversial relationships still exist within the literature with large inter-individual differences presented both in fatigued and non-fatigued running situations.

Furthermore, although several previous studies have reported changes in running economy and kinematics following cycling (Bonacci et al., 2010; Hausswirth et al., 1997; Marino & Goegan, 1993; Vercruyssen et al., 2005), others have not detected such changes in mechanics (Bonacci et al., 2011; Cala, Veiga, Garcia & Navarro, 2009; Hue et al., 1997; Quigley & Richards, 1996), or observed a meaningful effect on the energy cost of subsequent running (Etxebarria, Hunt, Ingham & Ferguson, 2014; Millet, Millet, Hofmann & Candau, 2000). For example, Etxebarria, and colleagues (2014) found that although running-related metabolic variables (pulmonary ventilation, rating of perceived exertion, heart rate and blood lactate concentrations) were substantially increased, significant changes in running economy did not occur irrespective of whether a variable- or constant-power cycling bout was completed by their well-trained triathletes. Millet and colleagues (2000) also did not find any metabolic or mechanical alterations following cycling during a 7-min run in

eight elite and 18 moderately-trained triathletes. However, the maximal cycling exercise bout performed to exhaustion in their study did not closely reflect triathlon race conditions. Hue and colleagues (1997) examined running economy and biomechanics during a 10-km run both with and without a preceding simulated 40 km triathlon cycle leg at the same speed in seven well-trained male triathletes. They found that $\dot{V}O_2$ and several other physiological variables relating to energy cost increased significantly, however no alterations were found in any of the biomechanical variables measured during running following cycling. Similarly, Tew (2005) found no effect of cycling cadence (slow, preferred or fast) on $\dot{V}O_2$ or biomechanical factors during a subsequent 10-km run when compared to running without prior cycling. Cala and colleagues. (2009) concluded that no loss in running efficiency occurred as a result of cycling, and that a decreased velocity and stride length was observed only near the end of the running component during a World Cup triathlon event. Due to the discrepancies in the literature, the effects of transitioning from cycling to running locomotor tasks in a triathlon are not yet fully understood.

It is worth considering whether the conditions under which the cycle bout is performed may influence study outcomes, as individual metabolic fatigue and responses would be differentially affected by the demands of certain cycle protocols with different variations in required power output (Suriano, Vercruyssen, Bishop & Brisswalter, 2007). Additionally, small sample sizes, different levels (training histories) of athletes used, the reporting of group-level data that can mask individual differences, and the variation in methods used to quantify movement economy are likely contributors to the inconsistencies. For example, reporting the energy cost ($J \cdot kg^{-1} \cdot m^{-1}$), rather than the oxygen cost, of running might be considered a valid way to quantify running economy because it takes into account the different substrate combinations and corresponding differences in energy provided per volume of oxygen used by the subjects (Di Prampero, Salvadego, Fusi & Grassi, 2009; Fletcher, Esau & MacIntosh, 2009). Despite this, few studies calculate the energy usage, instead using the rate of oxygen consumption or the oxygen cost to cover a given distance.

It is also worth noting that different methods exist for quantifying the joint kinematics. This includes the manner in which the kinematic constraints of the limbs are defined in terms of the joint angle's orientation relative to the vertical and sagittal planes.

One could investigate the relative sagittal joint angles between two segments or alternatively, investigate the global limb length and the absolute elevation and adduction of the limb segments (Borghese, Bianchi & Laquaniti, 1996). The latter also suggests an alternative way of presenting the kinematic data such as using angle-angle plots as opposed to the changes in relative joint angles over time. Nevertheless, through planar covariation analysis, (i.e. the absolute angles of elevation of the segments), the individual characteristics can be correlated with the energy cost of the movement (Bianchi, Angelini, Orani & Laquaniti, 1997). To the author's knowledge, this has not been done when investigating the influence of a prior task on a subsequent locomotor task.

Understanding mechanical modifications occurring with fatigue continues to be a challenge to furthering our understanding of performance factors and developing optimised training programs for triathletes. Moreover, a number of potentially important kinematic and kinetic variables have not been examined during running, so a complete understanding of the differences between pre- and post-cycle running has not be attained. In order to improve triathlon running performance, a comprehensive investigation of the individual's running gait is essential in order to understand the effect of preceding cycle exercise on running mechanics and its relationship with changes in running economy within a simulated triathlon cycle-to-run transition.

1.3 PURPOSE AND SIGNIFICANCE

It has been shown that a task can be negatively affected by fatigue or neuromuscular movement pattern interference, resulting from a prior task, when the tasks are performed in close temporal proximity. In a multidisciplinary sport such as triathlon, performance in the running leg following the cycle leg has been shown to be the most important to overall triathlon success. Yet controversy exists regarding the potential deleterious effects on running performance by prior cycling exercise. In addition, the relationship between economy of running and biomechanical movement patterns are not yet resolved. The present Masters research aimed to improve our current understanding through the completion of two controlled experimental studies.

The first study investigated and described the influence of a simulated Olympic distance cycling protocol on running economy and other physiological and psychological (perceptual) variables in moderately-trained triathletes. The findings from Study One were compared to a run where a cycling exercise did not precede a running condition. The aerobic energy cost was quantified in order to provide additional information regarding metabolic substrate usage in addition to the oxygen cost, as typically investigated in the literature.

The second study was developed to examine the changes in 3-D running mechanics when cycling exercise was imposed immediately prior to the run as compared to running without prior cycling and, importantly, the relationship between changes in running kinematic and kinetic variables were mathematically related to the changes in running economy to determine whether relationships existed between the variables. From this comprehensive gait analysis, information was obtained to understand how participants adapt their locomotor movement patterns, or how they were forcibly altered (by fatigue or perseveration), following cycling exercise. The findings from Study Two will improve our understanding of the mechanisms responsible for performance (i.e. running economy and perceived exertion) alterations. Additionally, investigating the locomotor movement patterns used by the more vs. less economical runners will lead to a greater understanding of the factors influencing running economy in triathlon.

From a practical standpoint, although technical efforts focussed on short cycle-to-run transitions is a component of typical training to promote physiological and/or neuromuscular adaptations, performance testing procedures typically involve only single disciplined ergometer testing starting in a non-fatigued state (Millet & Vleck, 2000; Tanner & Gore, 2012). The outcomes of the present research will establish whether to include a cycling bout prior to running during physiological testing to monitor the training adaptation of individual triathletes. It will also provide valuable information to triathletes, coaches and sport scientists to identify particular biomechanical factors that can influence performance (i.e. running economy), and may allow optimisation of a triathlete's running technique following cycling, improve testing procedures and ultimately aid to potentially improve overall triathlon performance. Finally, this research will provide more detail on the influence of one

exercise task on the physiological, perceptual exertion and biomechanical performance of a subsequent locomotor task.

1.4 RESEARCH QUESTIONS

The research questions within thesis have been divided into two studies, as listed below:

1.4.1 Study One (Chapter Two)

TITLE: Triathlon running economy: the influence of a simulated triathlon cycle leg on running economy in trained triathletes.

i. Are running economy (aerobic energy cost) and other physiological and psychological (perceptual) descriptors of work rate (heart and ventilation rates, perceived exertion and effort) altered when preceded by a triathlon-simulated 60-min cycle bout, when compared to running without preceding cycling?
ii. Are outcomes of the perceptual descriptors (i.e. using perception of exertion versus perception of effort) the same during running following cycling, when compared to running without preceding cycling?
iii. Are outcomes of the study the same irrespective of whether running economy is quantified as aerobic energy cost ($J \cdot kg^{-1} \cdot m^{-1}$), oxygen cost ($mL \cdot kg^{-1} \cdot m^{-1}$) or oxygen consumption ($\dot{V}O_2$, $mL \cdot kg^{-1} \cdot min^{-1}$)?
iv. Are there individual-specific effects of a triathlon-simulated 60-min cycle (as opposed to group average) in this study cohort?

1.4.2 Study Two (Chapter Three)

TITLE: The effect of a simulated cycle leg on running biomechanics and economy in trained triathletes.

i. Are lower body joint kinematics and joint powers altered when running is preceded by a triathlon-simulated 60-min cycle protocol when compared to running without prior cycling?
ii. Do differences in running economy measured before and after cycling correlate with differences in running biomechanical variables?

iii. Can differences in running economy resulting from preceding cycle exercise be predicted by a linear combination of biomechanical variables?

iv. Do biomechanical alterations differ between those that used less aerobic energy (improved) and those that used more aerobic energy (impaired) subgroups?

1.5 RESEARCH HYPOTHESES

1.5.1 Study One (Chapter Two)

i. Significant alterations will be observed for running economy (aerobic energy cost) and other physiological and psychological (perceptual) descriptors of work rate (heart and ventilation rates, perceived effort and exertion, etc.) when preceded by a triathlon-simulated 60-min cycle bout when compared to running without preceding cycling.

ii. Outcomes of perceptual descriptors (i.e. perception of exertion versus perception of effort) will differ when running following cycling, compared to when running without preceding cycling, which will enable better understanding of where fatigue predominantly stems from (i.e. from peripheral or central mechanisms).

iii. Outcomes of the study will vary depending on the method used for quantifying running economy (i.e. as aerobic energy cost, $J{\cdot}kg^{-1}{\cdot}m^{-1}$; oxygen cost, $mL{\cdot}kg^{-1}{\cdot}m^{-1}$; or $\dot{V}O_2$, $mL{\cdot}kg^{-1}{\cdot}min^{-1}$).

iv. Individual-specific effects of a triathlon-simulated 60-min cycle exercise (as opposed to group average) will be observed in this study cohort for the measured variables (particularly running economy).

1.5.2 Study Two (Chapter Three)

i. Significant differences in lower body joint kinematics and joint powers will be observed when running is preceded by a triathlon-simulated 60-min cycle protocol when compared to running without prior cycling.

ii. Strong and significant correlations will be found between differences in running economy and the differences in running biomechanical variables (due to the preceding cycling exercise).

iii. Differences in running economy will be more strongly predicted by changes in a cluster of variables describing running mechanics compared to single variables in isolation.

iv. Inter-individual biomechanical differences will exist between the subgroups of the study cohort and triathletes assigned to the 'impaired' subgroup will demonstrate greater biomechanical alterations.

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CHAPTER TWO - STUDY ONE

Triathlon running economy: the influence of a simulated triathlon cycle leg on running economy in trained triathletes

2.1 ABSTRACT

Movement economy and the rate of exertion are important determinants of endurance performance, both of which have been suggested to be influenced by prior exercise, particularly when the form of locomotion is different as in triathlon. This transition from one exercise mode to another (especially from cycling to running) may induce both metabolic and neuromuscular fatigue as well as movement pattern interference. Some studies have argued that cycling exercise may impair running economy, however this is not an unambiguous finding. It is also unclear whether the rating of perceived exertion (RPE) and perceived effort (%Effort) can be used to distinguish whether fatigue stems from predominantly peripheral or central mechanisms, specifically when different locomotor tasks are performed. Therefore, the aim of the present study was to examine the influence of a simulated Olympic-distance cycle bout on the physiological cost and perceptual responses (i.e. ratings of perceived exertion and effort) during a 10-min treadmill run, in a group of 17 (34 ± 6 years, 180.7 ± 6.0 cm, and 79.1 ± 11.9 kg) competitive male triathletes. Measures of running economy ($\dot{V}O_2$, +1.9%; oxygen cost, +2.5% and aerobic energy cost, +1.5%) and all other physiological parameters (RER, -3.7%; $\dot{V}E$, +15.6 and heart rate, +6.5%), were significantly impaired ($p < 0.05$) following a simulated Olympic-distance cycle bout, in a group of 17 (34 ± 6 years, 180.7 ± 6.0 cm, and 79.1 ± 11.9 kg; 55.2 ± 8.0 $mL \cdot kg^{-1} \cdot min^{-1}$ $\dot{V}O_{2max}$) competitive male triathletes. Similar changes in perceptual descriptors (RPE, +18.9% and %Effort, +17%) between the running conditions suggest that the interactive effects of both peripheral and central fatigue of the cycling bout acted to significantly ($p < 0.05$) increase the perceptual responses of subsequent running. The three methods of calculating running economy (i.e. the rate of oxygen consumption ($\dot{V}O_2$, $mL \cdot kg^{-1} \cdot min^{-1}$), oxygen cost ($mL \cdot kg^{-1} \cdot m^{-1}$) and aerobic energy cost ($J \cdot kg^{-1} \cdot m^{-1}$)) demonstrated a good level of agreement with minimal bias. 35% of the study cohort demonstrated an ability to run with better economy following cycling (i.e. aerobic energy cost decreased, -1.2%, $p < 0.001$). However, depending

on the method of calculating running economy, different numbers of participants were identified to be *impaired*. To conclude, the results confirmed a detrimental influence of a different locomotor task (i.e. a cycling exercise) on the aerobic energy cost and perceptual responses of a subsequent locomotor task (i.e. running), likely due to fatigue generated through both peripheral and central mechanisms. It is recommended that the true energy cost be calculated as a more precise measure of running economy to assist coaches and sport scientists identify individual responses of running following cycling exercise.

2.2 INTRODUCTION

Movement economy is an important factor influencing human locomotion and is an established performance indicator used by coaches, athletes and sport scientists (Barnes & Kilding, 2015). It is quantified as the inverse of the metabolic energy demand when exercising at a given submaximal (at steady-state) velocity (Moore, 2016; Saunders, Pyne, Telford & Hawley, 2004). During running, economy is calculated as the energy cost for a given distance or running velocity and it is assumed that a reduced energy cost for a given speed would allow a runner to run faster over a given distance or to run longer at a given speed (Di Prampero, Salvadego, Fusi & Grassi, 2009).

Nonetheless, movement economy has been suggested to be strongly influenced by prior exercise, especially when the form of locomotion is different (Bonacci et al., 2010; Hausswirth & Lehénaff, 2001; Millet & Vleck, 2000). This may be partly due to the previous exercise causing fatigue in locomotor muscles and consequently decreasing muscular performance (Candau et al., 1998; Lepers, Theurel, Hausswirth & Bernard, 2008). To compensate, greater muscular effort is required and thus a greater energy cost is imposed. However, an additional cost may be imposed by the use of inefficient movement patterns resulting from a movement pattern interference caused by the prior exercise (Chapman, Vicenzino, Blanch, Dowlan & Hodges, 2008; Gottschall & Palmer, 2002). This phenomenon is often referred to as perseveration, whereby a person will involuntarily continue a movement pattern after performing a rhythmic activity for an extended period of time (Classen, Liepert, Wise, Hallett, & Cohen, 1998; Gottschall & Palmer, 2000; Proios & Brugger, 2004). Although the precise factors responsible for the reduction in exercise performance (including other physiological, biomechanical and neuromuscular alterations) following a prior task are unclear, deviations in one's self-selected movement patterns has been shown to increase energy expenditure and reduce locomotor efficiency (Cavanagh & Williams, 1981; Saibene & Minetti, 2003).

A prime example in which fatigue and/or movement pattern inference may influence the economy of a subsequent task is in the multidiscipline endurance sport of triathlon. Triathlon involves the sequential performance of swimming, cycling and running, of which the Olympic distance is the most common event (1.5 km swim, 40

km cycle, and 10 km run) (Bentley, Millet, Vleck & McNaughton, 2002; Millet & Vleck, 2000). The physiological ability to cope with the high energy demands of a triathlon is considered to be a principal factor determining successful performance, since triathletes are required to efficiently utilise oxygen for energy production whilst maintaining a high average velocity throughout the three disciplines (Hausswirth & Lehénaff, 2001; Vercruyssen et al., 2002). Since the running component has been shown to have the greatest influence on overall finishing position (r = 0.81-0.98, p < 0.01), the physiological cost of running following cycling in triathlon has been a focus of numerous investigations (Bernard et al., 2003; Bonacci et al., 2010; Etxebarria, Hunt, Ingham & Ferguson, 2014; Hausswirth, Bigard & Guézennec, 1997; Hue, Le Gallais, Chollet, Boussana & Prefaut, 1997; Le Meur et al., 2009). Clearly evident in such studies is that cycling at high intensities, as observed in Olympic distance races, decreases economy and thus performance in the subsequent running leg. Reductions in running economy (measured either as the rate of oxygen consumption ($\dot{V}O_2$) or oxygen cost) of 1.6 to 16.9% have been observed in well-trained and recreational triathletes, especially during the first few minutes of the run following cycling, when compared to running without prior cycling (Millet & Vleck, 2000; Pialoux, Proust & Mounier, 2008).

However, some researchers have provided contrasting results, suggesting that cycling does not meaningfully impact the energy cost of running or alter biomechanical (technique) related variables (Bonacci, Saunders, Alexander, Blanch & Vicenzino, 2011; Millet, Millet, Hofmann & Candau, 2000; Walsh, 2015). For example, Bonacci and colleagues (2011) did not find significant changes in either running economy or neuromuscular control following either low- or high-intensity cycle bouts in elite international triathletes. Tew (2005) also found no changes in relation to fractional percentage of maximal $\dot{V}O_2$, heart rate or minute ventilation during running following 65 min of cycling at 70% of maximal power output. It is difficult to accurately determine the influence of the performance of cycling exercise on running economy from previous studies because of the variable results reported within and between the studies. Possible reasons attributable to these conflicting results include differences in the methodological protocols used, the level of participating athletes, data averaging techniques, gas analysis systems utilised in

measuring the oxygen cost, and the variation in methods used to quantify energy cost.

One particularly important factor complicating the comparison between studies, and of understanding the effect of prior exercise of subsequent locomotion (e.g. running) performance, is the calculation method used to determine running economy estimates. For example, running economy has been expressed as the $\dot{V}O_2$, per unit time (in mL $kg^{-1}\cdot min^{-1}$) (Bonacci et al., 2010; Bonacci et al., 2011; Etxebarria, Hunt, et al., 2014; Hue et al., 1997), oxygen consumption per metre ($mL\cdot kg^{-1}\cdot m^{-1}$) (Pialoux et al., 2008; Suriano, Vercruyssen, Bishop & Brisswalter, 2007) and energy cost per metre ($J\cdot kg^{-1}\cdot m^{-1}$) (Hausswirth et al., 1997; Millet et al., 2000; Pialoux et al., 2008) when running at a given velocity. The $\dot{V}O_2$ reflects the quantity of adenosine triphosphate production from wholly aerobic metabolism, however to determine the energy cost during submaximal locomotion, the respiratory exchange ratio (i.e. the RER) is required (Fletcher, Esau & MacIntosh, 2009; Shaw, Ingham & Folland, 2014). This is because the energy equivalent of oxygen varies depending on the substrate metabolised (i.e. the relative quantity of carbohydrates and fats oxidised) and the exercise intensity (Daniels, 1985; Saunders et al., 2004). Indeed, substrate utilisation is of great interest during prolonged periods of physical activity such as in triathlon, where movement (running) speeds are variable between competitors and the ability to spare glycogen stores (i.e. to utilise fat as a fuel) at high work rates is necessary. As a result, the calculation of energy cost would enable a more precise determination of running economy (Di Prampero et al., 2009) and will be more indicative of individual responses when running at different relative intensities or when running is preceded by an exercise such as cycling. Furthermore, identifying discrepancies between the methods of calculating running economy could contribute to understanding the contradictory findings regarding the effect of cycling before running on subsequent running economy, particularly as majority of studies report the $\dot{V}O_2$ as a measure of running economy.

Although it is well accepted that the efficiency with which locomotion is performed strongly influences movement success (e.g. triathlon performance), the speed at which a distance is covered is also affected by pacing strategies (Abbiss & Laursen, 2008; Hausswirth, Le Meur, Bieuzen, Brisswalter & Bernard, 2010). In turn, these strategies are affected by the perceived level of exertion or effort required for

movement, as evidenced by the finding that ratings of perceived exertion (RPE) and effort critically influence the intensity of pacing of a locomotor task (Abbiss, Peiffer, Meeusen & Skorski, 2015; Swart, Lindsay, Lambert, Brown & Noakes, 2012). Higher ratings of RPE have been demonstrated to be associated with increased physiological impairment and fatigue as well as with holistic perceptions of different exercise-related sensations (for example, pain and fatigue in the skeletal muscles, the heart and the lungs) and disturbances to homeostasis of multiple regulatory systems (Borg, 1982; Marcora, 2009). Typically used interchangeably with RPE is the perception of *effort,* which is suggested to be centrally derived, where efferent information is sent from the motor to the sensory regions of the brain (Abbiss et al., 2015; Swart et al., 2012). The ability to distinguish between the perceptions of exertion and effort will allow for a greater understanding of the causes of fatigue to be identified, and to determine whether fatigue stems predominantly from peripheral versus central mechanisms. Despite this, the assessment of individual RPE and effort as psychophysiological stress indicators when a locomotor task is immediately followed by another is limited within the literature. With reference to triathlon, most athletes perceive a difficulty when running immediately after cycling, frequently reporting higher RPE when compared to running without prior cycling (Bonacci, Vleck, Saunders, Blanch & Vicenzino, 2013; Chapman et al., 2008; Rendos, Harrison, Dicharry, Sauer & Hart, 2013). However, a limited number of studies (Etxebarria, Anson, Pyne & Ferguson, 2013, 2014) have obtained effort scores in order to investigate whether both RPE and effort are similarly associated with running performance and pacing strategies, when running immediately after cycling.

Given the above, the purpose of this study was to: i) describe the effect of an energetically demanding activity such as a triathlon-simulating cycle protocol on the aerobic energy cost and perceptual responses (perceived exertion and effort) of subsequent running, ii) determine if distinguishing between perception of exertion or effort indicates whether fatigue of the cycling bout is caused predominantly from peripheral or central mechanisms, iii) determine whether the method of calculation ($\dot{V}O_2$ vs. oxygen cost vs. aerobic energy cost) influences the conclusions made regarding the effect of prior cycling exercise on running economy, and iv) to investigate inter-individual responses to running following cycling. It was hypothesised that i) running economy and perceptual responses would be negatively

influenced by prior cycling exercise, ii) a discrepancy will exist between the perceived ratings of exertion and effort scores, which will enable better understanding of where fatigue predominantly stems from (i.e. from peripheral or central mechanisms), iii) discrepancies will exist when calculating running economy using each of the three methods and this will lead to different conclusions being reached, and iv) individual responses will be observed with some demonstrating minimal alterations in the running physiological and perceptual measures following cycling exercise, whereas others will be significantly affected.

2.3 METHODS

2.3.1 Participants

Nineteen moderately-trained, competitive male triathletes free from known illness or injuries volunteered to participate in this study. Two participants failed to meet the predetermined criteria to run at a physiological steady-state (see section 2.3.2.3. Running economy measurement) and were therefore excluded from the analysis. Therefore 17 male triathletes (mean ± SD; age 34.3 ± 6.2 y, height 180.7 ± 6.0 cm, body mass 79.1± 11.9 kg, body fat percentage 18.5 ± 5.4%, $\dot{V}O_{2max}$ 55.2 ± 8.0 $mL \cdot kg^{-1} \cdot min^{-1}$) with 4.3 ± 2.5 y of triathlon experience (swam 4.1 ± 2.1 km, cycled 163.3 ± 73.5 km and ran 31.7 ± 11.8 km per week) participated in this study. They were asked to avoid the consumption of alcohol and other stimulants, and to record and follow a similar dietary intake (including caffeine) for 24 h prior to all experimental trials. Participants were asked to avoid strenuous exercise in the 48 h preceding all experimental trials. They were asked to wear clothing free from metallic material and to wear the same pair of running shoes during all testing sessions. Approval for the study was obtained from the Edith Cowan University Human Research Ethics Committee and procedures conformed to the declaration of Helsinki (Appendix A). Informed written consent was also provided by all the participants prior to participation (Appendix B) following reading the information letter (Appendix C).

2.3.2 Experimental protocols

2.3.2.1 Overview of experimental protocols.

The participants reported to the laboratory on two separate occasions (i.e. an initial familiarisation session where baseline measures were performed and a secondary experimental session) separated by at least 48 h (see Figure 2.1). All testing took place at the Edith Cowan University Biomechanics laboratory under consistent environmental conditions. During the first visit, participants were given an initial introduction and completed the necessary pre-exercise questionnaires. A dual-energy x-ray absorptiometry scan was then performed to obtain body composition information and an incremental cycling test to exhaustion was completed in order to determine the participant's maximal oxygen consumption ($\dot{V}O_{2max}$) and maximal aerobic power (MAP). After a rest period of 30 min, the participants were familiarised with the remaining testing procedures, including a simulated 60-min cycling bout designed to replicate a 40-km cycle component of an Olympic-distance triathlon on a stationary bicycle ergometer. The mean power output during the 60-min cycle was 61% of MAP, as described in detail below (see section 2.3.2.2. Familiarisation of cycling protocol (simulated Olympic-distance). Finally, participants changed into their running shoes and completed a 10-km outdoor run (section 2.3.2.2. Running track familiarisation). Participants were instructed to minimise the time between the end of the 60-min cycle and the start of the run, and to maintain a running velocity corresponding to their Olympic-distance 10-km running velocity. The average running velocity over the first kilometre of the 10-km run was recorded and retained for replication in the subsequent experimental trial. Fluid and food (energy snack) intake were allowed *ad libitum* and no guidance was given to the participants as to what types or quantities of fluids or fuels they should consume. This ensured that the fuels that the individuals normally consumed as part of their performance in a typical race situation were replicated during testing. Fluid and food intake were recorded during the 60-min cycle and replicated in the ensuing experimental trial. During the second visit to the laboratory, (i.e. during the experimental trial 2), the participants ran for 10 min on a treadmill before and after the 60-min cycling protocol to determine the influence of the cycling exercise on running economy. In order to compare the running economy before and after cycling, the treadmill velocity was set

at the same velocity for both running conditions. This velocity was set at the pre-determined running speed obtained during the first experimental trial.

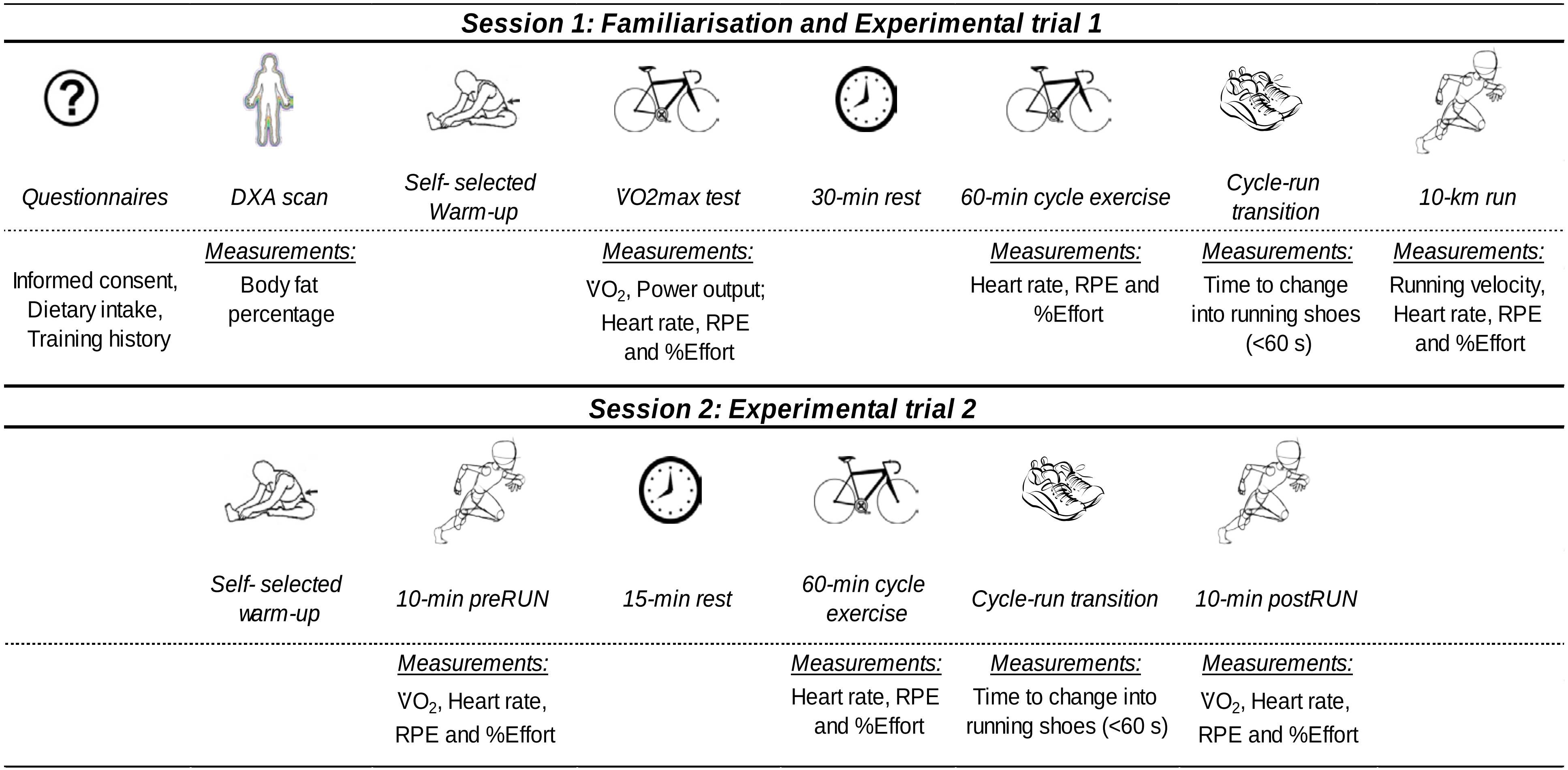


Figure 2.1 A diagrammatic representation of the experimental procedures of the current study. The experimental procedures involved two testing sessions: i) during the first session, participants were familiarised with the testing equipment, cycling and running protocols and baseline measurements were performed to obtain $\dot{V}O_{2max}$, maximal aerobic power output and running velocity, and ii) during the second session, physiological parameters were obtained to calculate running economy before and after a 60-min cycling bout (termed preRUN and postRUN, respectively). Abbreviations: DXA, dual-energy x-ray absorptiometry; $\dot{V}O_{2max}$, maximal oxygen consumption; $\dot{V}O_2$, oxygen consumption; RPE, rating of perceived exertion; %Effort, percentage effort (0% being no effort, 100; being absolutely ‘all out’ effort).

2.3.2.2 Session 1: Familiarisation and experimental trial 1, procedure and measurement.

A medical questionnaire (Appendix D), a training history report (Appendix E) and a 24-h food recall form (Appendix F) as well as a final confirmation checklist (Appendix G) were completed prior to commencement of the testing procedures. Anthropometric measures including height and body mass were taken and participants underwent a body composition assessment to obtain total body fat percentage with the use of a dual-energy x-ray absorptiometry scan (Hologic Discovery A, Waltham, MA; see Figure 2.2 for an illustration of the body positioning) after a system calibration. Thereafter, measurements of each participant's racing bicycle configurations were taken, including seat height, handlebar height, reach length and seat front-to-back position. These were used to configure the electronically-braked cycle ergometer (Velotron, RaceMate, USA) in order to replicate the individual's bicycle set-up during the 60-min cycle bouts. The ergometer configuration was kept constant for each experimental trial and the participants were required to use their own clip-in cycling shoes and pedals. Following bicycle setup, participants performed a self-selected intensity warm-up on the cycle ergometer for 5 min prior to commencing an incremental cycling test.

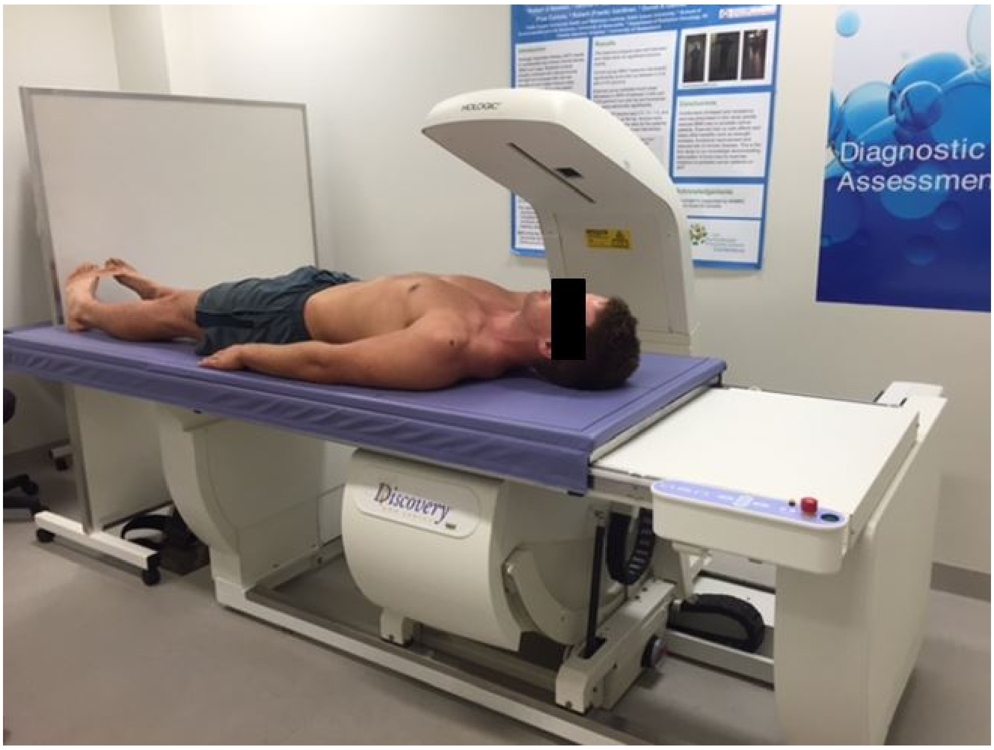


Figure 2.2 Participant body positioning during a dual-energy x-ray absorptiometry scan.

Incremental cycling test protocol.

The incremental cycling test commenced at 160 W and increased by 5 W every 15 s until voluntary exhaustion or until the participant's cadence dropped below 70 rpm. The test was completed at a freely chosen cycling cadence. Pulmonary ventilation ($\dot{V}E$) and expired gas concentrations were recorded breath-by-breath throughout the test using a metabolic cart system (ParvoMedics TrueOne 2400 diagnostic system, USA) and analysed as 15-s averages. The gas analysers were calibrated immediately before the commencement of the test using known gas mixtures (16% O_2 and 4% CO_2, balance N_2 Airgas Mid South, Tulsa, Oklahoma, USA) and a flowmeter was calibrated using a 3-L syringe (Series 5530, Hans Rudolph Inc., Kansas City, USA) according to the manufacture's recommendation. The participant's heart rates and rating of perceived exertion (RPE) were recorded every minute during the test using a Polar heart rate monitor (RS800 Polar Heart Rate Monitor, Finland) and Borg's 15 point scale (6-20 point scale, Borg, 1998, Appendix H), respectively. $\dot{V}O_{2max}$ was defined as the highest $\dot{V}O_2$ value averaged across a 1-min period and maximal aerobic power was defined as the average of the highest consecutive power output sustained for 1 min (Etxebarria, Anson, et al., 2014). Figure 2.3 shows a single participant completing the incremental cycling test.

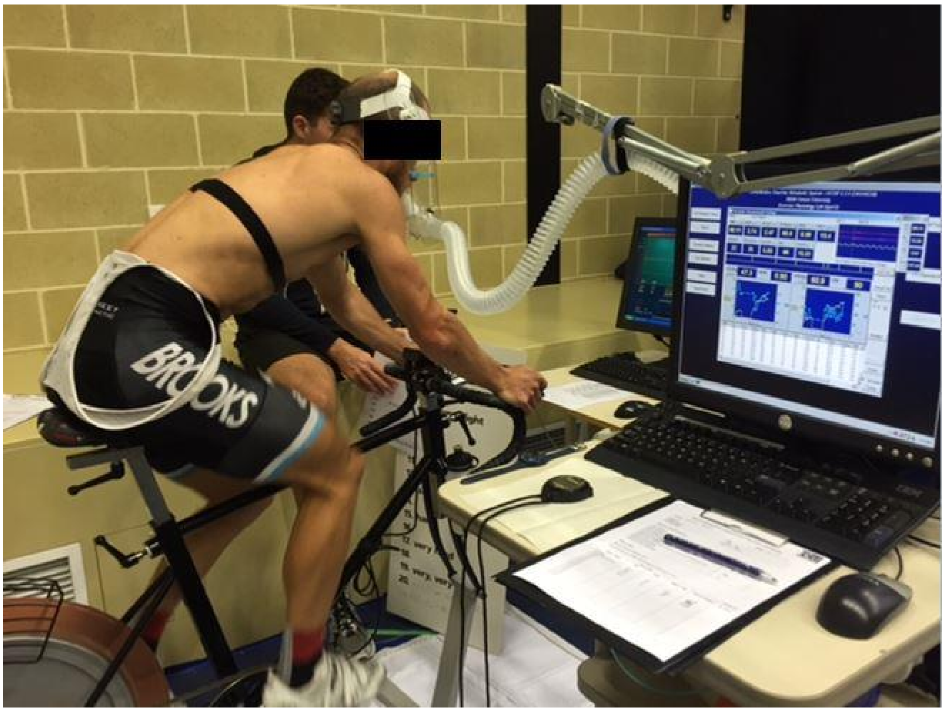


Figure 2.3 Participant completing the incremental cycling test, equipped with the head-and-mouthpiece of the metabolic cart system.

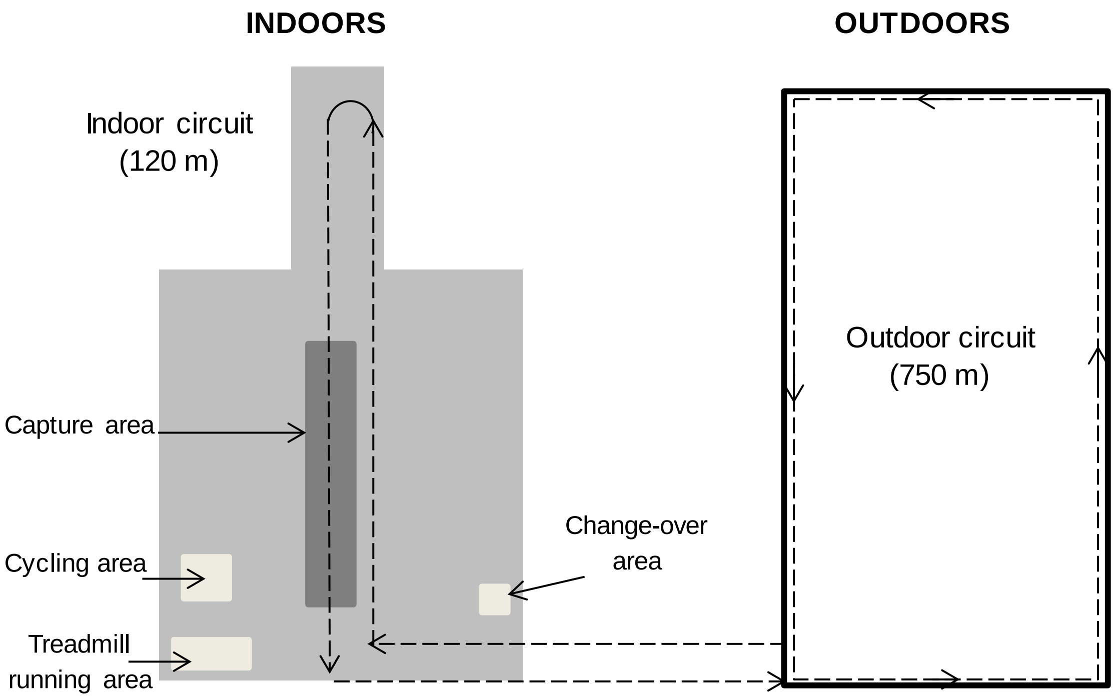
Familiarisation of cycling protocol (simulated Olympic-distance).

After completing the incremental cycling test, the participants were required to rest passively for 30 min. Following the rest period, they performed a self-selected warm-up of 5 min where they were encouraged to perform a minimum of two, 5-s maximal sprint efforts. Participants then commenced a 60-min cycle protocol simulating the intensity of a 40-km cycle component of an Olympic-distance triathlon, as described by Etxebarria and colleagues (2013). The power distribution varied between 40 and 140% of MAP throughout the cycle exercise and involved high-intensity efforts of 10, 40, 90, 30 and 20 s separated by lower-intensity efforts of 40 to 60 s (see Figure 2.4). The average cycling intensity was set to 61% of the MAP obtained during the incremental cycling test. Heart rate and RPE scores were recorded every 5 min throughout the duration of the cycle exercise. To quantify subjective perception of effort, the participants also reported an effort score (%Effort) every 5 min using an effort scale of 0-100% (0% being no effort at all, and 100% being all-out effort, giving absolutely everything; Etxebarria et al., 2013b). RPE was measured as a sense of perceived difficulty experienced during the task, whereas %Effort was measured as a perception of how hard they were trying (Abbiss et al., 2015) during the last 5 min.

Figure 2.4 The 60-min cycle protocol (adapted from Etxebarria, Anson, et al. (2014). A (left panel):60-min variable intensity efforts based on 61% of the triathlete's maximal aerobic power. B (right panel): 10-min section of the 60-min cycle protocol.

Running track familiarisation.

In the familiarisation session, the participants dismounted the cycle ergometer following the 60-min cycle protocol and were instructed to change into their running shoes as quickly as possible (< 60 s) before commencing a 10-km run (see Figure 2.5). The 10-km run was divided into three indoor and two outdoor running circuits, with data collection taking place indoors. The participant commenced the first 1.2-km of the 10-km run by completing 10 laps indoors, passing through a motion capture area once per lap. This was followed by a 3-km (4-lap) outdoor run on a concrete surface, after which they returned to the lab to complete 1.2 km (10 laps) indoors. They continued running the next 3.6 km (five laps) outdoors and then returned to the lab to complete the final 1-km (nine laps) indoors (see Appendix I and J for a more detailed schematic overview of the indoor and outdoor running track). The motion capture area consisted of 15 m of straight line running where timing gates (V2, Swift Performance Equipment, Australia) were placed 5 m apart to record the running velocity. Approximately 35 m of straight line running preceded the first timing gate. Running velocity was self-selected and corresponded with the speed they believe they would adopt during a 10-km run in an Olympic-distance triathlon. The average running velocity of the first 1.2 km (10 laps) was recorded and replicated (within ± 3%) for both the pre-and post-cycle running conditions the subsequent experimental trial. Heart rate, RPE and %Effort scores were recorded immediately following the cycling exercise and after every 5 laps of the indoor component of the 10-km run.



Distance	Number of laps	Data recorded
1.2 km	10 laps indoors	Running velocity, HR, RPE and %Effort
3 km	4 laps outdoors	
1.2 km	10 laps indoors	Running velocity, HR, RPE and %Effort
3.6 km	5 laps outdoors	
1.08 km	9 laps indoors	Running velocity, HR, RPE and %Effort

Figure 2.5 Diagrammatic representation of the 10-km running circuit completed following the 60-min cycling exercise during experimental trial 1. Participants commenced the 10-km run indoors by completing 10 laps, followed by an outdoor circuit of 4 laps before returning to the lab during the half way mark to run 10 laps indoors. They then completed 5 laps of the outdoor circuit and returned to the lab for the remaining 9-laps. Of particular interest was the running velocity obtained during the first kilometre which was used to set the treadmill speed during the subsequent testing session. Abbreviations: HR; heart rate; RPE, rating of perceived exertion; %Effort, percentage effort (0% being no effort, 100 being absolutely 'all out' effort).

2.3.2.3 Session 2: Experimental trial 2, procedure and measurement.

Forty-eight hours following the first session, the second experimental trial was conducted where the participant's running economy before and after the cycle exercise were determined. Prior to the commencement of the running tests, as a warm up, the participants ran at a self-selected intensity for 10 min on a treadmill

(TrackMaster, TMX 3030C, Newton, KS, USA). This was followed by any specific or individualised stretches they typically performed prior to competition.

Following the warm-up, the participant commenced a 10-min run at a constant velocity on the treadmill, hereafter referred to as *preRUN*. The treadmill was set at a velocity equal to the average running velocity of the first 1.2-km of the 10-km run obtained during the first session. A 1% treadmill incline was used to best replicate the energetic cost of overground running, as recommended by Jones and Doust, (1996), and a fan was placed in front of the treadmill. The metabolic cart system was calibrated according to the manufacturer's recommendation, and the mouthpiece and a compatible heart monitor were attached to the participant. Expired gas concentrations were recorded breath-by-breath during the preRUN and analysed as 15-s averages to calculate the $\dot{V}O_2$, carbon dioxide production ($\dot{V}CO_2$), $\dot{V}E$ and the RER. Additionally, heart rate, RPE and %Effort scores were obtained every 1 min.

After a 15-min passive recovery period, the 60-min cycle protocol was completed on the stationary bicycle ergometer, and heart rate, RPE and %Effort scores were obtained every 5 min. The participant dismounted the bicycle ergometer and changed into their running shoes, replicating the precise timing of the transition phase of the first experimental trial. They were again equipped with the mouthpiece of the metabolic cart system and commenced a second run for 10 min on the treadmill (i.e. termed *postRUN*) at the same speed as the preRUN. Expired gases were again measured continuously and heart rate, RPE and %Effort scores were obtained every 1 min during the postRUN.

Running economy measurement.

Running economy was calculated during the 10-min treadmill runs before and after the 60-min cycling exercise; see Figure 2.6 for a visual illustration of the participant equipped with the head-and-mouthpiece of the metabolic cart system. A 10-min run at a constant velocity was imposed in order to ensure that a physiological steady-state level of $\dot{V}O_2$ was achieved (Saunders et al., 2004). The physiological steady-state was defined as the 2-min period between 4 and 10 min with an increase of less than 100 mL $\dot{V}O_2$, RER < 1.0 to ensure an insignificant anaerobic contribution to energy expenditure, and the period with the lowest $\dot{V}O_2$ standard deviation (Fletcher

et al., 2009; Saunders et al., 2004). The typical error of $\dot{V}O_2$ ($L \cdot m^{-1}$) measurement in our laboratory was 1.57%.

Running economy was calculated for both the preRUN and postRUN in three ways:

i. The average $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) over the 2-min steady-state period.
ii. The oxygen cost ($mL \cdot kg^{-1} \cdot m^{-1}$) using the average $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) over the 2-min steady-state period, and the running velocity ($m \cdot min^{-1}$):

$$\textit{Oxygen Cost } (mL \cdot kg^{-1} \cdot m^{-1}) = \dot{V}O_2\, (mL \cdot kg^{-1} \cdot min^{-1}) \times \textit{speed } (m \cdot min^{-1})$$

iii. The aerobic energy cost ($J \cdot kg^{-1} \cdot m^{-1}$), using the average $\dot{V}O_2$ ($L \cdot min^{-1}$) over the 2-min steady-state period, the kilojoule equivalent of the $\dot{V}O_2$ ($kJ \cdot L^{-1}$ O_2, with caloric to kilojoule conversion factor of 4184; Leonard, 2010; 2012) determined by the RER (using the non-protein respiratory quotient tables of Katch, McArdle & Katch, 2011), and the running velocity ($m \cdot min^{-1}$) normalised to the participant's body mass (BM) (Fletcher et al., 2009).

$$\textit{Aerobic Energy Cost } (J \cdot kg^{-1} \cdot m^{-1}) = \dot{V}O_2\, (L \cdot min^{-1}) \times \textit{caloric equivalent } (kCal \cdot L^{-1}) \div BM\ (kg) \div \textit{speed } (m \cdot min^{-1})$$

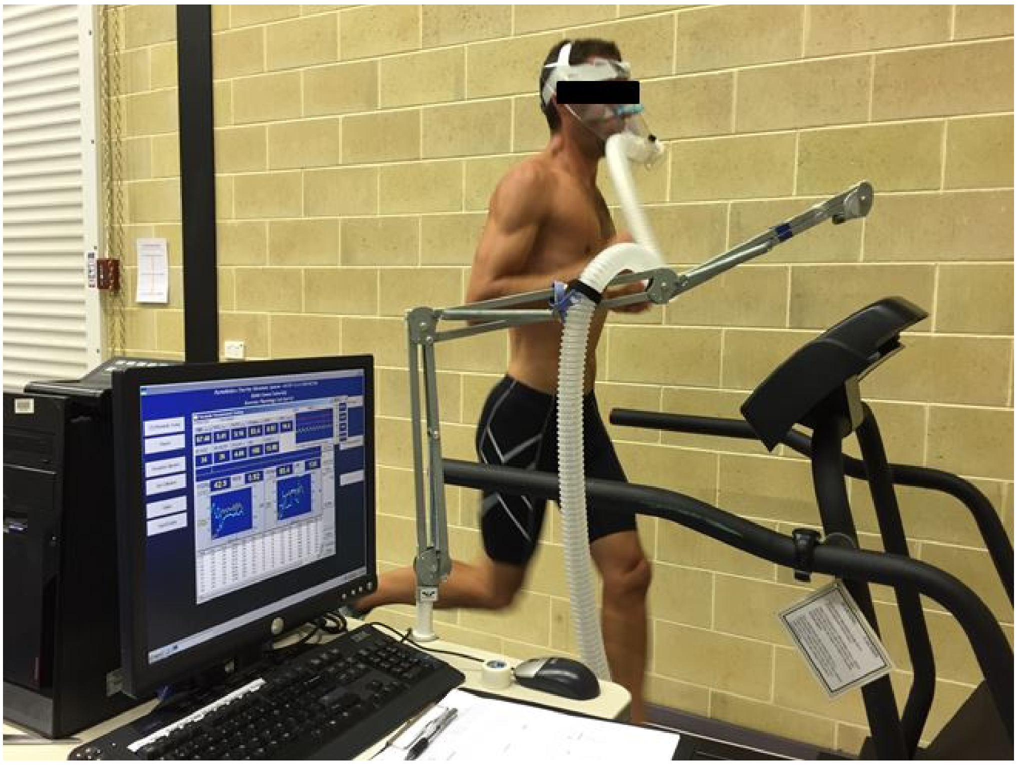


Figure 2.6 Illustration of a participant running on the treadmill at constant velocity with the head-and-mouthpiece of the metabolic cart system.

2.3.3 Statistical analysis

All statistical analyses were performed using SPSS statistical software (v 22 for Windows, SPSS, Inc., Chicago, IL, USA) and data were expressed as mean ± standard deviation (SD). Normality of the data set was assessed and ensured using the Levene's normality test. Statistical significance for all tests was accepted at an alpha level of 0.05.

Metabolic variables and perceptual responses recorded during the running conditions before and after the 60-min cycle exercise were compared using a multivariate analysis of variance (MANOVA) with repeated measures (8 variables × time). The following assumptions were met and included; 1) the dependent variables were continuous; 2) the independent variables consisted of at least two categorical groups that were related and the same participants were used for both the preRUN and postRUN; 3) no significant outliers were present in the related groups according to the outlier labelling rule; 4) the distributions of the dependent variables were normally distributed, and 5) sphericity was assumed because only two levels were present for the repeated measures MANOVA (Field, 2009). The percentage changes for all the variables were calculated between the preRUN and postRUN conditions and the precision of estimation was indicated with 95% lower and upper level of confidence limits (CL). Percentage change data were represented as mean ± 95% CL. Effect sizes (SD/mean) were calculated from the log-transformed data according to the Hopkins (2003) spreadsheet and interpreted according to the following criteria: < 0.2 trivial, 0.2 to 0.6 small, 0.6 to 1.2 moderate, 1.2 to 2.0 large and > 2 very large (Hopkins, 2010).

Pearson's product moment correlations were computed to characterise the relationships between the calculations methods of running economy (i.e. the changes in the rate of oxygen consumption ($\dot{V}O_2$; $mL \cdot kg^{-1} \cdot min^{-1}$), the changes in oxygen cost ($mL \cdot kg^{-1} \cdot m^{-1}$) and the changes in aerobic energy cost ($J \cdot kg^{-1} \cdot m^{-1}$)). The magnitudes of effect for correlations (r) were interpreted as follows: r = 0.0 to r = 0.10 considered trivial, r = 0.11 to 0.30 was considered small, r = 0.31 to 0.50 was considered moderate, r = 0.51 to 0.70 was considered to be large, r = 0.71 to 0.90 considered as very large and r = 0.91 to 1.0 was considered a nearly perfect correlation as per Hopkins (2010). In addition, Bland-Altman plots were used to assess the degree of

agreement and systematic bias with 95% limits of agreement between the different calculation methods of running economy. Upper and lower limits of agreement were defined as the mean difference ±1.96 times the standard deviation of the differences, respectively (Giavarina, 2015; Hazra & Gogtay, 2016). Furthermore, reliability and absolute agreement between the methods was assessed using intraclass correlation coefficients (ICC, two-way mixed with 95% confidence intervals) and were interpreted according to the following criteria: < 0.40, poor; 0.40 to 0.60, fair; 0.60 to 0.74, good and > 0.75, strong (Hazra & Gogtay, 2016). The level of agreement between the perceptual responses (i.e. RPE and %Effort), were also assessed using Bland-Altman plots and ICC statistics.

Lastly, independent *t*-tests were used to determine the inter-individual differences in the physiological and perceptual variables between the preRUN and postRUN. The participants were designated into either an i*mpaired* or an *improved* subgroup based on whether their aerobic energy cost following the cycling bout was increased or decreased respectively, compared to the preRUN. Therefore, as preRUN and postRUN were performed at the same velocity in order to assess the aerobic energy cost between the conditions, the *improved* subgroup were deemed to have an improved running economy, i.e. they used less energy to run at the same speed.

2.4 RESULTS

2.4.1 Incremental cycling test.

$\dot{V}O_{2max}$, peak power output, maximal heart rate and RPE at the completion of the incremental cycling test were 56.0 ± 7.0 $mL \cdot kg^{-1} \cdot min^{-1}$, 359 ± 22 W, 175 ± 6 $beats \cdot min^{-1}$ and 19 ± 1, respectively.

2.4.2 Physiological and perceptual responses before and after cycling.

Statistically significance differences ($F(7,10) = 40.80$, $p < 0.001$, power = 1.0) were observed for the physiological variables between the preRUN and postRUN. As shown in Table 2.1, significant differences were found for $\dot{V}O_{2}$, oxygen cost, aerobic energy cost, RER, $\dot{V}E$ and average heart rate. Furthermore, higher average ratings of perceived exertion (RPE) and perception of effort (%Effort) scores were obtained in the postRUN.

2.4.3 Correlation between aerobic energy cost and changes in physiological and perceptual responses.

A large and significant correlation was found between the differences in aerobic energy cost and the differences in $\dot{V}E$ (r = 0.608; 95% CI [0.18, 0.86]; p = 0.01) during running before and after cycling. However, small and non-significant correlations were observed between the differences in aerobic energy cost and all other physiological measures, including both the average cycling RPE (r = 0.235 [-0.31, 0.62], p = 0.364) and the RPE during the last 5 min of cycling (r = 0.225 [-0.30, 0.70], p = 0.385).

Table 2.1 Changes in physiological and perceptual (ratings of exertion and effort) measures observed during treadmill running before (preRUN) and after (postRUN) the simulated Olympic distance cycling protocol (n = 17).

	PreRUN		PostRUN		% Change	*p*-value	Cohen's *d*
	Mean ± SD	95% CL [Lower, Upper]	Mean ± SD	95% CL [Lower, Upper]	± 95% CL		± 95% CL
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	45.4 ± 6.9	[41.9, 49.0]	46.4 ± 6.8	[42.8, 49.8]	1.9 ± 1.2	0.002*	0.13 ± 0.1
Oxygen cost ($mL \cdot kg^{-1} \cdot m^{-1}$)	0.211 ± 0.0	[0.21, 0.22]	0.217 ± 0.0	[0.21, 0.22]	2.5 ± 1.3	0.001*	0.60 ± 0.3
Aerobic energy cost ($J \cdot kg^{-1} \cdot m^{-1}$)	4.42 ± 0.2	[4.3, 4.5]	4.49 ± 0.1	[4.4, 4.6]	1.5 ± 1.3	0.023*	0.36 ± 0.2
RER	0.960 ± 0.03	[0.94, 0.98]	0.925 ± 0.03	[0.91, 0.94]	-3.7 ± 1.2	<0.001**	-1.14 ± 0.49
$\dot{V}E$ ($L \cdot min^{-1}$)	90.2 ± 15.0	[82.7, 97.9]	104.3 ± 17.5	[95.3, 113.3]	15.6 ± 5.4	<0.001**	0.96 ± 0.3
Heart rate ($beats \cdot min^{-1}$)	151.8 ± 12.0	[145.6, 157.9]	161.2 ± 13.9	[154.0, 168.3]	6.5 ± 2.0	<0.001**	0.82 ± 0.2
RPE during running	13.4 ± 1.1	[12.8, 13.9]	15.9 ±1.4	[15.1, 16.6]	18.9 ± 3.7	<0.001**	2.26 ± 0.4
%Effort during running	64.5 ± 8.7	[60.0, 68.9]	75.6 ± 7.7	[71.7, 79.5]	17.8 ± 6.1	<0.001**	1.28 ± 0.4

Data presented as mean ± standard deviation. Percentage change (%change) data represented as mean ± 95% confidence limits (CL). A significant difference from the preRUN denoted by * ($p < 0.05$) and ** ($p < 0.001$).

Abbreviations: preRUN, pre-cycle running condition; postRUN, post-cycling running condition; $\dot{V}O_2$, rate of oxygen consumption; RER, respiratory exchange ratio; $\dot{V}E$, pulmonary ventilation; heart rate; RPE, rating of perceived exertion; %Effort, percentage effort (0% being no effort, 100 being absolutely 'all out' effort).

2.4.4 Comparison of running economy calculation methods.

No significant difference was found between the percentage changes in oxygen cost and $\dot{V}O_2$ (p = 0.175), however significant differences were found between the percentage changes in aerobic energy cost and oxygen cost (p < 0.001), and between the percentage changes in aerobic energy cost and $\dot{V}O_2$ (p = 0.01). Regardless, very large and significant (p < 0.001) positive correlations were found between the percentage changes in aerobic energy cost and oxygen cost (r = 0.961), between the percentage changes in aerobic energy cost and $\dot{V}O_2$ (r = 0.923), and between the percentage changes in oxygen cost and $\dot{V}O_2$ (r = 0.956), during running before and after cycling. The results displayed a good level of agreement with minimal systematic error between the three calculation methods of running economy, as minimal bias (< 1%) were found and most of the data points fell within the small limits of agreement (see Figure 2.7). On average, the percentage changes in aerobic energy cost consistently displayed smaller differences in the scores compared to the percentage changes in oxygen cost (-0.89 [0.43, -2.2]) and $\dot{V}O_2$ (-0.65 [1.15, -2.45]). Alternatively, the percentage changes in $\dot{V}O_2$ consistently displayed an average difference of 0.24% ([1.62, 1.14]) smaller than the percentage changes in oxygen cost. Furthermore, strong ICC [95% CI] scores demonstrated good absolute agreement and reliability and between the methods of calculating running economy; 0.974 [0.291, 0.988], 0.943 [0.763, 0.982] and 0.976 [0.934, 0.991] for the percentage changes in aerobic energy cost versus oxygen cost, aerobic energy cost versus $\dot{V}O_2$ and for oxygen cost versus $\dot{V}O_2$, respectively.

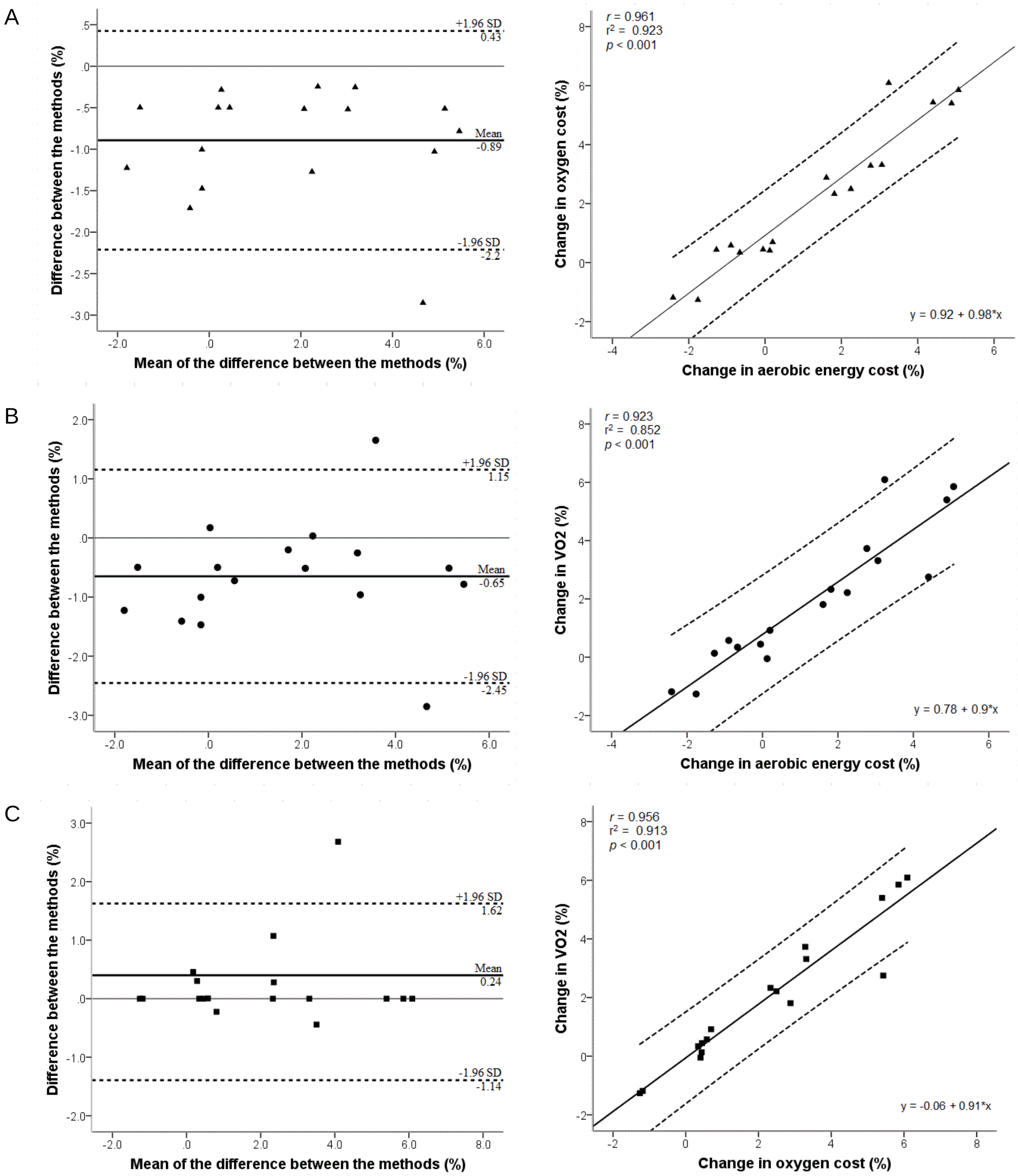


Figure 2.7 Comparisons of the running economy calculation methods represented by the percentage changes in a) aerobic energy cost versus the oxygen cost, b) aerobic energy cost versus $\dot{V}O_2$, and c) oxygen cost versus $\dot{V}O_2$, presented as Bland-Altman plots (left figures) and linear correlations (right figures). For the B-A plots, the solid horizontal lines display the mean bias between the calculation methods, the dotted horizontal lines represent the 95% upper and lower limits of agreement, the Y-axes represent the difference between the methods and the X-axes show the mean of the differences between the methods. The running economy calculation methods demonstrated strong correlations and good levels of agreement with minimal bias.

2.4.5 Comparison of the perceptual responses (i.e. rating of perceived exertion and effort).

No significant difference (p = 0.784) was found between the percentage changes in perception of exertion (RPE) and effort (%Effort). A moderate correlation (r = 0.420, p = 0.093) with minimal bias, yet large 95% limits of agreement (-0.76 [21.2, -22.7]) were shown (see Figure 2.8). On average, the changes in RPE displayed 0.76% smaller differences than the changes in %Effort. Furthermore, fair ICC scores (0.549 [-0.301, 0.839]) were demonstrated.

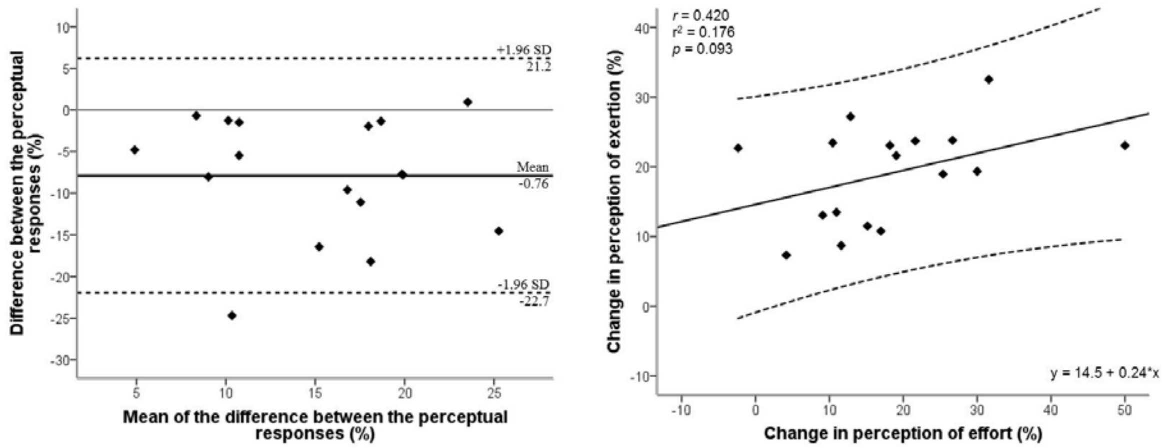


Figure 2.8 Comparison of the perceptual responses represented as the percentage changes in the ratings of perceived exertion (RPE) and effort (%Effort), presented as a Bland-Altman plot (left figure) and a linear correlation (right figure). For the B-A plots, the solid horizontal lines display the mean bias between the calculation methods, the dotted horizontal lines represent the 95% upper and lower limits of agreement, the Y-axes represent the difference between the measures and the X-axes show the average of these measures. A moderate correlation with fair absolute agreement and large limits of agreement were shown between the perceptual responses, yet minimal bias were demonstrated (<1%).

2.4.6 Individual responses during running following cycling.

Participant-specific responses to the cycle bout were evident for the physiological and perceptual measurements (see Figure 2.9). When running at the same velocity, some participants expended more aerobic energy (i.e. *impaired* subgroup, n = 11), and others expended aerobic energy less (i.e. *improved* subgroup, n = 6), following the cycling exercise. No significant differences were found in participant characteristics, running velocity or cycling RPE between the subgroups (see Table 2.2).

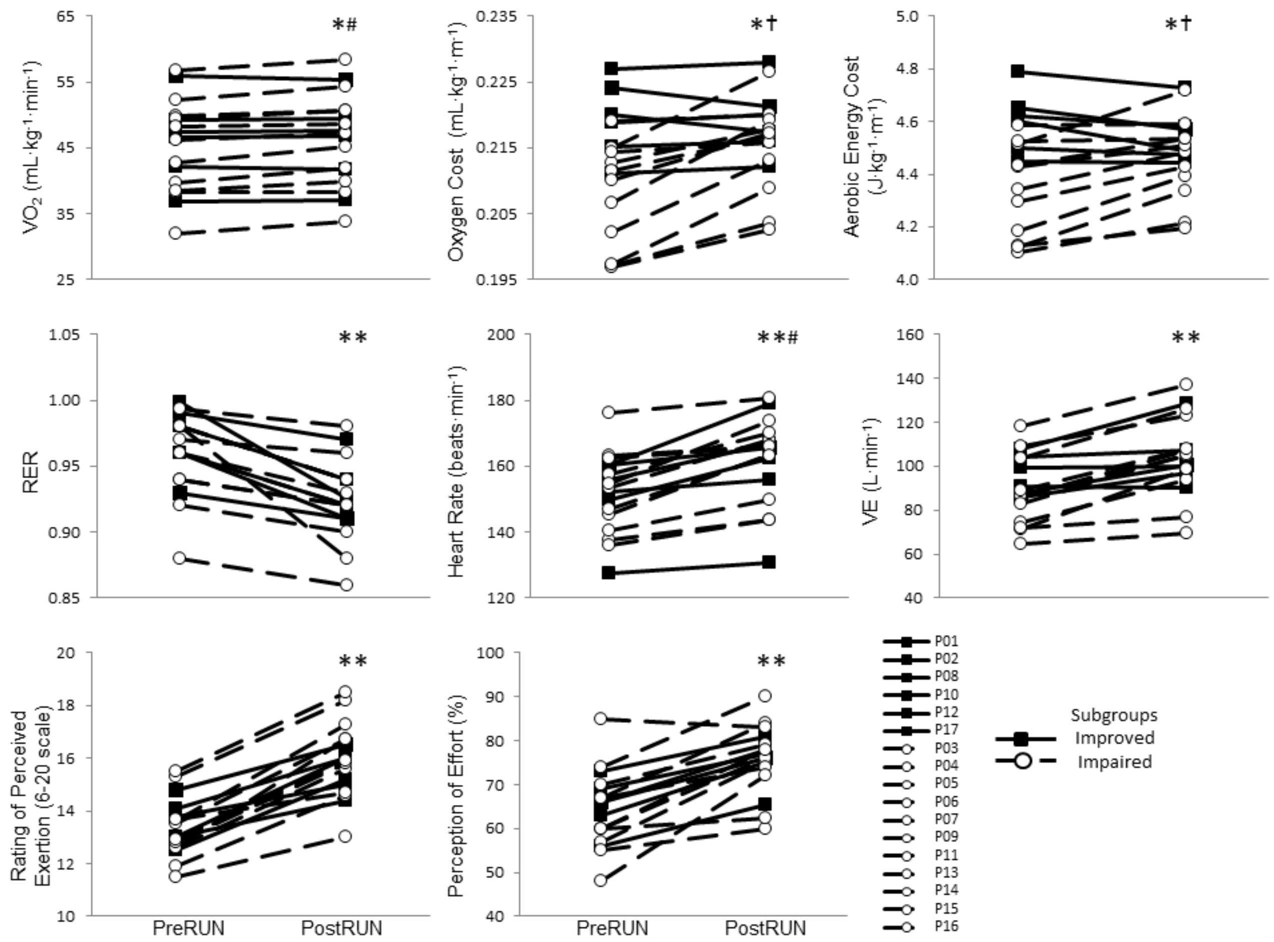


Figure 2.9 Individual differences for physiological and perceptual variables obtained during running before and after cycling. Variation in the individual responses for all parameters measured demonstrated in this figure.

A significant difference between the preRUN and postRUN denoted by * ($p < 0.05$) and ** ($p < 0.001$). Significant differences between the subgroups denoted by $^{\#}$ ($p < 0.05$) and † ($p < 0.01$).

Abbreviations: preRUN, pre-cycle running condition; postRUN, post-cycling running condition; $\dot{V}O_2$, rate of oxygen consumption; RER, respiratory exchange ratio; $\dot{V}E$ pulmonary ventilation; RPE, rating of perceived exertion; %Effort, percentage effort (0% being no effort, 100 being absolutely 'all out' effort).

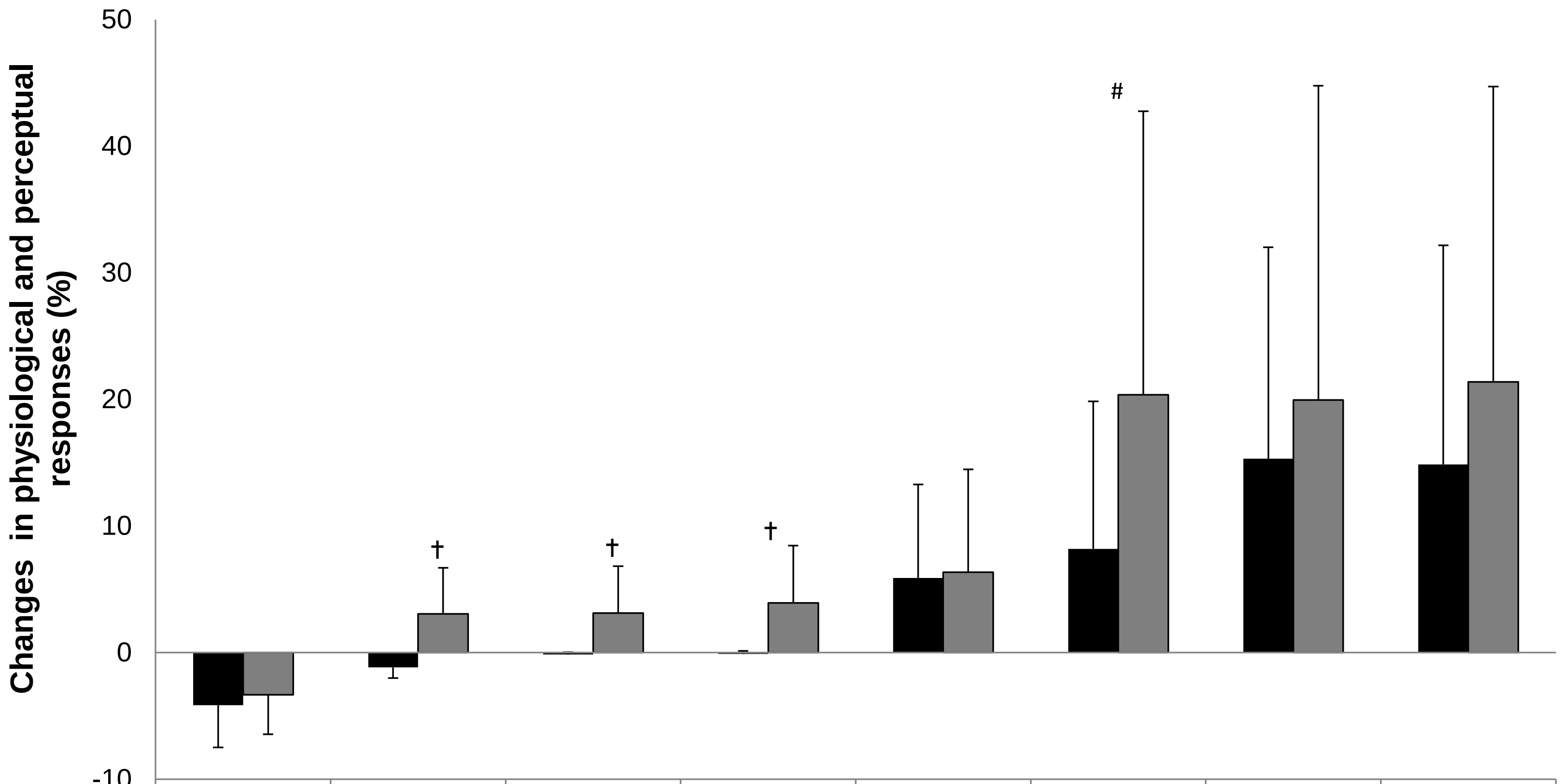
Table 2.2 Participant characteristics, running velocity and perceptual measures observed during the simulated Olympic distance cycling protocol for the *improved* and *impaired* running economy subgroups (n = 17).

	Improved (n = 6)		Impaired (n = 11)		
	Mean ± SD	95% CL [Lower, Upper]	Mean ± SD	95% CL [Lower, Upper]	p-value
Age (y)	34.8 ± 4.0	[32.0, 38.5]	34.19 ± 7.3	[29.5, 38.4]	0.822
Height (cm)	178.5 ± 7.7	[172.5, 184.5]	181.8 ± 4.7	[179.2, 184.5]	0.272
Body mass (kg)	77.9 ± 16.6	[67.0, 93.5]	79.7 ± 9.9	[74.1, 85.6]	0.786
$\dot{V}O_{2max}$ ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	58.0 ± 5.7	[52.9, 59.6]	54.9 ± 7.7	[50.7, 59.6]	0.411
Running velocity ($km{\cdot}h^{-1}$)	12.7 ± 1.5	[11.3, 13.8]	12.5 ± 2.1	[11.3, 13.7]	0.865
Average RPE during cycle	15.9 ± 0.7	[15.4, 16.5]	16.5 ± 1.4	[15.7, 17.3]	0.426
RPE during last 5 min of cycle	17.8 ± 1.2	[17.0, 18.7]	18.4 ± 1.2	[17.7, 19.0]	0.395

Data presented as mean ± standard deviation for participants within the subgroups; 95% CL, 95%confidence limits; $\dot{V}O_{2max}$, maximal oxygen consumption; RPE, rating of perceived exertion.

2.4.7 Comparisons of physiological and perceptual responses between subgroups.

$\dot{V}O_2$ (p = 0.001), oxygen cost (p = 0.008), aerobic energy cost (p < 0.001) and $\dot{V}E$ (p = 0.024) were significantly different between the subgroups (Figure 2.10 and Table 2.3). A trend was illustrated towards all physiological and perceptual (RPE and %Effort) responses of the *impaired* subgroup to increase to a greater extent following cycling, when compared to the *improved* subgroup. In addition, the *improved* subgroup demonstrated a trend towards a reduced RER (-4.2 ± 2.1 versus -3.4 ± 1.7, p = 0.490) following cycling.



	RER	Energy Cost	V̇O2	Oxygen Cost	Heart rate	V̇E	%Effort	RPE
■ Improved	-4.2	-1.2	-0.2	-0.1	5.9	8.2	15.3	14.9
■ Impaired	-3.3	3.1	3.1	3.9	6.4	20.4	19.9	21.4

Figure 2.10 The percentage change in physiological and perceptual responses of running following cycling between the two subgroups. $\dot{V}O_2$, oxygen cost, aerobic energy cost and $\dot{V}E$ differed significantly between the subgroups. Data are presented as the percentage change between the improved (i.e. a decrease in aerobic energy cost, *n* = 6) and impaired (i.e. an increase in aerobic energy cost, *n* = 11) subgroups.

Significant differences between the subgroups denoted by $^{\#}$ ($p < 0.05$) and † ($p < 0.01$). Abbreviations: RER, respiratory exchange ratio; $\dot{V}O_2$, rate of oxygen consumption; $\dot{V}E$, pulmonary ventilation; RPE, rating of perceived exertion; %Effort, percentage effort (0% being no effort, 100 being absolutely 'all out' effort).

Table 2.3 Changes in physiological and perceptual (ratings of exertion and effort) measures observed during treadmill running before (preRUN) and after (postRUN) the simulated Olympic distance cycling protocol for the *improved* and *impaired* running economy subgroups (n = 17).

	Improved (n = 6)			Impaired (n = 11)			
	PreRUN	PostRUN	%Change ± 95% CL	PreRUN	PostRUN	%Change ± 95% CL	p-value
$\dot{V}O_2$ ($mL\cdot kg^{-1}\cdot min^{-1}$)	46.4 ± 6.5	46.3 ± 6.3	-0.2 ± 0.9*	44.9 ± 7.3	46.3 ± 7.3	3.1 ± 1.3*	0.001#
Oxygen cost ($mL\cdot kg^{-1}\cdot m^{-1}$)	0.219 ± 0.0	0.219 ± 0.0	-0.1 ± 0.9*	0.207 ± 0.0	0.215 ± 0.0	3.9 ± 1.2*	< 0.001†
Aerobic energy cost ($J\cdot kg^{-1}\cdot m^{-1}$)	4.6 ± 0.1	4.5 ± 0.1	-1.2 ± 0.9*	4.3 ± 0.2	4.5 ± 0.2	3.1 ± 1.0*	< 0.001†
RER	0.970 ± 0.0	0.929 ± 0.0	-4.2 ± 2.1**	0.955 ± 0.0	0.923 ± 0.0	-3.4 ± 1.7*	0.490
$\dot{V}E$ ($L\cdot min^{-1}$)	95.9 ± 9.1	103.8 ± 13.3	7.9 ± 8.8**	87.0 ± 16.9	104.6 ± 20.1	20.0 ± 6.2*	0.024#
Heart rate ($beats\cdot min^{-1}$)	151.0 ± 12.4	160.1 ± 16.2	5.8 ± 3.8**	152.2 ± 12.4	162.7 ± 12.0	6.9 ± 2.7*	0.881
RPE during running	13.5 ± 0.8	15.5 ± 0.8	14.7 ± 6.2**	13.3 ± 1.2	16.1 ± 1.6	21.2 ± 4.6*	0.098
%Effort during running	65.5 ± 5.7	75.4 ± 5.3	15.3 ± 3.6**	63.9 ± 10.1	75.8 ± 8.8	19.1 ± 9.9*	0.571

Data presented as mean ± standard deviation. Percentage change (%Change) in the mean data presented as mean ± 95% confidence limits (CL). Significant differences between the subgroups denoted by # (p < 0.05) and † (p < 0.001), and changes between preRUN and postRUN denoted by * (p < 0.05) and ** (p <0.001).

Abbreviations: preRUN, pre-cycle running condition; postRUN, post-cycling running condition; $\dot{V}O_2$, rate of oxygen consumption; RER, respiratory exchange ratio; $\dot{V}E$, pulmonary ventilation; RPE, rating of perceived exertion; %Effort, percentage effort (0% being no effort, 100 being absolutely 'all out' effort).

2.4.8 Calculation method of running economy and the allocation of individuals to the subgroups.

The number of triathletes allocated to either the *impaired* or *improved* subgroup varied depending on the running economy calculation method (i.e. $\dot{V}O_2$, oxygen cost and aerobic energy cost). When using $\dot{V}O_2$, oxygen cost and aerobic energy cost, 14, 15 and 11 participants were found to be *impaired*, respectively (see Figure 2.11). Therefore, reporting running economy in terms of oxygen cost lead to a greater number of participants being labelled as *impaired* following cycling.

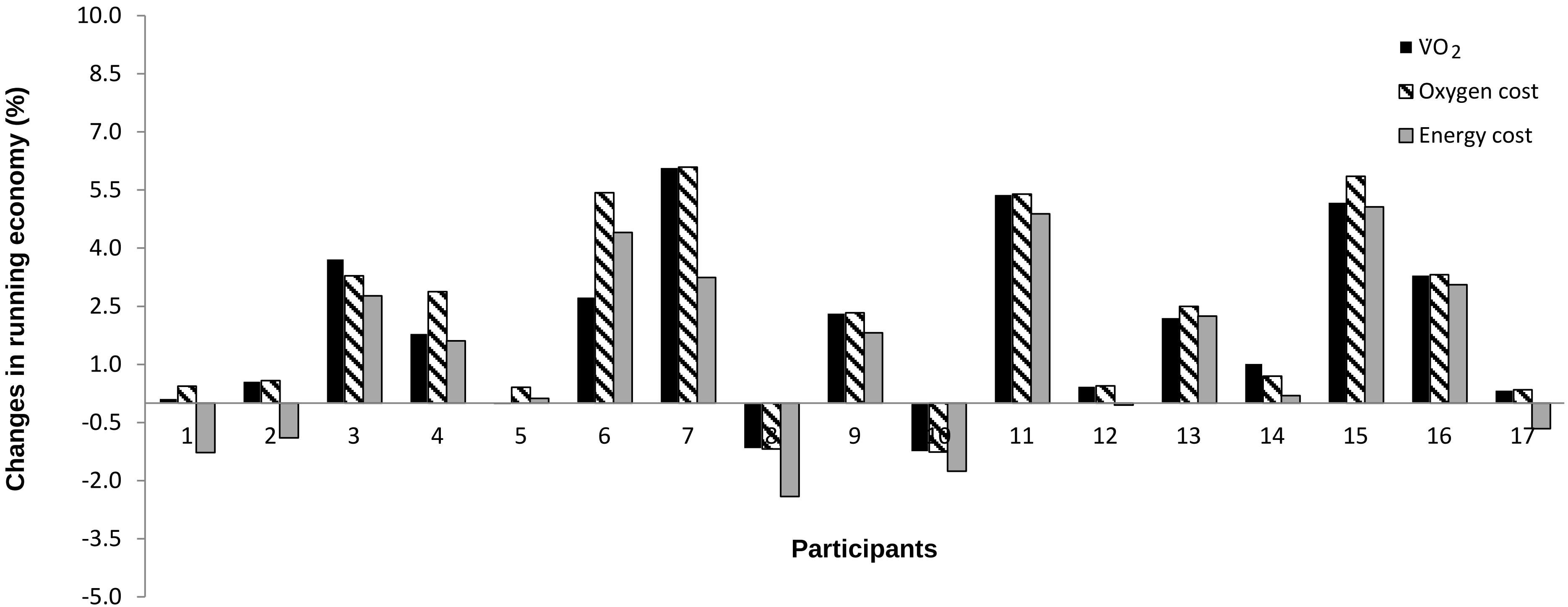


Figure 2.11 Individual percentage changes in $\dot{V}O_2$ (black, $mL \cdot kg^{-1} \cdot min^{-1}$), oxygen cost (diagonal lines, $mL \cdot kg^{-1} \cdot m^{-1}$) and aerobic energy cost (grey, $J \cdot kg^{-1} \cdot m^{-1}$) during treadmill running before and after the simulated Olympic-distance cycle component. Variation of individual differences for all participants (*n* = 17) were found between the running conditions in which running economy was measured using these typically reported calculation methods.

2.5 DISCUSSION

The aim of the present study was to describe the individual effect of an energetically demanding activity (i.e. cycling) on the economy and perceptual responses (perceived exertion and effort) of a subsequent task (i.e. running) in trained triathletes. An additional aim was to compare and identify any discrepancies between the three methods of calculating running economy ($\dot{V}O_2$, oxygen cost and aerobic energy cost) that influences the conclusions made regarding the effect of prior cycling exercise on running economy. Group-level results confirmed a significant ($p < 0.001$) detrimental influence of prior cycling exercise on the economy and all other physiological and perceptual responses to running. Ratings of perceived exertion and effort were used in this study as psychophysiological stress indicators, where perceived exertion scales typically provide an indication of peripheral mechanisms, and effort ratings typically provide an indication of central mechanisms, relating to fatigue (Abbiss et al., 2015). Increases in both parameters were found following the cycling exercise which may indicate that alterations in both peripheral and central neuromuscular mechanisms were related to fatigue generated by the cycling bout. Although no significant difference ($p = 0.784$) was found between the perception of exertion and effort, a moderate correlation and a small discrepancy were observed between the measures, proposing that different information was obtained from each measure. In addition, changes in running economy (measured using the three methods) were highly correlated with minimal bias, suggesting that the methods of calculating running economy could be used interchangeably. However, significant differences existed between the changes in observed aerobic energy cost versus oxygen cost and $\dot{V}O_2$. Also, the number of participants whose running economy was shown to decrease after cycling differed between calculation methods (i.e. 14, 15 and 11 for $\dot{V}O_2$, oxygen cost and aerobic energy cost, respectively). These results indicate that the three different methods used resulted in different outcomes. Therefore, the controversy regarding the effect of cycling exercise on subsequent running economy may indeed be partly explained by the differences in the methods used to calculate running economy.

Significant increases in running $\dot{V}O_2$ (+1.9%), oxygen cost (+2.5%), aerobic energy cost (+1.5%), $\dot{V}E$ (+15.6%) and heart rates (+6.5%) were observed during the first 10

min of running following cycling exercise. Consistent with previous studies examining running economy in triathletes in both outdoor and laboratory settings (Hausswirth et al., 1997; Hue et al., 1997; Kreider, Boone, Thompson, Burkes & Cortes, 1988; Pialoux et al., 2008), increases of 1.6 to 16.9% in $\dot{V}O_2$, breathing frequency, $\dot{V}E$ and heart rates have been reported during the first few minutes of running following cycling, when compared to running without prior cycling. It is likely that these impairments resulted from cycling at high and variable intensities that induced both neuromuscular and metabolic fatigue, corresponding to increased body temperature, dehydration, muscle glycogen depletion or a shift to greater fat oxidation (Hue et al., 1997; Lepers et al., 2008; Pialoux et al., 2008). Specifically, fatigue caused by prolonged exercise is often associated with increased $\dot{V}E$, cardiac output and blood lactate accumulation resulting in a reduced metabolic efficiency (i.e. an increased $\dot{V}O_2$ at a given workload) and results in a progressive decline in the voluntary activation of contracting muscles (Candau et al., 1998; Jentjens & Jeukendrup, 2003; Kyröläinen et al., 2000). It has been shown that 30 min of prolonged cycling at 70 to 80% of maximal aerobic power was sufficient to significantly reduce maximal voluntary contraction torque and muscle activation levels in the knee extensors (Lepers et al., 2008; Theurel & Lepers, 2008), which is indicative of neuromuscular fatigue (Taylor & Gandevia, 2008). In comparison, it is likely that such neuromuscular fatigue was induced by the cycling exercise in the present study since it involved a greater duration and intensity of variable cycling power outputs. Moreover, the augmented $\dot{V}E$ accounted for a considerable portion of the increase in aerobic energy cost (r = 0.608, p = 0.01), suggesting a lower ventilatory efficiency (that is, the work of breathing increases with an increase in ventilation) which has been reported during respiratory muscle fatigue conditions (Candau et al., 1998; Hue et al., 1997). Therefore, it can be concluded that neuromuscular and metabolic fatigue contributed to the physiological alterations observed during running following cycling exercise.

Several authors (Abbiss & Laursen, 2008; Le Meur et al., 2012; Lepers et al., 2008; Millet & Vleck, 2000) have also suggested that the fatigue generated during prolonged exercise, as experienced in a triathlon (approximately 1 h of cycling, and 30-35 min of running), induces both peripheral and central alterations in neuromuscular function. This can be related to the perceptual cues which is

important in regulating the intensity of self-paced exercise; i.e. the perception of exertion and effort (Abbiss et al., 2015; Marcora, 2009). Typically used interchangeably, these perception scores have been suggested to be different from one another and regulated within various parts of the brain (Abbiss et al., 2015; Swart et al., 2012). For example, the rating of perceived *exertion* (RPE) provides a means of evaluating an individual's subjective response and conscious sensations of the physical demands of exercise. It pertains to the "degree of heaviness and strain experienced during physical work" (Abbiss et al., 2015, p3) and may be influenced by variations in afferent feedback of muscular sensations (associated with disturbances to homeostasis), and includes factors such as pain, a change in temperature and a sense of position and movement (Abbiss et al., 2015; Borg, 1982; Marcora, 2009). Alternatively, perception of *effort* is believed to be centrally generated by the central motor command that regulates the locomotor and respiratory muscles, and is associated with the anticipation of the remaining work required for the completion of the exercise (Abbiss et al., 2015; Marcora, 2009; Swart et al., 2012). It can also be described as the "amount of mental or physical energy given to the task" (Abbiss et al., 2015, p 3). The ability to differentiate between the perception of exertion and effort may enhance the understanding of the peripheral and central origins of these perceptions and the regulation of fatigue when one task immediately follows another.

In the present study, triathletes demonstrated a similar increase of 19% and 18% in running RPE and perception of effort, respectively following the cycling exercise when compared to running without prior cycling. A moderate correlation with minimal bias and large limits of agreement were observed between the changes in RPE and perception of effort, demonstrating a fair agreement between the measures. It is likely therefore that the interactive effects of peripheral and central mechanisms relating to fatigue, generated by the cycling bout, acted to increase both physical sensations and psychological effort of subsequent running. Moreover, the *impaired* subgroup demonstrated a trend to increase their perception of exertion and effort to a greater extent following cycling (+21% versus +19% for RPE, $p = 0.09$, and %Effort, $p = 0.571$, respectively) when compared to the *improved* subgroup (+15% for both RPE and %Effort). It can therefore be suggested that runners with impaired economy also experienced greater physical sensations and psychological effort when compared to runners whose economy was improved following cycling exercise.

However, few studies have attempted to assess this difference by measuring both the perception of exertion and effort when investigating a locomotion task's influence on a subsequent task, making it difficult to compare our results to previous findings. It is recommended that future studies incorporate both these measures to further our understanding of a cycling bout's influence on the perceptual (or anticipatory) responses of subsequent self-paced running. Furthermore, this could enhance the understanding of the mechanisms underpinning the selection of pace during both the locomotor tasks, particularly when the pacing is not controlled (as typical observed in laboratory conditions).

In addition to the fatigue caused by the high intensity cycling bout, a movement pattern interference, or perseveration, have also been suggested to influence the subsequent running locomotion (Gottschall & Palmer, 2002). It has been suggested that following a rhythmic activity (e.g. cycling) over an extended period of time, the movement pattern frequency and muscle activation of the following task (e.g. running) will be affected (Gurfinkel, Levik, Kazennikov & Selionov, 1998; Proios & Brugger, 2004). Changes in several biomechanical parameters and muscle activities (as measured by electromyography; EMG) during running following cycling exercise, have been demonstrated when compared to running without prior cycling (Chapman et al., 2008; Heiden & Burnett, 2003; Rendos et al., 2013). Gottschall and Palmer (2002) demonstrated that by increasing the cycling cadence, the average running speed and stride frequency were substantially greater than after cycling at lower cadences. With the participant's heart rates being equivalent to those in the controlled running condition, the authors concluded that the coordinated neural control of prior cycling interfered with the neural firing rates of subsequent running. Although the exact mechanisms responsible for this interference are not well known, deviations of preferred movement patterns may reduce locomotion economy by increasing the energy expenditure (Cavanagh & Williams, 1981; Hunter & Smith, 2007), and such changes may partly explain the current findings.

However, other studies have not found evidence for perseveration of prior cycling exercise and indicated no biomechanical alterations when compared to running without prior cycling in both laboratory and outdoor (triathlon simulated) studies (Hue et al., 1997; Quigley & Richards, 1996). Neither Walsh (2015) nor Bonacci and colleagues (2011) found any lower limb muscle activity pattern (EMG) alterations in

highly trained triathletes following a high-intensity 20-and 45-min cycling bout, respectively. It should be noted however, that EMG responses are highly variable between individuals and as small sample sizes in these studies impose a limitation suggesting that it was underpowered to detect any changes. Nevertheless, these authors and others (Bonacci et al., 2011; Millet et al., 2000; Suriano et al., 2007) also found no meaningful impact of cycling on the energy cost of running. For example, Millet and colleagues (2000) found no significant alterations in the energy cost of subsequent running in a group of elite and moderately trained triathletes, even when imposing a maximal cycle exercise to exhaustion prior to running. These findings are in contrast to the present study and many of the aforementioned studies that indicate cycling exercise negatively influences subsequent running economy and biomechanics. Clearly, further work is required to understand the effects of prior cycling exercise on running mechanics, and its subsequent potential effect on running economy.

These contradictory findings, however, may partly result from averaging the responses across the whole group, which does not highlight differences in individual responses that exist at various relative workload intensities. This was confirmed in the retrospective analysis used in the present study. For example, a negative influence of prior cycling exercise was found on running economy when considering the group average, however 35% of the test population demonstrated an improvement in running economy following cycling (identified as the *improved* subgroup). Other researchers (Bonacci et al., 2011; Millet et al., 2000) suggested that this conjecture may be related to the experience level of triathletes, with more experienced triathletes demonstrating less mechanical and physiological impairments following cycling. The participants of the present study were all of a similar performance level (for example, $\dot{V}O_{2max}$ values of 58.0 ± 5.7 versus 54.9 ± 7.7, $mL \cdot kg^{-1} \cdot min^{-1}$, p = 0.411 for the *improved* and *impaired* subgroup respectively) and there were no differences in their personal best times in the most recent season. Thus there is no evidence that the effect of prior cycling exercise on running economy is influenced by triathlete participation or experience levels, at least in the relatively homogenous, moderately-trained triathlete cohort who participated in the present study.

Discrepancies in the literature might also partly be explained by the different methods used to calculate running economy (i.e. $\dot{V}O_2$, oxygen cost and aerobic energy cost). In the present study, the relationships between the measurements' errors and the true values were investigated through using the Bland-Altman method and ICC assessment. Results indicated strong correlations, minimal bias (< 1%) and small limits of agreement (< ±2.5%) between the three methods of calculating running economy, suggesting the presence of minimal systematic bias within the measurements. Strong ICC scores further indicated a good agreement between the three methods and it can therefore be concluded that these methods could be used interchangeably. This suggests that the method of calculating running economy may not contribute to the controversy found in the literature of the cycling's influence on subsequent running economy. However, in contrast, a significant difference was observed between the changes in observed aerobic energy cost versus oxygen cost and $\dot{V}O_2$, which was further indicated by a different number of participants being allocated to either the *improved* or *impaired* subgroups depending on the criterion variable used. For example, when using $\dot{V}O_2$, oxygen cost and aerobic energy cost assessments, 14, 15 and 11 participants were found to be impaired, respectively. Since these are the most common methods of calculating running economy within the triathlon literature, the small discrepancy between these methods could result in different findings and could therefore in fact be partly related to the controversy found regarding the influence of cycling exercise on running economy.

Furthermore, running economy is defined as the *energy* spent to move the body over one unit of distance or at a certain velocity (Di Prampero, 1986; Shaw et al., 2014). A great variability of substrate usage exists between athletes during exercise, and the energy yielded per litre of oxygen is dependent on the substrate metabolised (McArdle, Katch & Katch, 2010; Roberts, Weber, Hoppeler, Weibel & Taylor, 1996). The respiratory exchange ratio (RER) in the present investigation decreased from 0.96 to 0.92 following cycling, reflecting a shift toward greater use of fats to fuel energy usage. Since fat oxidation requires more oxygen to produce the same quantity of adenosine triphosphate compared to carbohydrate (McArdle et al., 2010), the increase in lipid utilisation as metabolic substrate appears to offset the greater oxygen required following cycling. Although not statistically significant, the *improved* subgroup also demonstrated a trend towards an increase in fat usage (see Table

2.3), suggesting a benefit in performance through the sparing of glycogen stores (Fletcher et al., 2009; Saunders et al., 2004). Since neither the $\dot{V}O_2$ nor the oxygen cost account for the variation in substrate usage, they do not provide valid substitutes for measurements of the energy cost of running. Thus aerobic energy cost, rather than the $\dot{V}O_2$ or oxygen cost, is required in order to estimate true running economy when running at submaximal intensities.

In conclusion, it is commonly shown that the performance time and economy of a secondary task is influenced by either movement pattern interference or from fatigue induced by the initial task. In agreement, the findings of the current study collectively indicated an overall detrimental impact of a high-intensity cycling bout on subsequent running economy, and other physiological and perceptual responses measured. It is highly likely that neuromuscular and metabolic fatigue were contributing factors, generated both physically and psychologically. However, further investigation of potential changes in running mechanics after cycling, and their relationship with changes in running economy, are needed in order to infer the effect of the movement pattern interference on running economy. Furthermore, the assessment of the relationship between mechanical parameters and running economy will aid in our understanding of why some triathletes are less influenced by prior cycling exercise compared to others. Good agreement with strong correlations were observed between the three calculation methods for running economy, however different numbers of individuals were considered to be negatively influence by the cycling, depending on the method used (see Figure 2.11). Therefore, the different methods used to calculate running economy could partly be attributable to the conjecture in the literature regarding a cycle bout's influence on subsequent running economy. Runners who exerted less energy aerobically following cycling displayed smaller increases in all measured physiological and psychological parameters and demonstrated a trend towards enhanced lipid mobilisation as substrate utilisation. It is therefore recommended to calculate the individual's energy cost rather than $\dot{V}O_2$ and oxygen cost as it provides a precise determination of running economy and will be more indicative of individual responses when running is preceded by an exercise such as cycling. Of particular importance is the focus on individualisation of the effects, as group data-averaging techniques can likely mask individual variability. Moreover, from a practical standpoint and for the purposes of monitoring the

adaptation to training in individual triathletes, it is recommended that the protocol for running physiological performance testing should involve prior cycling exercise rather than assessing running economy from the rested state.

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CHAPTER THREE - STUDY TWO

Influence of cycling on running biomechanics and economy in trained triathletes

3.1 ABSTRACT

Movement economy is an essential predictor of successful performance and individuals are able to self-select the most economical movement pattern to complete a task, i.e. they are able to minimise the energy expenditure. However, when performing sequential locomotor tasks, such as in the sport of triathlon, running economy may be heavily influenced by the preceding cycling exercise. The aim of this study was to determine whether high-intensity cycling influences subsequent running mechanics, and whether these changes are associated with alterations in running economy in competitive male triathletes. Stride parameters, and three-dimensional lower limb kinematics and maximal joint power production during running were compared before and after a simulated Olympic-distance triathlon cycling bout. Significant ($p < 0.05$) decreases in maximal knee extension power and knee flexion angle during both the support and the swing phases of running were observed following cycling, compared to when running was performed without prior cycling. Running velocity, stride length, flight time, anterior pelvic tilt centre of mass vertical oscillation ($CoM_{vertical}$) and horizontal distance between the heel and vertical projection of the centre of mass at initial foot contact during running ($CoM_{horizontal}$) were significantly different between running with and without prior cycling. Changes in a group of mechanical parameters (i.e. flight time, knee flexion angle during the support phase and lateral pelvic drop) were identified and significantly associated (50%, $p = 0.03$) with changes in aerobic energy cost following cycling. Two athlete subgroups were identified whose running economy following the cycle bout were either *improved* or *impaired*. Although not significant, it was an interesting observation that the *improved* subgroup demonstrated a greater magnitude of alteration in most biomechanical parameters measured following the cycle bout compared to the impaired subgroup. The results of this study indicate that triathletes adopted a post-cycling running movement strategy that was different from pre-cycling. These findings suggest that a prior locomotor task (i.e. cycling exercise)

influences the mechanics of a subsequent locomotor task (i.e. running), and that a group of biomechanical variables were closely related with the changes in running economy. It is recommended that coaches and athletes firstly include cycling before running performance testing procedures as opposed to single-disciplined ergometer testing from a fresh start; and secondly to assess individual technique and investigate the relevance of any alterations following cycling, as maintaining pre-cycling running mechanics might not be the main objective related to triathlon running performance.

3.2 INTRODUCTION

The ability to minimise the physiological cost of locomotion and particularly to adopt efficient movement patterns is essential to locomotor performance during tasks such as cycling, walking or running (Cavagna, Thys & Zamboni, 1976; Di Prampero, 1986). Consequently, the actions that reduce oxygen or energy expenditure for a given workload (i.e. an improved economy) allow individuals to run at higher velocity for a given distance or run longer distances before fatigue (Barnes & Kilding, 2015; Daniels, 1985). When running at a given velocity, individuals typically self-select a movement pattern that minimises the energy expenditure (Cavanagh & Kram, 1989; Saibene & Minetti, 2003), and are thus able to self-optimise during locomotion (Cavagna, 2010; De Ruiter, Verdijk, Werker, Zuidema & de Haan, 2014). For example, when compared with novices, experienced runners are able adopt stride rate and stride length combinations that minimise the energy cost (Hunter & Smith, 2007). However, tasks that require athlete to deviate from their preferred, economical movement patterns may increase the energy cost and effectively impair movement efficiency (Saibene & Minetti, 2003). Self- optimisation may be negatively affected when a locomotor task is performed prior to a different movement task. The sport of triathlon is a prime example where, during an Olympic distance event, a 40-km cycling leg is subsequently followed by what is often classified as the most important 10-km running leg. Yet, the ability to immediately change between distinctly different movement patters and preserve natural running movement patterns following approximately 1 h cycling may prove challenging within Olympic distance triathlon.

Cycling prior to running has been found to significantly alter running economy and biomechanics, when compared with running without prior cycling (Bonacci et al., 2010; Connick & Li, 2015; Rendos, Harrison, Dicharry, Sauer & Hart, 2013). Some of these biomechanical variations include decreases in velocity and stride length and increases in stride frequency (Gottschall & Palmer, 2000; Hausswirth, Bigard & Guézennec, 1997), greater stride time variability (Connick & Li, 2015), a more forward leaning trunk posture (Hausswirth et al., 1997) and modifications in lower body joint kinematics (Bonacci et al., 2010; Rendos et al., 2013; Vercruyssen, Suriano, Bishop, Hausswirth & Brisswalter, 2005). These changes may be underpinned by changes in muscle activation patterns, which have been found to be

affected after a bout of cycling (Chapman, Vicenzino, Blanch, Dowlan & Hodges, 2008; Heiden & Burnett, 2003). In addition, some triathletes also report an inability to pursue a consistent rhythm or maintain a constant running pace following a cycling bout (Connick & Li, 2015; Gottschall & Palmer, 2000). This may be partly due to cycling causing locomotor muscle fatigue, which consequently decreases muscular performance during running (Candau et al., 1998; Lepers, Theurel, Hausswirth & Bernard, 2008).

Alternatively, the inability of triathletes to immediately adapt to a new locomotor pattern within the initial stages of the run may be partly due to movement pattern interference caused by the prior cycling (Chapman et al., 2008; Gottschall & Palmer, 2002). A preceding task (such as a locomotor task) can affect the execution of a subsequent task, leading to a reduction in performance, a phenomenon called perseveration (Giannouli, 2013; Ramage, Bayles, Helm-Estabrooks & Cruz, 1999). In motor tasks, the perseveration of a motor control strategy of a rhythmic task may interfere with performance of a subsequent activity (Classen, Liepert, Wise, Hallett & Cohen, 1998; Proios & Brugger, 2004). For example, Gottschall and Palmer (2002) found that triathletes adopted a higher running velocity through increasing the stride frequencies immediately following cycling with high cadences, whilst demonstrating a consistent physiological demand across the various cycling cadences. They suggested that it was therefore likely that the coordinated neural control of higher cadence cycling possibly translated into the subsequent changes in running mechanics. Since it is recommended to maintain pre-cycling running mechanics and limit the deleterious effect of cycling on running (Millet & Vleck, 2000; Vleck, Bentley, Millet & Bürgi, 2008), this can result in detrimental performance outcomes.

Irrespective of the mechanisms responsible for the altered movement patterns, the effect of an energetically demanding task such as cycling performed prior to running further complicates the relationship between running economy and running technique. Indeed, within distance running it has been shown that running economy may be significantly influenced by a runner’s technique (Dallam, Wilber, Jadelis, Fletcher & Romanov, 2005; Folland, Allen, Black, Handsaker & Forrester, 2017; Kyröläinen, Belli & Komi, 2001; Moore, 2016), however complex interactions exist between multiple biomechanical factors. Inconsistencies also exist between runners due to the diverse running techniques of athletes. Moreover, disagreement exists

within the triathlon literature regarding the influence of running mechanics on economy and, in particular, the overall impact of cycling exercise on running mechanics. For example, several studies have not found changes in running mechanics in both laboratory and field-based settings (Bonacci, Saunders, Alexander, Blanch & Vicenzino, 2011; Cala, Veiga, Garcia & Navarro, 2009; Hue, Le Gallais, Chollet, Boussana & Prefaut, 1997), even following cycling to exhaustion (Millet, Millet, Hofmann & Candau, 2000). Inconsistency within the research might be attributed to variations in experimental and methodological procedures and equipment utilised to obtain biomechanical information, as well as the diversity in the number of biomechanical variables measured, measurement errors and reproducibility of the results. It is therefore difficult to delineate the influence of cycling on subsequent running performance, and furthermore, to establish the mechanisms responsible for any alterations in running economy following cycling.

Whilst previous research has indicated that movement pattern alterations caused by prior cycling likely contribute to the increase in energy cost of running, the amount to which the biomechanical alterations influence the changes in running economy are unknown. Therefore, the aims of the current research study were to initially describe the biomechanical differences in running prior to and following a high-intensity cycling bout using 3-dimentional motion analysis, and secondly to investigate the relationship between the biomechanical changes and the variation in running economy. Moreover, a specific aim was to investigate the biomechanical differences between those triathletes who *improved* their running economy, compared with those whose running economy was *impaired* following the cycling bout.

3.3 METHODS

3.3.1 Participants

Seventeen competitive male triathletes (34.3 ± 6.2 years; 180.7 ± 6.0 cm; 79.1± 11.9 kg; 18.5 ± 5.4 % body fat; with a $\dot{V}O_{2max}$ of 55.2 ± 8.0 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) free from known illness or injury, volunteered to participate in this study. Participants had competed in triathlon for 4.3 ± 2.5 years, swam 4.1 ± 2.1; cycled 163.3 ± 73.5, and ran 31.7 ± 11.8 km per week, and completed more than two Olympic distance triathlons in the past year. Participants were asked to record and follow their normal dietary intake

(including caffeine) in the 24 h period prior to all testing sessions. During this time they were also asked to avoid the consumption of alcohol and other stimulants. Participants avoided strenuous exercise in the 48 h preceding all experimental trials. The study was approved by Edith Cowan University Human Research Ethics Committee (Appendix A) and participants provided written informed consent prior to participation (Appendix B).

3.3.2 Experimental procedures

3.3.2.1 Overview of the experimental procedures.

Participants were required to attend the Edith Cowan University Biomechanics laboratory on three separate occasions, which were separated by at least 48 h. Sessions 1 and 2 are as per Chapter Two, Study One (see Figure 3.1). Briefly, during Session 1, an incremental cycling test to exhaustion was completed and baseline measures were obtained during a 10-km outdoor run following a 60-min cycling bout designed to replicate a 40-km cycle component of an Olympic-distance triathlon on a stationary bicycle ergometer (Velotron, RaceMate, USA). The mean power output during the 60-min cycle was 61% of MAP, as described in detail in Chapter Two, Study One (see section 2.2.2.1. Familiarisation of a simulated Olympic-distance cycle leg: 60-min cycle protocol). The average running velocity achieved during the first kilometre of the 10-km run was used as the running velocity for subsequent testing sessions. During Session 2, participants ran on a treadmill (TrackMaster, TMX 3030C, Newton, KS, USA) for 10 min, at the pre-determined velocity, prior to and following the 60-min cycle bout from which running economy was determined. Additionally, participants attended the laboratory for a third session, during which they performed a 1.2-km on-ground run at the average velocity achieved during the first kilometre of the 10-km run performed in Session 1. Running kinematics and kinetics were measured prior to and following the 60-min cycling bout. All participants were required to wear clothing free of metallic material, the same pair of running shoes and to use their own clip-in cycling shoes and pedals to all testing sessions. All sessions were completed on the same time of day, under the same environmental conditions. Sessions 2 and 3 were completed in a randomised counterbalanced order.

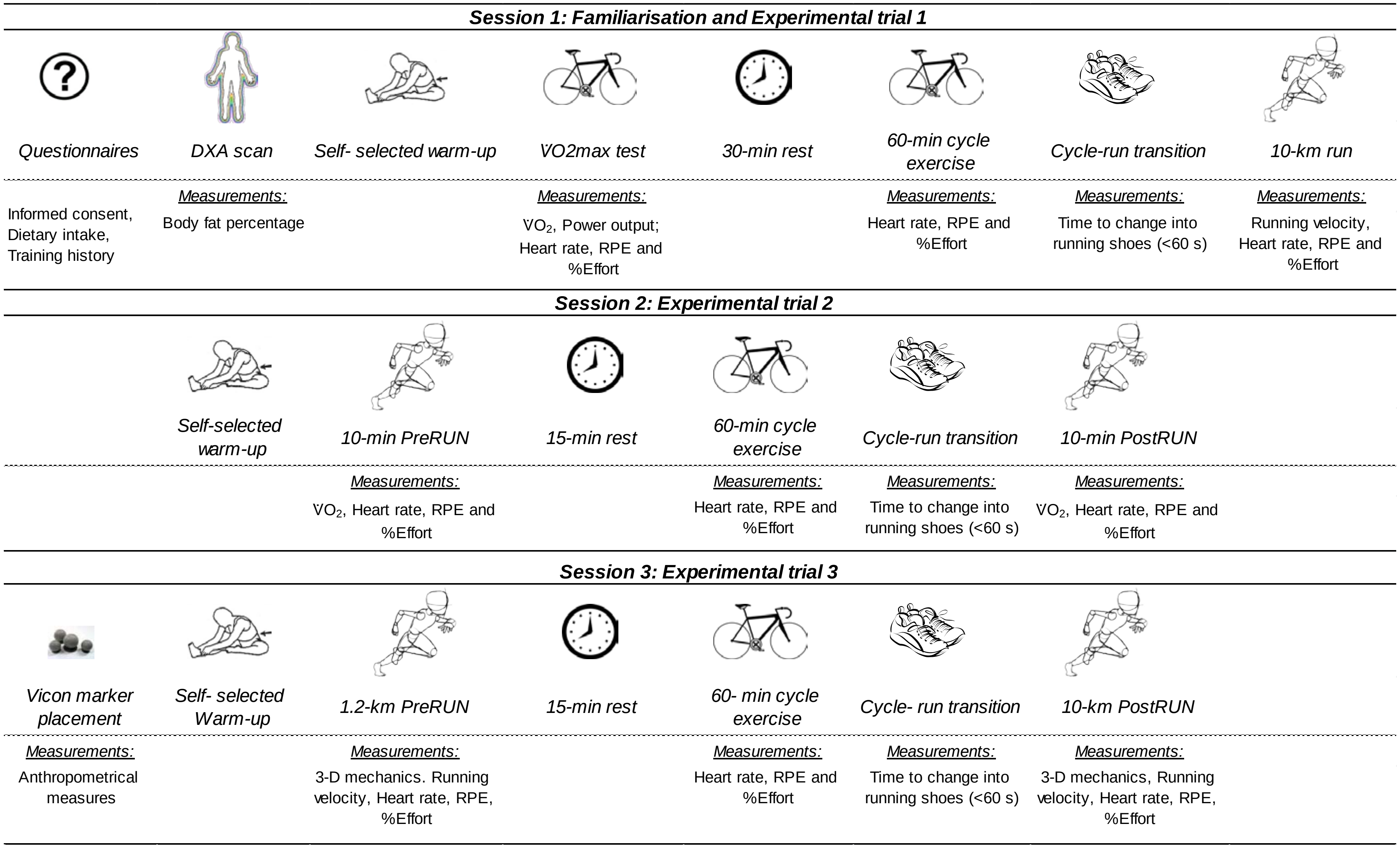


Figure 3.1 Diagrammatic representation of the experimental procedures used in each experimental trial. Abbreviations: DXA, dual-energy x-ray absorptiometry; $\dot{V}O_{2max}$, maximal oxygen consumption; $\dot{V}O_2$, oxygen consumption; RPE, rating of perceived exertion; %Effort, percentage effort (0% being no effort, 100 being absolutely ‘all out’ effort); preRUN, pre-cycle running condition; postRUN, post-cycling running condition.

3.3.2.2 *Session 3: Experimental trial 3, procedures and measurements.*

Temporal running kinematics and lower body joint powers were assessed using three-dimensional (3-D) motion analysis before and after the 60-min cycling bout. A 10-camera Vicon motion analysis system (Vicon MX, Oxford, UK) sampling at 250 Hz was synchronised with five 600 mm × 900 mm tiaxial force platforms (Kistler Quattro, Type 9287BA and 9287CA, Victoria, Australia), sampling at 1000 Hz to obtain stride parameters and lower body joint powers. The force plates were imbedded underneath a Mondo indoor track surface (Mondo, USA). The capture space had a length of 8 m of a 60 m track and was positioned to allow for adequate distance (approximately 40 m) of straight line running prior to the capture space to ensure participants were running at a constant velocity (see Figure 3.2 and Appendix I). Running velocity was monitored and recorded using timing gates (V2, Swift Performance Equipment, Australia) placed 5 m apart to record 15 m of straight line running. Verbal feedback was provided by the testers to ensure that the running velocity was adopted within ± 3% of the pre-determined velocity obtained during the initial visit to the laboratory. Prior to testing, the motion capture system was calibrated according to the manual procedures using the Vicon Nexus software (Vicon NEXUS 2.2.3, Vicon, Oxford, UK).

It should be noted that the overground and treadmill running energy cost were validated according to procedures by Jones and Doust (1996). The treadmill was set to a 1% inclination to best replicate the energetic cost of overground running, and a fan was placed in front of the treadmill. Since portable VO_2 measuring devices could not be utilised without obstructing the view of some of the reflective markers by the motion analysis cameras, the current experimental protocol was properly designed to test our hypothesis.

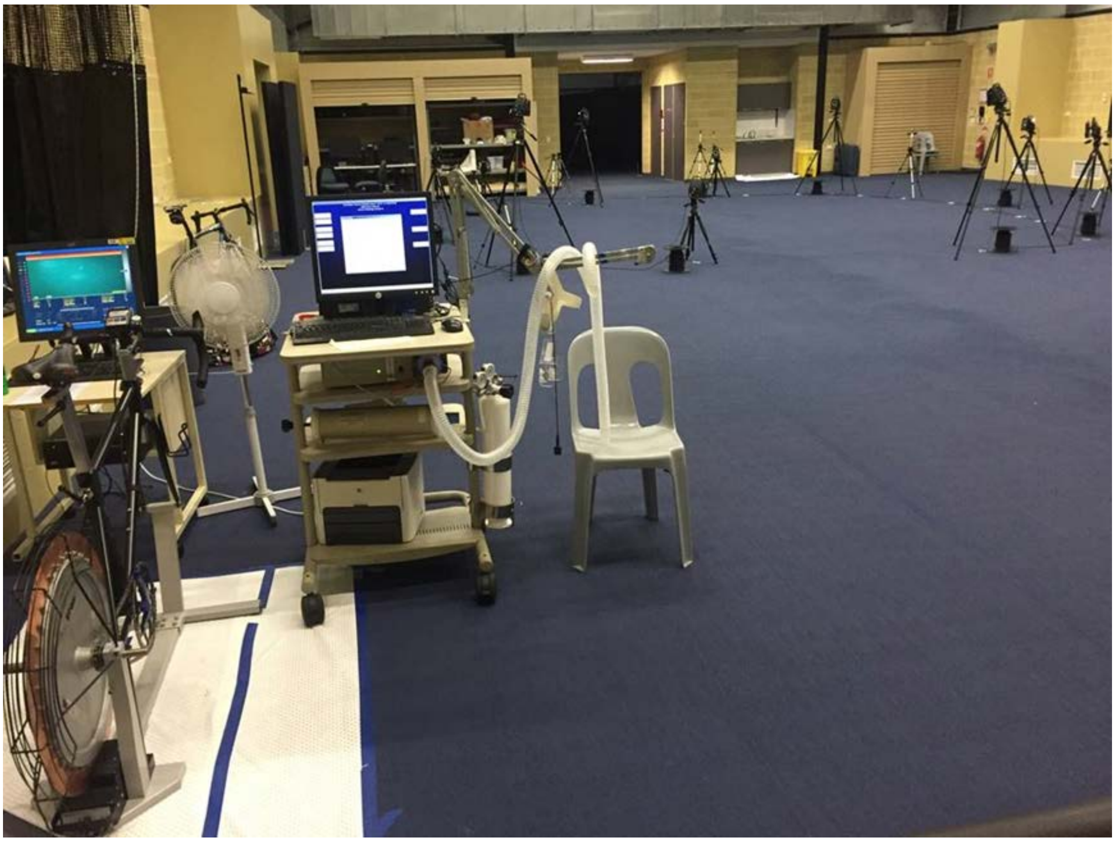


Figure 3.2 The Edith Cowan University biomechanics laboratory set-up for the experimental trials.

Upon arrival, 25-mm retro-reflective markers were positioned on 39 specific body landmarks using medical tape and Fixomul extensible dressing (BSN Medical, Germany). The markers were specifically placed in accordance to the Vicon Plug-in-Gait-Full-Body-Ai model (see Appendix K). A static subject calibration was performed to locate anatomical landmarks and define joint coordinate systems (see Figure 3.3).

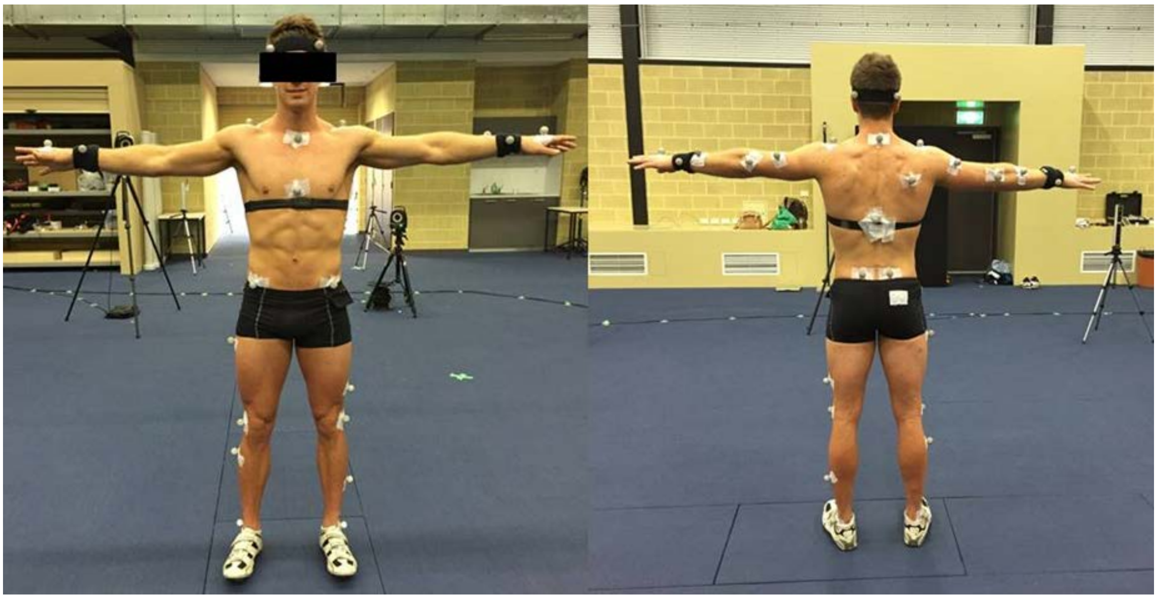


Figure 3.3 Participant in the 'T-pose' during the static calibration using the Plug-in-Gait-Full-Body-Ai model marker placement of the Vicon Motion Analysis system.

Following a 10-min self-selected warm up (similar to Session 2), the participants ran 10 laps (i.e. for 1.2 km) inside the laboratory, passing through the motion capture area once per lap (herein referred to as: *preRUN).* The first preRUN trial was recorded from a standing start. Running stride parameters, kinematics and lower body maximal joint powers during the stride (herein referred to as *running mechanics*) were obtained as participants passed through the motion capture area. Heart rate was recorded after every lap using a polar (RS800 Polar Heart Rate Monitor, Finland) heart rate monitor and rating of perceived exertion (RPE; 6-20 point scale, Borg, 1982) and perceived effort (%Effort; 0-100%; 0% being no effort at all, and 100% being all-out effort; (Etxebarria, Hunt, Ingham & Ferguson, 2014) were recorded after the 1st, 5th and 10th lap of the 1.2-km run (see Figure 3.4).

After a 15-min passive recovery period, the participants performed the 60-min cycle bout on the stationary cycle ergometer where heart rate, RPE and %Effort scores were recorded every 5 min. Participants changed into their running shoes and completed a 10-km outdoor *postRUN* with instructions to maintain a similar transition time between the end of the 60-min cycle bout and the start of the run as obtained in Session 1. The 10-km postRUN was separated into five sections; i) 10 laps indoors (1.2 km), followed by ii) four laps outdoors (3 km), iii) 10 laps indoors (1.2 km), iv) five laps outdoors (3.6 km) and v) the final nine laps (1 km) were completed indoors (see Figure 2.5 of Chapter Two, Study One). Running mechanics and heart rate were

recorded as participants passed through the motion capture area once per lap, and RPE and %Effort scores were recorded after the 1st, 5th and 10th laps. Verbal feedback was again provided to ensure that a running velocity was within ± 3% of the average velocity determined during the initial session.

Figure 3.4 Participant running through the motion capture area during the third experimental trial.

Running mechanics (stride characteristics, kinematics and kinetics) analyses.

The 3-D marker trajectories were filtered using a zero-lag fourth order, low-pass Butterworth filter with a 10-Hz cut-off frequency determined post-hoc to smooth and remove noise from the raw data (Ferber, Davis & Williams Iii, 2003; Tartaruga et al., 2013; Winter, 1979). The cut-off frequency was determined using residual analysis of the X, Y and Z position data of the ankle, knee and hip. The running mechanics data were analysed using customised code by means of the ViconNexus and MATLAB (Mathworks Inc., USA, R2015b) software interface (see Appendix L). It should be noted that although the participants completed a full 10-km postRUN, only the first 10-laps (i.e. 1.2 km) were used for analysis in the current study. Therefore, a

total of 22 trials (i.e. 11 preRUN, and 11 postRUN trials) were analysed for each participant.

Complete running strides, defined from one foot contact to the ipsilateral foot contact (Novacheck, 1998), of both the left and right legs were used for analysis. Analysis of the stride characteristics, obtained via the integrated force platforms and Vicon motion capture system included average contact time, flight time, stride length and stride rate, maximal vertical oscillation of the centre of mass (i.e. $CoM_{vertical}$) and the horizontal distance between the centre of mass and the heel marker at initial foot contact (i.e. $CoM_{horizontal}$). Analysis of the 3-D kinematic data included the sagittal plane joint and segmental angles (i.e. the flexion-extension axis) of the ankle, knee, hip, pelvis (the sacroiliac joint) and trunk (see Figure 3.5); as well as the frontal plane (i.e. the pelvic lateral flexion about the abduction-adduction axis) and transverse plane (i.e. the pelvic rotation about the rotational axis) angles of the pelvis. Specifically, the ankle dorsiflexion angle at landing and plantarflexion at toe-off; the maximum knee flexion during the support and swing phases, the maximum knee extension, the maximum hip flexion and extension, the maximum lateral pelvic flexion, the maximum pelvic rotation, and the maximum trunk flexion during the stride were measured. The average ankle, knee and hip joint angles, including the $CoM_{vertical}$ of the completed strides, were time-normalised to 101 data points and graphically represented as the percentage of the stride phase (i.e. 0% as the initial foot contact to 100% as the ipsilateral foot contact). In addition, the maximum lower body joint powers of the ankle, knee and hips were calculated through inverse dynamics procedures.

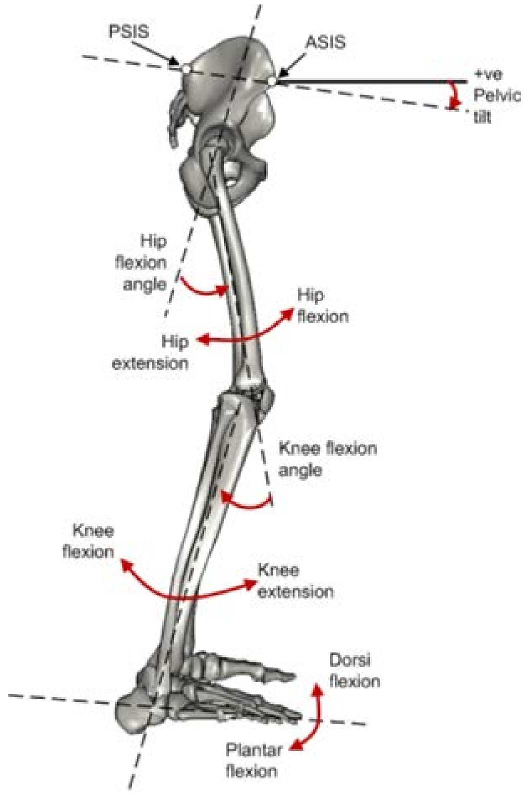


Figure 3.5 Schematic representation of the lower body joint angles using the Vicon Plug-in-Gait-Full-Body-Ai model from the Vicon Motion Analysis manual. This image illustrates a sagittal plane view of the flexion-extension axis of the pelvis, hip, knee and ankle joint angles. Note that the lateral pelvic flexion and the pelvic rotation axes are not illustrated in the image, but are described in the text.

3.3.3 Statistical analysis

All biomechanical variables were tested for normal distribution, using the Levene's normality test, and for homogeneity of variances before statistical analysis. Separate multivariate analyse of variance (MANOVA) with repeated measures were used to compare the changes in running mechanics between preRUN and postRUN. These biomechanical variables included; stride parameters (7 biomechanical factors × time), kinematic variables (10 biomechanical factors × time) and lower body joint powers (3 biomechanical factors × time). Statistical analyses were performed using SPSS statistical software (v 22 for Windows, SPSS, Inc., Chicago, IL, USA) and data were expressed as mean ± standard deviation. Statistical significance for all tests was accepted at an alpha level of 0.05.

The percentage change for all the variables were analysed between the preRUN and postRUN conditions and precision of estimation was indicated with 95% confidence

limits (CL). Effect sizes were calculated and interpreted according to the following criteria: <0.2 trivial, 0.2 to 0.6 small, 0.6 to 1.2 moderate, 1.2 to 2.0 large and > 2 very large (Hopkins, 2010).

Pearson's product moment correlations were used to characterise the univariate relationship between the changes in running economy (i.e. aerobic energy cost, obtained in Study One (Chapter Two) and the changes in running mechanics following cycling. The magnitude of effect for correlations (*r*) were interpreted as follows: r = 0.0 to r = 0.10 considered trivial, r = 0.11 to 0.30 was considered small, r = 0.31 to 0.50 was considered moderate, r = 0.51 to 0.70 was considered to be large, r = 0.71 to 0.90 considered as very large and r = 0.91 to 1.0 was considered a nearly perfect correlation (Hopkins, 2010).

In order to determine the most accurate set of mechanical variables that predict an alteration in running economy following cycling, significant univariate correlations between running mechanics and running economy were retained and entered into a backward stepwise multiple-linear regression model. Mechanical variables (i.e. independent predictor variables) included: flight time, lateral pelvic flexion, knee flexion during the stance phase, maximal hip flexion during the swing phase and the $CoM_{horizontal}$ distance. All assumptions for running a multiple-linear regression model were met prior to the use of the model.

An independent *t*-test was used to compare the biomechanical changes between preRUN and postRUN conditions of the subgroups (i.e. from Chapter Two, Study One) the *impaired* subgroup consisted of the triathletes who increased their aerobic energy cost whereas the *improved* subgroup decreased their aerobic energy cost following cycling).

3.4 RESULTS

3.4.1 Running stride parameters before and after cycling.

No significant difference were observed in a group of stride parameters (F(7,10) = 2.88, p = 0.063, power = 0.659) between the preRUN and postRUN (see Table 3.1). However, significant differences were observed in individual parameters, i.e. for running velocity (-3.0 ± 2.0% (mean ± 95%CL), p = 0.033), flight time (-2.2 ± 1.3%, p

= 0.007), stride length (-2.6 ± 1.6%, p = 0.022), $CoM_{vertical}$ (-3.3 ± 2.7% , p = 0.049) and for $CoM_{horizontal}$ (i.e. the horizontal distance of the foot relative to the centre of mass at landing, -13.0 ± 7.3%, p = 0.023) (see Figure 3.6).

3.4.2 Running kinematics (i.e. joint and segment angles) before and after cycling.

A significant difference was observed for a group of lower body kinematic variables (F(10,7) = 10.67, p = 0.002, power = 0.994) between the preRUN and postRUN (see Table 3.2). Significant differences were found for maximal knee flexion angle during the support phase (-1.7 ± 1.2%, p = 0.039), maximal knee flexion angle during the swing phase (-2.7 ± 1.4%, p = 0.005), and for the anterior pelvic tilt angle (-5.9 ± 1.9%, p < 0.001) (see Figure 3.7 and Figure 3.8). However, none of the remaining joint and segment angles of the ankle, hip, pelvis and trunk were significantly different between preRUN and postRUN.

3.4.3 Lower body joint powers before and after cycling.

A significant difference (F(3,14) = 15.94, p < 0.001, power = 1.0) was observed for a group of maximal lower body joint power production variables between the preRUN and postRUN conditions (see Table 3.3). A significant difference was observed for the knee joint extension power (-8.5% ± 4.4, p = 0.014) and a trend towards significance was shown for the ankle plantarflexion power (-4.8 ± 3.4%, p = 0.057) between the preRUN and postRUN (see Figure 3.9).

Table 3.1 Changes in stride parameters observed during overground running before (preRUN) and after (postRUN) the simulated Olympic distance cycling protocol (n = 17).

	PreRUN		PostRUN		% Change	*p* - value	Cohen's *d*
	Mean ± SD	95% CL [Lower, Upper]	Mean ± SD	95% CL [Lower, Upper]	± 95 CL		± 95% CL
Running velocity ($m \cdot s^{-1}$)	3.6 ± 0.4	[3.4, 3.8]	3.5 ± 0.5	[3.2, 3.8]	-3.0 ± 2.4	0.033*	-0.2 ± 0.2
Contact time (s)	0.24 ± 0.0	[0.22, 0.26]	0.24 ± 0.0	[0.23, 0.26]	1.2 ± 2.1	0.215	0.1 ± 0.1
Flight time (s)	0.479 ± 0.0	[0.47, 0.49]	0.468 ± 0.0	[0.46, 0.48]	-2.2 ± 1.5	0.007**	-0.4 ± 0.3
Stride length (m)	2.6 ± 0.2	[2.4, 2.7]	2.5 ± 0.3	[2.3, 2.7]	-2.6 ± 2.0	0.022*	-0.3 ± 0.2
Stride rate (Hz)	1.39 ± 0.1	[1.36, 1.43]	1.41 ± 0.1	[1.38, 1.44]	1.1 ± 1.2	0.095	0.2 ± 0.2
$CoM_{horizontal}$ (m)	0.0904 ± 0.04	[0.07, 0.11]	0.0819 ± 0.04	[0.06, 0.10]	-13.0 ± 8.9	0.023*	-0.2 ± 0.2
$CoM_{vertical}$ (m)	0.0912 ± 0.01	[0.09, 0.09]	0.0884 ± 0.01	[0.09, 0.09]	-3.7 ± 2.7	0.049*	-0.6 ± 0.4

Data are represented as mean ± standard deviation. Percentage change (%change) data are represented as mean ± 95% confidence limits (CL). Significant differences from the preRUN denoted by * ($p < 0.05$), ** ($p < 0.01$), *** ($p < 0.001$)

Abbreviations: preRUN, pre-cycle running condition; postRUN, post-cycling running condition; CoM, centre of mass; $CoM_{horizontal}$, horizontal distance of the CoM to the heel marker at initial foot contact, $CoM_{vertical}$, vertical oscillation of the CoM.

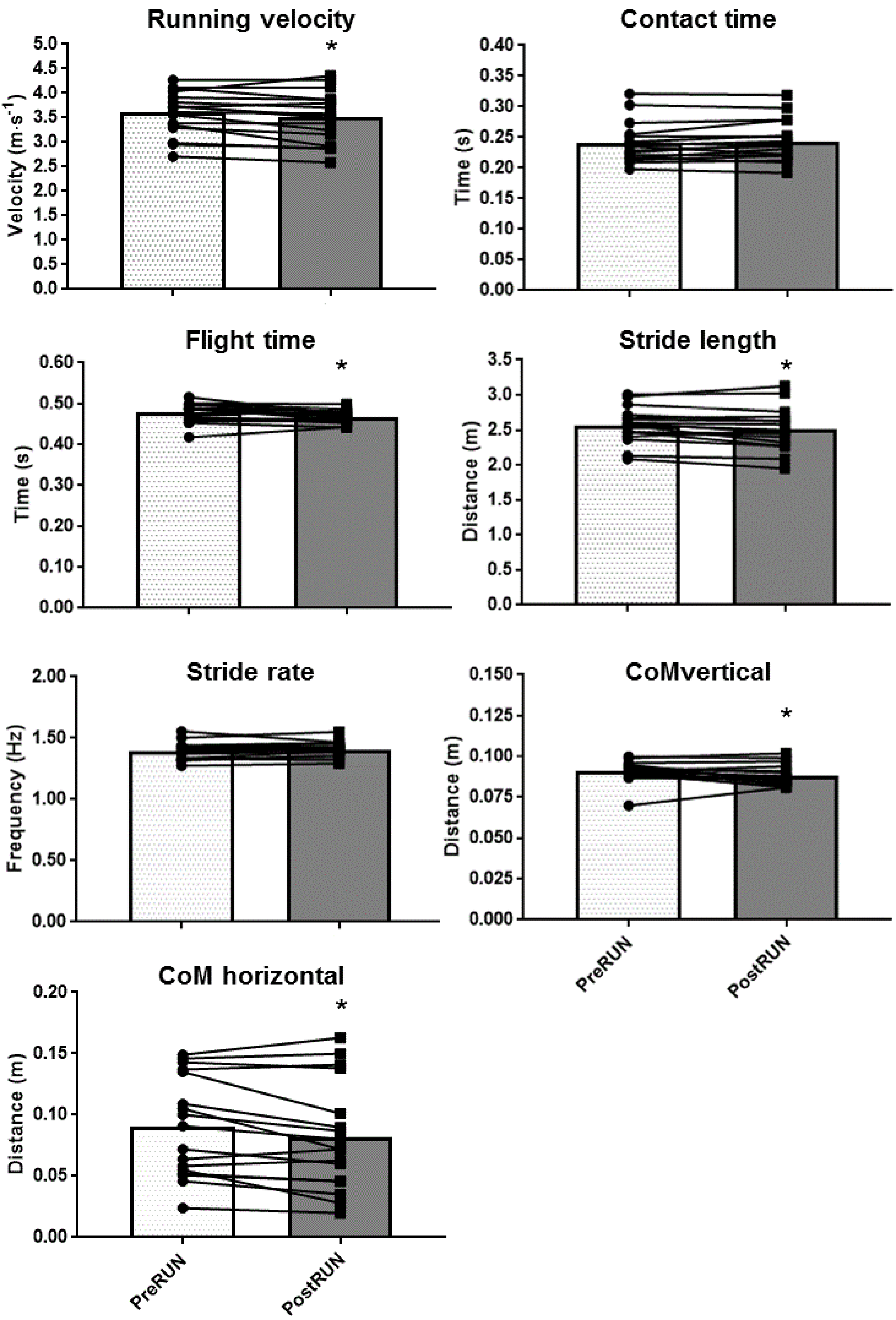


Figure 3.6 Differences in stride parameters between preRUN and postRUN conditions. The bar graphs represent the average preRUN and postRUN stride parameters and the lines represent the individual differences between the running conditions. Significant differences were obtained between the preRUN and postRUN velocity, flight time, stride length, horizontal distance of the centre of mass (CoM) to the heel marker at initial contact and the vertical oscillation of the CoM.

Table 3.2 Changes in joint angles observed during overground running before (preRUN) and after (postRUN) the simulated Olympic distance cycling protocol (*n* = 17).

	PreRUN		PostRUN		% Change	*p* - value	Cohen's *d*
	Mean ± SD	95% CL	Mean ± SD	95% CL	± 95 CL		95% CL
Ankle dorsiflexion at contact (˚)	12.0 ± 5.3	[9.3, 14.8]	11.8 ± 4.9	[9.2, 14.3]	-2.6 ± 19.0	0.728	-0.1 ± 0.1
Ankle plantarflexion at toe-off (˚)	-20.8 ± 6.6	[-24.1, -17.4]	-22.1 ± 7.7	[-26.0, -18.1]	5.7 ± 10.5	0.180	0.2 ± 0.2
Max knee flexion during support (˚)	44.9 ± 5.1	[42.3, 47.5]	44.1 ± 5.0	[41.5, 46.7]	-1.7 ± 1.5	0.039*	-0.1 ± 0.1
Max knee flexion during swing (˚)	102.2 ± 10.8	[96.7, 107.8]	99.5 ± 11.2	[93.7, 105.3]	-2.7 ± 1.7	0.005**	-0.2 ± 0.1
Max hip flexion (˚)	51.8 ± 7.3	[48.1, 55.6]	51.3 ± 7.1	[47.7, 55.0]	-0.9 ± 2.0	0.341	-0.1 ± 0.1
Max hip extension (˚)	-6.5 ± 4.7	[-8.8, -4.2]	-6.3 ± 5.3	[-8.9, -3.5]	-4.1 ± 22.9	0.534	0.1 ± 0.1
Max anterior pelvic tilt (˚)	22.1 ± 3.5	[20.4, 23.9]	20.9 ± 3.7	[19.0, 22.7]	-5.9 ± 2.3	<0.001***	-0.4 ± 0.2
Max trunk flexion (˚)	10.9 ± 3.4	[9.2, 12.7]	11.2 ± 3.5	[9.4, 13.0]	2.2 ± 8.3	0.526	0.1 ± 0.2
Max lateral pelvic flexion (˚)	5.8 ± 1.1	[5.2, 6.4]	5.9 ± 1.2	[5.3, 6.5]	1.1 ± 5.9	0.637	-0.02 ± 0.1
Max pelvic rotation (˚)	7.7 ± 1.5	[6.9, 8.4]	7.4 ± 1.9	[6.4, 8.4]	-5.4 ± 8.0	0.284	-0.2 ± 0.26

Data are represented as mean ± standard deviation. Percentage change (%change) data are represented as mean ± 95% confidence limits (CL). Significant differences between the preRUN and postRUN are denoted by * ($p < 0.05$), ** ($p < 0.01$), *** ($p < 0.001$).

Abbreviations: preRUN, pre-cycle running condition; postRUN, post-cycling running condition; Max, maximum.

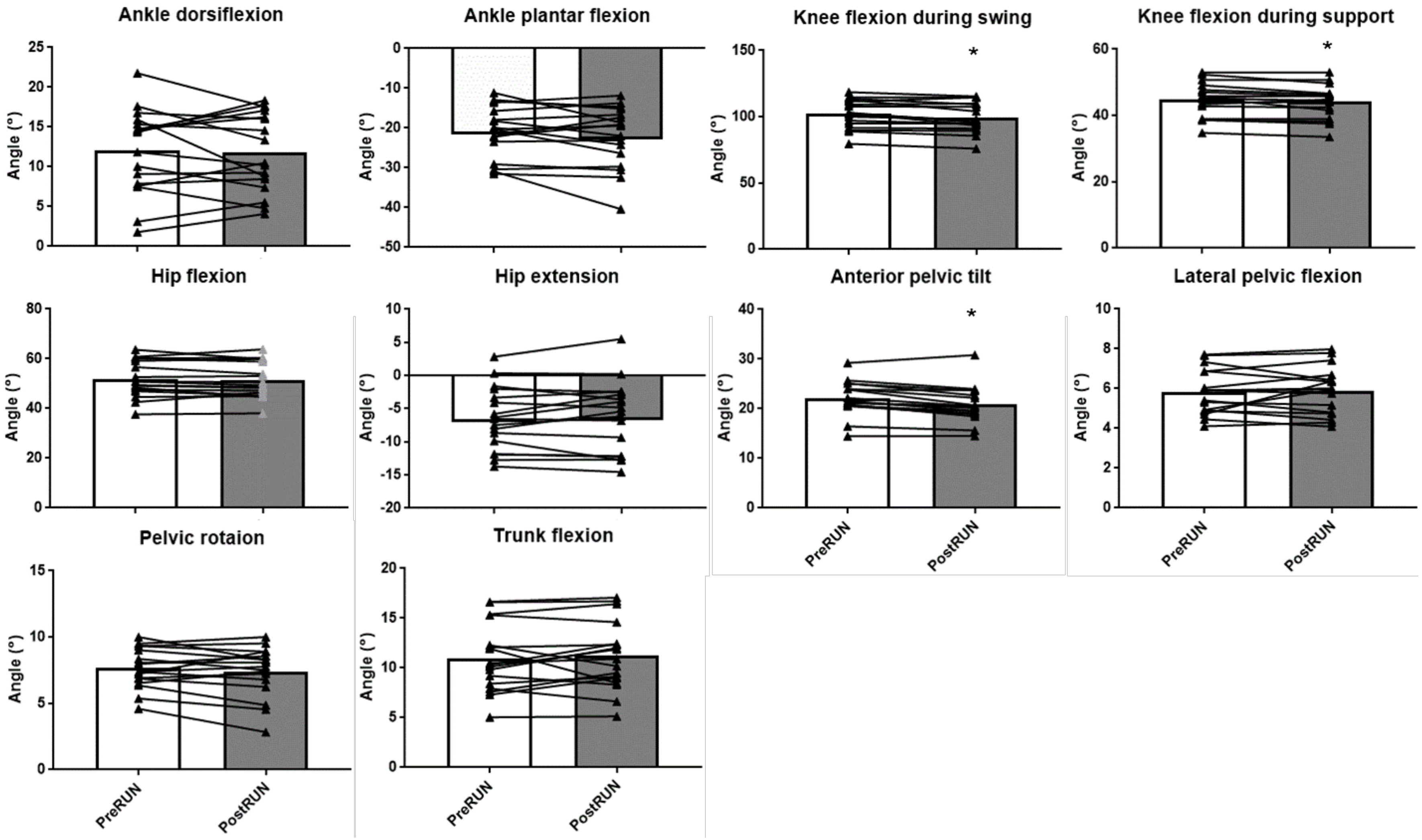


Figure 3.7 Joint angle differences of the ankle, knee, hip, pelvis and trunk between the preRUN and postRUN. Bar graphs represent the average joint angles and the lines represent the individual differences of the participants between the running conditions. Significant differences between the preRUN and postRUN are denoted by * ($p < 0.05$). Significant differences in the maximal knee flexion during the support and swing phases and for the anterior pelvic tilt were found between the preRUN and postRUN.

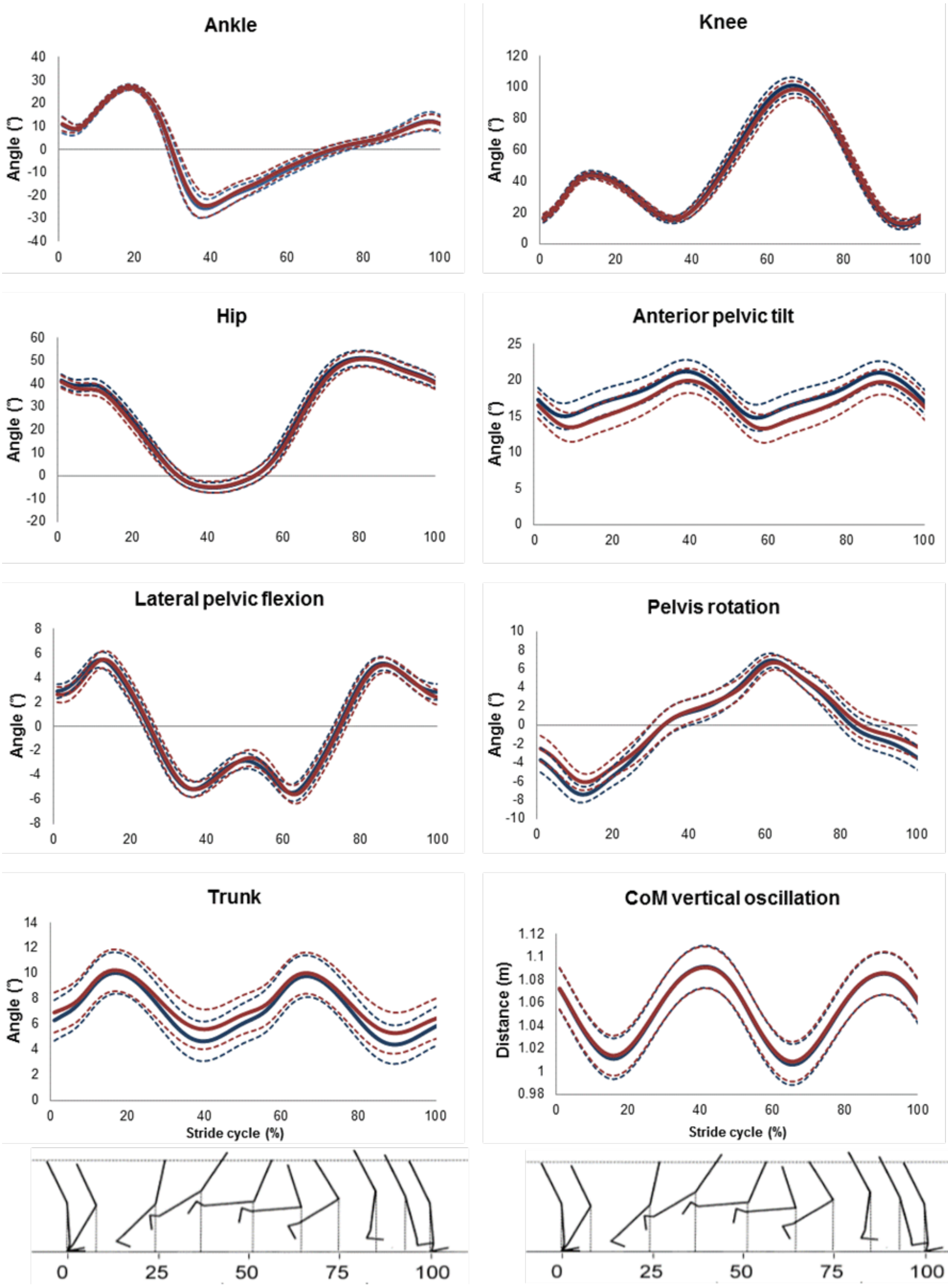


Figure 3.8 The difference in joint angles and the vertical oscillation of the centre of mass (CoM) as a percentage of the stride cycle between the preRUN and postRUN. Blue solid lines represent the average of the preRUN. Red solid lines represent the average of the postRUN joint angles. Blue and red dotted lines illustrate the ± 95% CL (lower and upper limits) of the average scores. Sagittal plane joint angles were obtained for the ankle, knee, hip and trunk flexion angles including the CoM vertical oscillation and the anterior pelvic tilt. Frontal plane angles were obtained for the pelvis as illustrated by the lateral pelvic flexion. Additionally, a transverse plane joint angle of the pelvis was obtained and illustrated by the pelvic rotation. Bottom stick figures represent an illustration of the running stride adapted from (Mizrahi, Verbitsky, Isakov & Daily, 2000).

Table 3.3 Changes in maximal joint power during the stride observed during overground running before (preRUN) and after (postRUN) the simulated Olympic distance cycling protocol (n = 17).

	PreRUN		PostRUN		% Change	*p* -value	Cohen's *d*
	Mean ± SD	95% CL	Mean ± SD	95% CL	± 95% CL		± 95% CL
Ankle power ($W{\cdot}kg^{-1}$)	9.26 ± 2.0	[8.2, 10.3]	8.89 ± 2.3	[7.7, 10.1]	-4.8 ± 4.2	0.057	-0.1 ± 0.2
Knee power ($W{\cdot}kg^{-1}$)	12.28 ± 2.8	[10.8, 13.7]	11.36 ± 3.1	[9.7, 13.0]	-8.5 ± 5.4	0.014*	-0.3 ± 0.2
Hip power ($W{\cdot}kg^{-1}$)	8.61 ± 2.4	[7.3, 9.9]	8.98 ± 3.0	[7.4, 10.5]	2.9 ± 6.0	0.178	0.2 ± 0.2

Data represented as mean ± standard deviation. Percentage change (%change) data are represented as mean ± 95% confidence limits (CL). Significant differences between preRUN and postRUN are denoted by * ($p < 0.05$).

Abbreviations: preRUN, pre-cycle running condition; postRUN, post-cycling running condition. Maximal powers refer to the ankle plantar flexion power, knee extension power and hip flexion power.

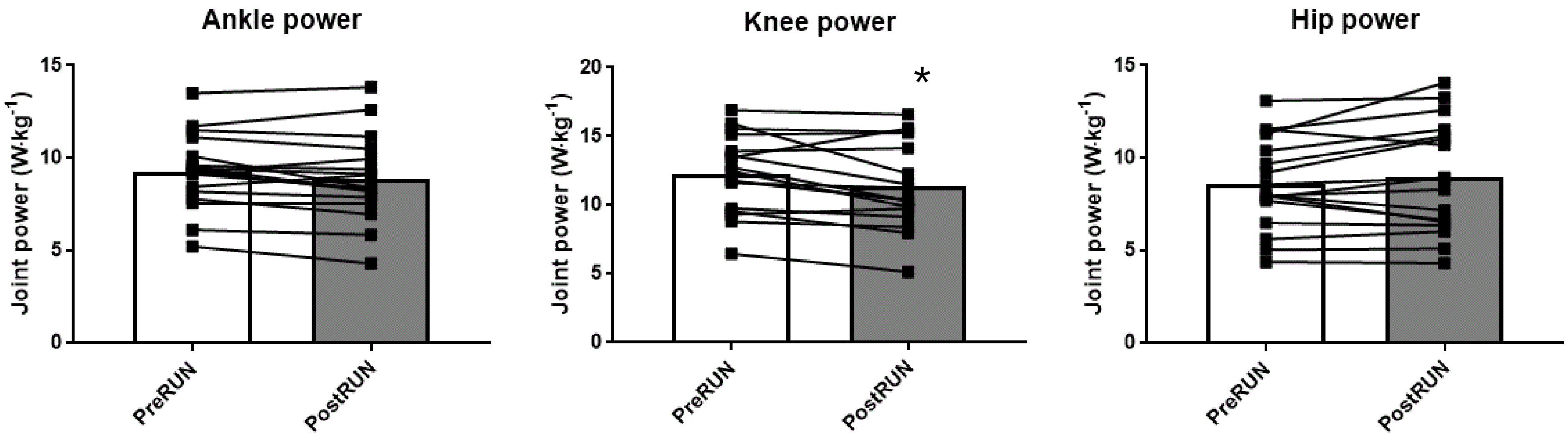


Figure 3.9 Differences in maximal joint powers of the ankle, knee and hip during the running stride between the preRUN and postRUN. Bar graphs represent the average changes and the lines represent the individual differences of the participants between the running conditions. Significant differences between preRUN and postRUN are denoted by * ($p < 0.05$). A significant difference can be observed for the maximal knee extension power during the stride between the preRUN and postRUN.

3.4.4 Correlations between the differences in running mechanics and between the differences in running economy and running mechanics before and after cycling.

Large and significant correlations were observed between some of the differences in stride parameters, joint kinematics and lower body joint powers (see Figure 3.10), indicating multicollinearity existed some of the mechanical variables. Moderate (non-significant) correlations were observed between the differences in running economy (i.e. the aerobic energy cost, described in detail in Chapter Two, Study One) and the differences in stride parameters, joint kinematics or lower body joint powers (see Figure 3.11) between the preRUN and postRUN conditions.

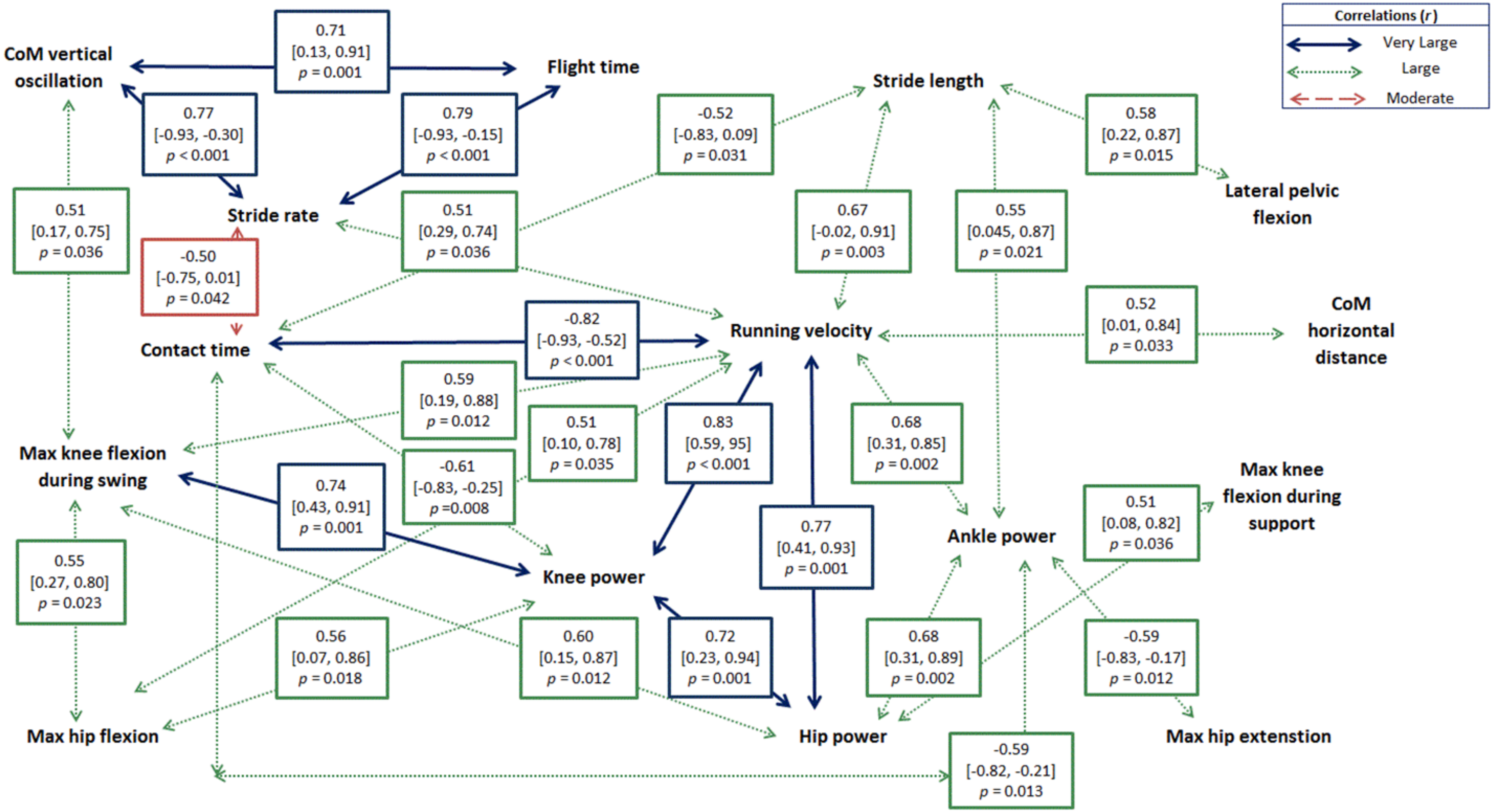


Figure 3.10 Correlations (*r*) between the running mechanic variables. Blue solid lines represent very large correlations, green dotted lines represent large correlations and the red dotted lines represent moderate correlations between the biomechanical variables. Data presented as correlation (*r*) with 95% confidence limits. Abbreviations: CoM, centre of mass; CoM horizontal distance, horizontal distance of CoM to heel marker at initial foot contact; .Max, maximum joint angle during a running stride.

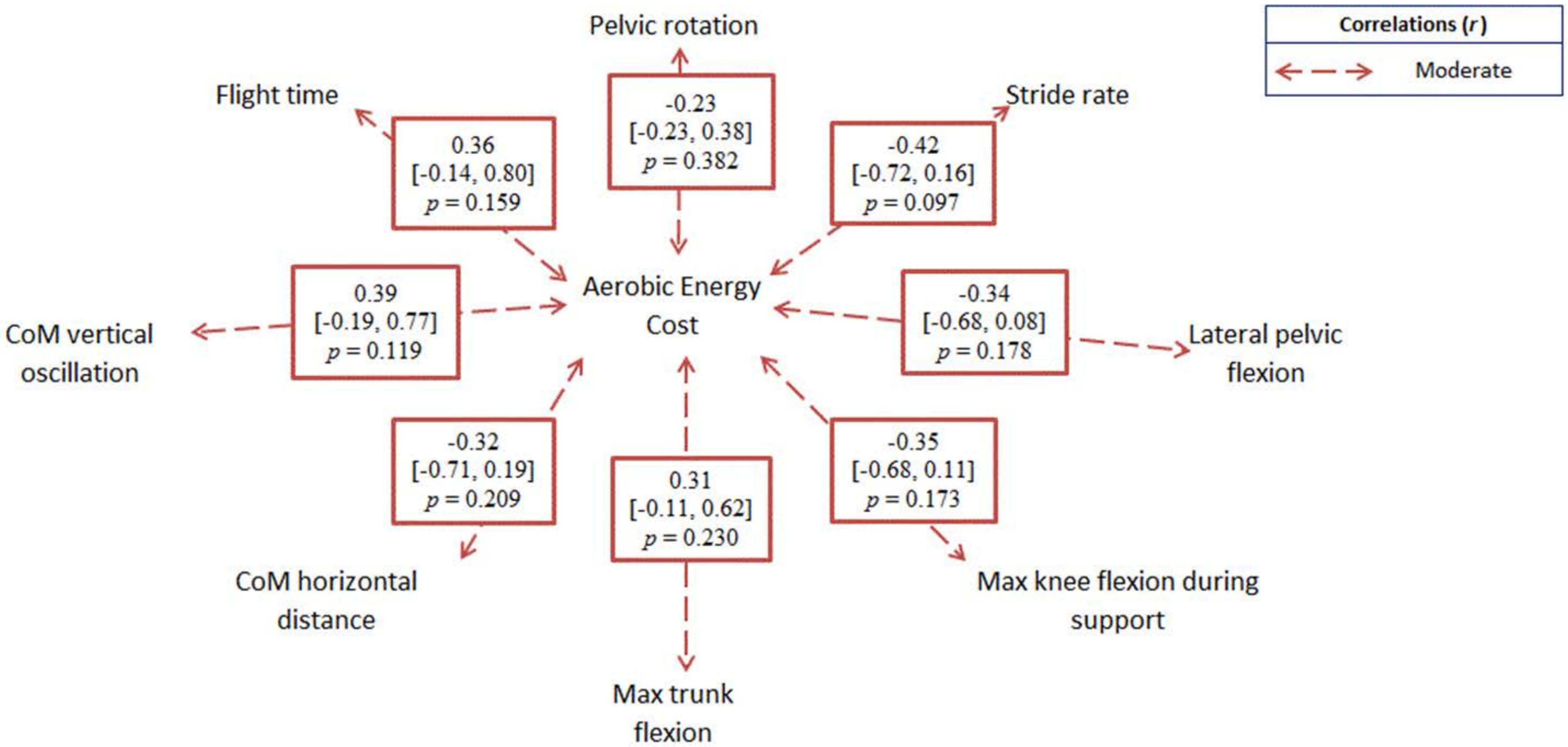


Figure 3.11 Correlations of the differences in running economy and the differences in running mechanical variables before and after the 60-min cycle exercise. Non-significant and moderate correlations were observed between the changes in the aerobic energy cost and the changes in the mechanical variables.

Data presented as correlation (*r*) with 95% confidence limits. Aerobic energy cost ($J \cdot kg^{-1} \cdot m^{-1}$) was used as the running economy criterion variable. Abbreviations: CoM, centre of mass; CoM horizontal distance, horizontal distance of CoM to heel marker at initial foot contact; .Max, maximum joint angle during a running stride.

3.4.5 Linear regression analysis

A multilinear regression was run to predict a change in running economy between pre-and post-cycling running, from changes in a group of biomechanical variables. These variables [flight time, maximum knee flexion during the stance, maximum lateral pelvic flexion], statistically significantly predicted the changes in aerobic energy cost, $F(3,13) = 4.29$, $p = 0.026$, $r = 0.705$. These variables were identified to have the strongest correlations with aerobic energy cost, without collinearity. The participants' predicted [changes in aerobic energy cost] were equal to 0.98 + 4.08 [change in flight time (s)] - 0.03 [change in max knee flexion during support (˚)] - 0.09 [change in lateral pelvic flexion (˚)] (see Table 3.4). In addition, the $R^2_{observed}$ value indicated a relatively good cross-validity of this model (i.e. a 0.12 unit difference between the R^2 and the $R^2_{adjusted}$). Together, flight time ($t(13) = 2.5$, $p = 0.027$) and lateral pelvic flexion ($t(13) = -2.4$, $p = 0.029$) made significant contributions ($F(1,13) = 2.94$, $r = 0.620$, $p = 0.034$) to the model, whereas the maximum knee flexion angle during the support phase did not contribute significantly to the model ($t(13) = -1.7$, $p = 0.110$).

Table 3.4 Linear regression model for predicting the changes in running economy based on a cluster of biomechanical variables.

	B	SE	β
Step 1			
Constant	0.98	0.03	
Flight time (s)	4.08	1.59	0.54*
Max knee flexion during the support (˚)	-0.03	0.02	-0.34
Lateral pelvic flexion (˚)	-0.09	0.04	-0.56*
Step 2			
Constant	0.12	0.03	
Flight time (s)	4.18	1.70	0.56
Lateral pelvic flexion (˚)	-0.09	0.04	-0.55

Note: $r = 0.705$, $R^2 = 0.498$ for Step 1 ($p = 0.026$),

Note: $r = 0.620$, $R^2 = 0.384$ for Step 2 ($p = 0.034$),

Significant contribution to the model denoted by * ($p < 0.05$). Abbreviations: B-value, the individual contribution of the predictors; SE, standard error, β, Beta (the number of standard deviations that the outcome will change as a result of one standard deviation change in the predictor variable).

3.4.6 Biomechanical differences between subgroups

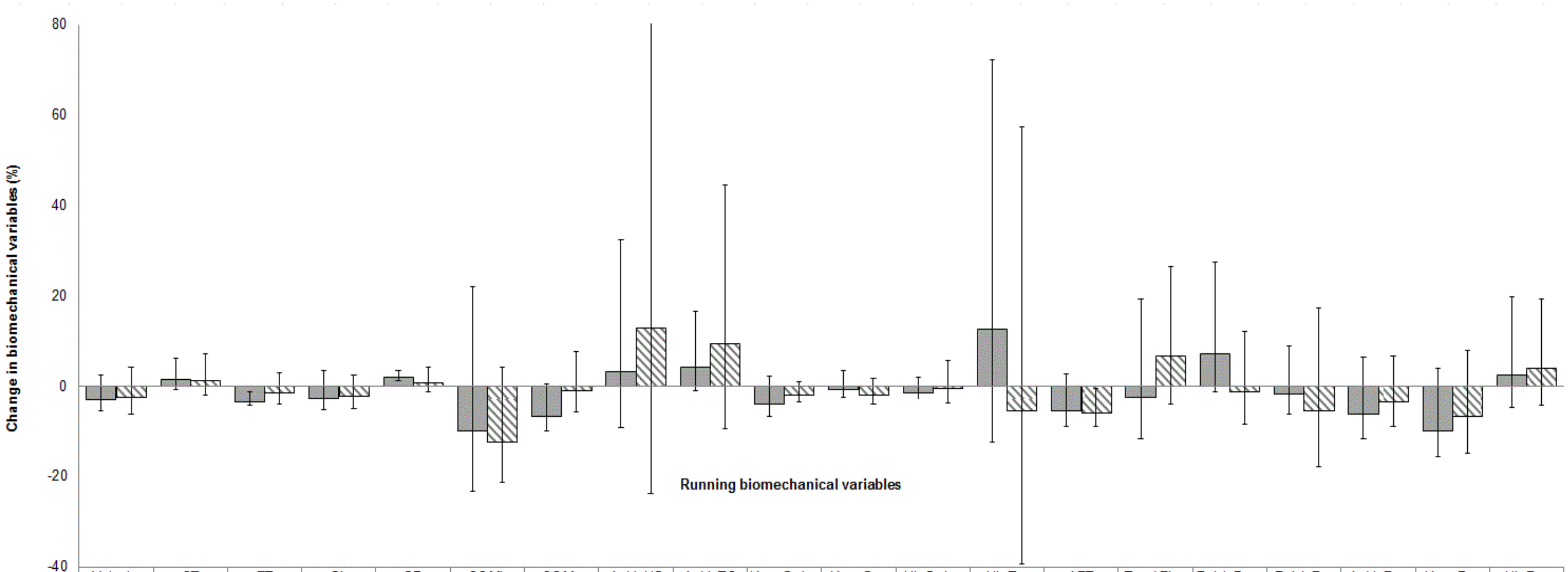
Based on the findings in Chapter Two, Study One of this thesis regarding the changes in running economy (i.e. between the preRUN and postRUN), the participants were allocated into two subgroups. These consisted of the participants whose aerobic energy cost increased or decreased following cycling, i.e. the *impaired* subgroup (n = 11) and *improved* subgroup (n = 6), respectively (see Table 3.5).

Table 3.5 Participant characteristics for the *improved* and *impaired* subgroups.

	Improved (n = 6)	Impaired (n = 11)
Age (years)	34.8 ± 4.0	34.19 ± 7.3
Height (cm)	178.5 ± 7.7	181.8 ± 4.7
Body mass (kg)	77.9 ± 16.6	79.7 ± 9.9
$\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1})	58.0 ± 5.7	54.9 ± 7.7

Data presented as mean ± standard deviation.

No significant differences were observed for the preRUN and postRUN mechanical variables between the subgroups (see Figure 3.12). Nevertheless, the *improved* subgroup tended towards greater differences in a majority of the variables such as: CoM vertical oscillation (-6.8%, p = 0.057), running velocity (-3.1%, p = 0.871), flight time (-3.4%, p = 0.272), stride length (-2.7%, p = 0.801), stride rate (+1.9%, p = 0.277), knee flexion during the swing phase (-4.0%, p = 0.181), hip flexion during the swing phase (-1.4%, p = 0.724), lateral pelvic flexion (+7.2%, p = 0.185), hip extension following take-off (+12.6%, p = 0.548), ankle plantarflexion power (-6.3%, p = 0.698) and knee joint extension power (-9.9%, p = 0.359). Alternatively, the *impaired* subgroup tended towards greater differences in variables such as: ankle dorsiflexion upon landing (+12.7%, p = 0.798), ankle plantar-flexion at take-off (+9.4%, p = 0.617), $CoM_{horizontal}$ (-12.3%, p = 0.621), knee flexion during the support phase (-2.1%, p = 0.470), trunk flexion (+6.6%, p = 0.271), pelvic rotation (-1.3%, p = 0.640) and hip joint power (+4.0%, p = 0.691).



	Velocity	CT	FT	SL	SR	COMh	COMv	AnkleHS	AnkleTO	KneeSwing	KneeSup	HipSwing	HipExt	APT	TrunkFlex	PelvicDrop	PelvicRot	AnklePwr	KneePwr	HipPwr
Improved	-3.08	1.36	-3.38	-2.70	1.95	-9.89	-6.83	3.09	4.27	-4.03	-0.79	-1.43	12.63	-5.54	-2.56	7.18	-1.66	-6.26	-9.88	2.53
Impaired	-2.51	1.23	-1.49	-2.37	0.65	-12.32	-0.99	12.74	9.45	-1.95	-2.06	-0.48	-5.60	-5.98	6.59	-1.26	-5.60	-3.52	-6.83	4.02

Figure 3.12 Percentage change in the biomechanical variables in both the *improved* and *impaired* running economy subgroups. No significant differences were demonstrated between the subgroups. However, the *improved* subgroup demonstrated a trend towards a greater amount of biomechanical differences between the preRUN and postRUN conditions.

Abbreviations: CT, contact time; FT, flight time; SL, stride length; SR, Stride rate; CoMh, horizontal distance between the centre of mass and the heel marker at landing; CoMv, vertical oscillation of the centre of mass; AnkleHS, ankle dorsiflexion at initial contact, AnkleTO, ankle plantar flexion at toe-off; KneeSwing, knee flexion during the swing; KneeSup, knee flexion during the support phase; HipSwing, hip flexion during the swing phase; HipExt, hip extension; APT; anterior pelvic tilt; TrunkFlex, trunk flexion; PelvicDrop, pelvic lateral flexion; PelvicRot; rotation of pelvis; AnklePwr, ankle plantarflexion power; KneePwr, knee extension power; HipPwr, hip flexion power.

3.5 DISCUSSION

This study examined the influence of an energetically-demanding cycling exercise on the biomechanics of a subsequent running exercise in a group of trained male triathletes. Additionally, the relationships between biomechanical and running economy changes were investigated, with a particular focus on the triathletes who ran with improved economy following the cycling bout. The main findings indicated that: i) a high-intensity cycling exercise altered lower body kinematics and joint kinetics during running, ii) changes in a group of biomechanical variables (flight time, maximal knee flexion angle during the stance phase and lateral pelvic flexion) were significantly associated with the changes in running economy, iii) large inter-individual differences existed between the pre- and post-cycling running conditions (i.e. between the preRUN and postRUN) for multiple biomechanical variables, and iv) no significant biomechanical differences were found between the triathletes who *improved* their economy following cycling, compared to those whose economy was *impaired*. Although not statistically significant, an interesting observation was made for the triathletes who *improved* their running economy; they demonstrated a greater magnitude of biomechanical alterations following cycling, when compared to running without prior cycling. These results may potentially suggest that some runners altered their mechanics to a greater extent when a prior movement task was performed in order to maintain movement economy.

In agreement with previous studies investigating running mechanics before and after cycling exercise (Bonacci et al., 2010; Hausswirth et al., 1997; Rendos et al., 2013), significant differences ($p < 0.05$) in running mechanics were found in the present study when running following cycling, compared to when cycling was not performed prior. This included decreases in running velocity, flight time, stride length, the horizontal distance between the centre of mass (CoM) and the heel at initial foot-ground contact (i.e. triathletes landed with their foot closer to the CoM), as well as for the vertical oscillation of the CoM. Significant decreases were also found in the knee flexion angle during both the support and the swing phases, as well as for the maximal knee extension power production and the anterior pelvic tilt. However, apart from these alterations, other measured parameters of the ankle, hip, pelvis, and trunk remained unchanged following the cycling bout. Although contributors responsible

for these alterations in running mechanics may involve the repetitive cyclic movement patterns of cycling resulting in fatigue and/or a locomotor pattern interference of subsequent running, uncertainty still remains within the literature as to the precise factors responsible (Chapman et al., 2008; Gottschall & Palmer, 2002; Lepers et al., 2008). Therefore, in order to provide some insight into the causes of the biomechanical changes observed in this study, differences in the running mechanics will be discussed and compared to previous research on running following a cycling exercise and fatigued running conditions.

It is likely that movement pattern interference was responsible for the reduced velocity and altered mechanics observed, particularly since the participants consciously attempted to maintain a constant velocity following cycling, that was similar to the pre-cycle running condition. Indeed, when performing different movement tasks in succession, a short-term adaptation may occur that can interfere with the performance of the second task that follows the first, a phenomenon known as perseveration (Brugger & Gardner, 1994; Classen et al., 1998; Proios & Brugger, 2004). Furthermore, it is likely that fatigue induced by the repeated and prolonged use of the muscle structures on the bicycle, could have produced changes in the muscle fibres and affected the mechanical capacities such as the ability of the knee extensor to produce force optimally (Nicol, Komi & Marconnet, 1991). For example, a decrease in knee extensor torque and muscle activation levels have been shown following 30 min of cycling at 75-80% maximal aerobic power, which lasted up to 6 h (Bentley, Smith, Davie & Zhou, 2000; Lepers et al., 2008). It would be valid to assume that neuromuscular fatigue was induced by the 60-min, high-intensity cycling bout in the current study, which was further indicated by the observed decrease in the knee joint power production (-8.5%, $p = 0.014$). It is known that majority of the power in both cycling and running originates from the knee extensors to propel the body forward (Gregor, Cavanagh & LaFortune, 1985). The knee extensors also play a role in stabilising the knee by increasing knee joint stiffness during the stance phase in running (Kyröläinen et al., 2001) It can therefore be suggested that the cycling bout induced neuromuscular fatigue through altering the knee extensor force generation capability, influencing the biomechanics of the support and propulsion phases of subsequent running.

Consequently, the neuromuscular fatigue of the knee extensors could have resulted in an inability to extend the knee forcefully prior to foot-ground contact, leading to the foot landing closer to the CoM, and ultimately, decreasing stride length and running velocity. Results from the current study demonstrated that the knee remained more extended and moved through a smaller range of motion, indicated by a decrease in knee flexion angle during the swing phase (-2.7%, p = 0.005) to a decrease in knee flexion angle during the support phase (-1.7%, p = 0.039), following cycling exercise. The stride length decreased (-2.6%, p = 0.022), the foot landed closer to the body (-13.0%, p = 0.023), and the vertical oscillation of the CoM (-3.7%, p = 0.049) and the flight time (-2.2%, p = 0.007) reduced following cycling exercise. These adaptations following cycling were not expected and were similar to running profiles observed during and running when not fatigued and 'economical' situations. For example, the ability to maintain horizontal velocity and place the supporting leg close to the vertical projection of the centre of mass has been shown to be optimal for performance. This reduces the speed lost during the braking phase of the stride upon foot contact with the ground (Elliott & Roberts, 1980; Moore, 2016), and is typical of a 'pose-style' running method (Dallam et al., 2005; Moore, 2016). Furthermore, a more extended knee during both the support and swing phases (i.e. a smaller knee range of motion), have been associated with a lower energy cost in non-fatigued running studies (Folland et al., 2017; Sinclair, Taylor, Edmundson, Brooks & Hobbs, 2013). To increase knee stability during the ground contact phase, the knee remains more extended to produce isometric contractions and increase leg stiffness (Folland et al., 2017; Williams, Snow & Agruss, 1991). In addition, the ability to reduce the vertical oscillation of the CoM has been associated with more economical running technique (Cavagna, Mantovani, Willems & Musch, 1997; Moore, 2016; Williams & Cavanagh, 1987). It is interesting to find that the participants of the current study utilised more economical movement strategies similar to that found in non-fatigued running conditions. Therefore, it can be suggested that the triathletes attempted to maintain movement economy by reducing the braking forces during landing or by increasing the lower limb stiffness and stability during the stance phase, or a possible combination of both.

However, it should be noted that discrepancy exists between the changes of some biomechanical variables deemed as 'economical' running movement patterns. For

example, although a smaller range of motion of the knee during the swing phase of a running stride has been associated with better economy and performance (Folland et al., 2017; Sinclair et al., 2013), it can be more beneficial to increase the knee flexion during the swing phase, in order to reduce the moment of inertia about the hip joint. This can reduce the magnitude of the hip flexor torques required to move the leg through the swing phase and maintain angular velocity of the lower limb, reducing the metabolic work performed (Elliott & Roberts, 1980; Williams et al., 1991). Although no significant differences were observed for the hip or ankle joint following cycling in the present study, it is possible that the moment of inertia and torque at the hip joint increased as a result of a more extended knee angle moving through the swing phase. As the ankle and knee extension power production reduced, the proximal musculature of the hip was responsible for the power generation to maintain a constant running velocity. Evidently, the triathletes demonstrated a trend to increase their maximal hip joint flexion power production (+2.9%, p = 0.178) without a concomitant increase in the hip extension at toe-off, resulting in an insufficient force transfer to increase or maintain the pre-cycling running velocity.

Regardless that the exact mechanisms responsible for the alterations in a number of running biomechanical variables following cycling are not clear, it is important that the self-selected movement patterns chosen, minimise, the energy cost (De Ruiter et al., 2014; Williams & Cavanagh, 1987). In general overview of the group of triathletes in the study cohort, it can be interpreted that by altering the running mechanics following cycling exercise, an attempt was made to self-optimise their movement strategies by adopting a more economical running technique. This is further evident through retrospective analysis indicating that the triathletes, whose running economy was *improved* following cycling, tended to adopt a strategy to alter their mechanics after a cycling bout to a more economical running technique. However, it should be noted that no significant changes were observed between the triathletes whose running economy was *improved* or *impaired* following cycling, due to the large inter-individual variability. Nevertheless, this study demonstrated that self-optimisation can continue to function when a running bout is preceded by a repetitive cycling locomotor task. It can be advantageous to performance to change aspects of running mechanics when it results in a runner using less energy at a given speed,

and triathletes may therefore be capable of adjusting their stride patterns towards more favourable outcomes to maintain running economy.

Although a number of biomechanical factors have been identified to influence movement economy, complex and controversial relationships exist with large individual differences observed between athletes both in fatigued and non-fatigued running situations (Tartaruga et al., 2012; Williams & Cavanagh, 1987). Since a large number of biomechanical predictors have been identified, it is not clear which of these variables and to what extent they correlate best with running economy. Folland and colleauges (2017) identified a combination of biomechanical variables (the vertical oscillation of the pelvis, knee extension angle during ground contact, and the horizontal pelvic velocity) to explain 39% of the variability in energy cost during normal, non-fatigued running conditions. Findings of Bonacci and colleagues (2010) indicated that a group of variables (knee angle at foot contact, ankle angle at foot contact, total excursion of the knee motion and minimum excursion of the knee) were related to running economy (R^2 = 77.5%) following a 45-min cycling bout. Results of the present study suggested that together, flight time, lateral pelvic drop and the knee flexion angle during the support phase, contributed significantly to the linear regression model (p = 0.034) and explained 50% of variance of the changes in running aerobic energy cost. It should be noted majority of the aforementioned studies investigating running following cycling exercise, involve two-dimensional motion analysis to measure sagittal plane joint kinematics only. As a result, the lateral pelvic flexion (or ‘pelvic drop’) is not a commonly measured variable in the triathlon literature, making it difficult to compare our findings. Due to large differences between runners and the inconsistency in identifying particular biomechanical parameters that are related to an ‘optimal’, economical running technique (whether in fatigued, non-fatigued, or in a triathlon- related situation), a clear conclusion of a single-best running technique is not conclusive from these results.

Furthermore, care should be taken when considering the current results as the underestimation of the true energy cost of locomotion was likely due to the lack of calculating the anaerobic energy contribution. It is typically inferred that when running at a submaximal intensity, at a physiological steady state (as observed in this study and majority of triathlon studies in the literature), the measurement of oxygen

consumption can account for the total rate of energy release (Fletcher, Esau & MacIntosh, 2009; Svedahl & MacIntosh, 2003). As a result, the rate of oxygen consumption, oxygen cost and aerobic energy cost is mostly used as measures of running economy within the triathlon literature. However, it is known that the total energy cost of running at a given speed dependents not only on aerobic metabolism, but reflects the sum of both aerobic and anaerobic metabolism (Di Prampero et al., 1993). Therefore, the contribution of anaerobic energy sources to the total energy cost estimation is largely unknown. It is recommended that future research investigating the influence of a prior locomotor task on a subsequent task, include the calculation of anaerobic energy cost to estimate the true energy cost.

In conclusion, the biomechanics of subsequent running locomotion are affected by the repetitive movement patterns of a prior cycling exercise likely due to both fatigue and a movement pattern interference effect. Moreover, triathletes demonstrated a trend to self-optimised their kinematics in an attempt to maintain movement economy following cycling. This can be illustrated by the athletes who performed better economically following the cycling exercise, as they demonstrated an overall greater change (however, not statistically significant) in most of the biomechanical parameters analysed. This is in contrast to previous research suggesting that the ability to minimise the deleterious effects of cycling, and maintain pre-cycle running mechanics is essential to the mechanical efficiency and running performance. It is still not clear whether particular biomechanical parameters are related to the optimal economical running technique as large inter-individual differences were present. Therefore, care should be taken to assume a single approach to identifying an economical running technique especially following fatiguing cycling exercise as each athlete is unique in terms of their abilities, training, nutritional status and anatomical structure, which affects their biomechanics.

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CHAPTER FOUR - GENERAL DISCUSSION

4.1 GENERAL DISCUSSION

When a movement task is immediately followed by another movement task, the performance of the latter task is typically found to be negatively influenced. It is important to investigate and understand the influence of an initial task on a subsequent task's movement economy and technique, particularly when fatigue and movement pattern interference of the prior task, are likely. Research into this would be applicable to a wide range of activities and subject populations, and triathlon provides a particularly good model for testing this, since different locomotor tasks are performed consecutively (i.e. swimming, cycling and running). Findings of this research would benefit athletes, coaches and sport scientists from a performance-enhancement perspective, and also from an injury prevention perspective, as the body may be placed in a potential position susceptible to injury when consecutive tasks are performed.

The research in this thesis aimed to examine the influence of a prior movement task (e.g. cycling) on the economy and mechanics of a subsequent movement task (e.g. running) and used triathlon as a model for this, where similar lower limb musculature are active during the repetitive cyclic actions. A majority of the research in this area concludes that a triathlete's ability to limit the negative influence of cycling on subsequent running economy is important for running performance, and also overall triathlon performance success. Similarly, the ability to maintain pre-cycle running mechanics has been reported to be essential to the mechanical efficiency and running performance. However, not all findings are in agreement that running economy and mechanics are altered following cycling exercise, compared to running without prior cycling. Large individual differences are also observed between runners during such fatiguing situations experienced in triathlon, but it is unknown whether specific biomechanical parameters are associated with an 'optimal' economical running technique. Therefore, two research studies were conducted in this thesis with the underlying focus of describing and better understanding the influence of a prior rhythmic cycle bout on the economy, perceptual responses and mechanics of running in trained male triathletes. An additional aim of the thesis was to examine the magnitude of the relationship between the differences in running economy and

mechanics when performed before and after cycling. This was done to enable sport scientists, coaches and athletes to identify particular biomechanical factors that influence performance (i.e. running economy).

The major findings of this thesis were that i) measures of physiological and perceptual descriptors (perception of exertion and effort), as well as running mechanical variables (i.e. stride parameters, lower body joint kinematics and maximal joint power production during the stride), were significantly impaired ($p < 0.05$) following 60 min of cycling; ii) both peripheral and central fatigue during the cycling bout likely contributed to these impairments as indicated by similar increases ($p = 0.784$) in ratings of physical exertion and psychological effort; iii) perseveration also likely contributed to these impairments and can be indicated by the deviations of the preferred (i.e. pre-cycling) movement patterns following cycling which may reduce locomotion economy by increasing the energy expenditure, iv) changes in a group of biomechanical variables (flight time, knee flexion angle during the support phase and lateral pelvic drop) were significantly related to the changes in aerobic energy cost, yet these were different to other research findings and indicates that a single economical running technique is not applicable to all, v) 35% of the study cohort demonstrated a decrease in running aerobic energy cost (i.e. *improved* subgroup), and demonstrated a trend ($p > 0.05$) towards lower increases in all physiological measures and perceptual descriptors, yet interestingly, they also changed their mechanics to a greater extent when compared to the *impaired* subgroup (i.e. who increased their aerobic energy cost) during running following cycling, yet vi) different conclusions may be drawn regarding the influence of prior cycling on subsequent running depending on the calculation method of economy and therefore it is suggested that aerobic energy cost should be calculated as a more precise measure as it accounts for measures of energy substrate utilisation.

As outlined in Chapter Two, the first study sought to investigate the differences in physiological (e.g. heart and ventilation rates) and perceptual descriptors (perceived exertion and effort) during running following cycling, when compared to running without prior cycling. Additionally the aims of this study were to determine if distinguishing between perception of exertion or effort indicates whether fatigue generated by the cycling bout is caused predominantly from peripheral or central mechanisms, and also to assess the agreement between the three typically used

calculation methods of running economy (i.e. rate of oxygen consumption ($\dot{V}O_2$) versus oxygen cost versus aerobic energy cost). Running was performed on a treadmill for 10 min at a constant and self-selected, sub-maximal speed to simulate race pace conditions, before and after an Olympic-distance triathlon simulated cycle bout.

The results of Study One confirmed a detrimental influence of cycling exercise on the measures physiological parameters, as well as the perceptual responses of subsequent running. As ratings of perceived exertion and effort are typically used as psychophysiological stress indicators, an increase in both parameters following cycling exercise, suggested that fatigue was generated from alterations in both peripheral and central neuromuscular mechanisms. These result also indicated that different information can be obtained from both perceptual descriptors and that future studies are required to confirm this and to assess the anticipatory influence of cycling on the pacing strategies of subsequent running. The three methods of calculating running economy provided a good level of agreement, however differences between the methods could partly explain the differences in the literature regarding the influence of cycling on subsequent running. For example, the number of participants whose running economy was shown to decrease after cycling differed depending on which calculation method was used (i.e. 14, 15 and 11 for $\dot{V}O_2$, oxygen cost and aerobic energy cost, respectively). It is also important to note that fat oxidation requires more oxygen to produce the same quantity of adenosine triphosphate compared to carbohydrate and since an increase in lipid utilisation as metabolic substrate ($p < 0.001$) was identified following cycling, it appears to offset the greater oxygen required following cycling. Calculating the $\dot{V}O_2$ and oxygen cost does not account for substrate utilisation however the calculation of aerobic energy cost does, which emphasises the requirement to calculate the true energy cost when investigating the influence of cycling on subsequent running. These results also emphasised the necessity to investigate individual athletes, as averaging group-only results neglects to identify those that are better able to expend energy following cycling exercise.

As outlined in Chapter Three, the purpose of the second study was to determine whether high-intensity cycling influences subsequent running mechanics, and whether these changes were associated with alterations in running economy in

competitive male triathletes. Additionally, the differences between the running biomechanical profiles of those who used less aerobic energy (35%, identified in Chapter Two, Study One) following cycling exercise were compared to those who used more energy aerobically (65%). Running was performed overground for 1.2 km at a constant and self-selected sub-maximal speed to simulate race pace conditions, before and after an Olympic-distance triathlon simulated cycle bout.

The results of Study Two indicated that the biomechanics of subsequent running were affected by a prior cycling exercise, likely due to both fatigue and movement pattern interference. Significant ($p < 0.05$) decreases in stride parameters, and lower body kinematics and joint power production of mainly the knee joint were observed following cycling, compared to when running was performed without prior cycling. It should be noted that these differences in joint angles were small in magnitude ($< 3^{\circ}$) and variable amongst individuals. Other measured parameters of the ankle, hip, pelvis and trunk remained unchanged. Nevertheless, these observed changes in running mechanics replicated running profiles which are typically associated with economical running techniques, suggesting that triathletes either self-optimised their kinematics in an attempt to maintain movement economy following cycling, or as an effective pacing strategy to decrease their running velocity. Furthermore, those athletes who performed better economically following the cycling exercise (i.e. the *improved* subgroup), demonstrated a trend ($p > 0.05$) towards changing most of the biomechanical parameters analysed. This is in contrast to previous research which suggests that maintaining pre-cycling running mechanics are essential to the mechanical efficiency of running, and overall running performance. It is also unknown whether specific biomechanical parameters are related to the 'optimal' economical running technique as large individual differences existed between runners and also between this study and other findings in the current literature. Therefore, care should be taken to assume a single approach to identifying an economical running technique, especially following fatiguing cycling exercise, as each athlete is unique in terms of their physiology and biomechanical structure.

Collectively, these findings indicated that a prior locomotor task (i.e. cycling exercise) influenced the economy, perceptual descriptors and mechanics within the first few minutes of a subsequent locomotor task (i.e. running). It is likely that these alterations were at least partly due to movement pattern interference and both

peripheral and central fatigue generated through the 60-min cycling exercise. In agreement with other findings in the literature, a group of biomechanical variables were closely related with the changes in running economy (50%, $p = 0.03$). However, due to the inconsistency in identifying particular biomechanical parameters that are related to an 'optimal', economical running technique and to large differences between runners, a clear conclusion of a single-best running technique is not conclusive from these results. It can be interpreted that by altering the running mechanics following cycling exercise, an attempt was made to self-optimise their movement strategies by adopting a more 'economical' running technique. Furthermore, the triathletes who demonstrated an ability to run with a lower energy cost following cycling, also demonstrated a trend towards lower increases in all physiological and perceptual parameters measured, yet interestingly they tended to alter their mechanics to a greater extent following cycling. As a result, maintaining pre-cycling running mechanics, as previously thought, might not be a main objective for triathlon running performance. It can be advantageous to performance to change aspects of running mechanics when it results in a runner using less energy at a given speed and maintaining or improving running economy. It is therefore suggested that athletes attempt to self-optimise their movement patterns following prior tasks, such as cycling, that may cause fatigue or perseveration. However, it is not yet clear why some runners are better able to self-optimise compared to others, at least in the relatively homogenous cohort who participated in the present study. It is nevertheless recommended that coaches and sport scientists include cycling exercise before running performance testing procedures, as opposed to single-disciplined ergometer testing from a fresh start to assess running performance in a more competition-like environment and to assess specific training adaptations on individual athletes.

CHAPTER FIVE - LIMITATIONS, DELIMITATIONS AND FUTURE RESEARCH RECOMMENDATIONS

5.1 LIMITATIONS AND DELIMITATIONS

Methodological limitations of the study need to be considered. Firstly, data of Study One and Study Two were collected on separate days. Running economy, used as a performance indicator, was measured when running on a treadmill at a constant velocity during one session, whereas running mechanics were collected when running overground during a separate session. Albeit attempts made to replicate the energetic cost of overground running by increasing the treadmill gradient to 1%, introducing a light fan at the front of the treadmill to circulate air around the subjects (Jones & Doust, 1996), and controlling running velocity to minimise kinematic variability during treadmill and overground running; biomechanical data was not collected during treadmill running. Therefore we cannot quantify or completely eliminate the day-to-day variation between the separate sessions, and neither can we conclude with certainty that there were no differences between treadmill and overground running technique. Furthermore, the kinematics of the full 10-km run (when running overground in Chapter Three, Study Two) were not analysed, and consequently we are unable to infer if the reduced running velocity following cycling was as a result of cycling fatigue or due to the pacing strategies used by triathletes following cycling. It is also acknowledged that running at a constant velocity does not replicate competition conditions where pacing strategies play a large role.

Secondly, the intensity of the cycling bout is worth considering as individual metabolic responses and fatigue would be affected depending on the demands of certain cycle protocols and power output variations (Suriano, Vercruyssen, Bishop & Brisswalter, 2007). The mean power output observed in the cycling component of elite races such as that observed during World Cup and Olympic events, is typically measured at 61-65% maximal aerobic power (MAP) for males where the distribution ranges can vary between 20-130% MAP (Bernard et al., 2009; Le Meur et al., 2009). This can induce greater physiological demands and metabolic cost when compared to even-paced trials (or time trials) employed in the laboratory conditions. Much narrower cycling power distributions (± 15% of the constant power trial) can be observed in these conditions that rarely exceeds 100% of the MAP intensity (Lepers,

Theurel, Hausswirth & Bernard, 2008; Suriano et al., 2007). The cycle exercise employed in the current study was performed at a mean power output of 61% MAP (adapted from Etxebarria, Hunt, Ingham & Ferguson, 2014) and was representative of a 40-km cycling component of age-group triathletes participating in a World Cup race (Bentley, Millet, Vleck & McNaughton, 2002; Tew, 2005). However, it is likely that the range of power output distributions exceeded the subject cohort's typical training and racing intensity. Therefore, care must be taken when interpreting the findings of the current study as greater physiological demands and metabolic cost could have been induced by the high intensity cycle protocol. Three-dimensional motion mechanics produced during road cycling in competition, may also be different to that encountered during stationary cycling as performed in the current study, and as a result the kinematic movement patterns may differ in competition when compared to laboratory testing.

Thirdly, it is important to consider that the accuracy of true energy cost estimates rely on the measurements being obtained not only from aerobic metabolism, but reflects the sum of both aerobic and anaerobic metabolism. Unfortunately the current study did not include the measurement of blood lactate analysis, and as a result, the relative anaerobic contribution of the total energy cost was not included (Di Prampero et al., 1993). Instead, only aerobic energy cost could be calculated during the running conditions. In addition, a maximal running test to exhaustion was not performed to measure the maximal oxygen consumption ($\dot{V}O_{2max}$) and establish relative physiological thresholds during the running conditions. Nevertheless, since a physiological steady-state was established (according to criteria of (Fletcher, Esau & MacIntosh, 2009; Saunders, Pyne, Telford & Hawley, 2004)) during the submaximal running conditions before and after cycling, it was assumed that the running velocity was slower than the speed at lactate threshold (i.e. assuming that the arterial blood lactate concentration was constant). Therefore, as the $\dot{V}O_2$ reflects the quantity of adenosine triphosphate turnover during physiological steady-state running, the measurement of aerobic energy cost could account for the total rate of energy release (Fletcher et al., 2009; Shaw, Ingham & Folland, 2014; Svedahl & MacIntosh, 2003). Consequently, aerobic energy cost was calculated in this dissertation as an estimation of the total energy cost of the system during running. However, care should be taken when considering the current results, and also that of the current

literature, as the underestimation of the energy cost of locomotion is likely due to the lack of calculating the anaerobic energy contribution.

5.2 FUTURE RESEARCH RECOMMENDATIONS

Several interesting findings arose from the dissertation, and together with the review of the literature, potential areas for future research opportunities are recommended. It is recommended to measure the energetics (i.e. both the energy intake and output) of running following cycling during the same testing session. This is needed to eliminate any systematic error involved between running overground and running on a treadmill, which is typically performed separately. This is due to experimental limitations of measuring both three-dimensional mechanics and measures of running economy simultaneously, and is therefore also typically performed on separate days in order to minimise fatigue.

Further research could investigate the duration of movement pattern alteration during a full 10-km run following cycling, to include the assessment of pacing strategies as a possible means to conserve energy. For example, triathletes may initially commence the running component with a lower velocity due to the fatigue or movement pattern interference of the cycling excise, yet they may adjust their speed throughout the run once they reach a point in the run where the rhythm is more consistent. Consequently, this could impose greater physical demands later in the run as an increasing running velocity will be required to reach the same overall time when compared to non-fatigued running. Moreover, by measuring the ratings of perceived exertion and effort during the cycle exercise and also during the full 10-km run, essential information can be obtained regarding the anticipatory influence of cycling on subsequent running, and also on the pacing strategies and how it changes during running. This will aid in further understanding the influence of cycling exercise on the physical sensations and the central or psychological effort of the entire running component following a cycling bout. Additionally, recording the velocity profile and the total time for the 10-km run without and with a preceding cycle will provide measures of the effect of the cycle on overall run performance.

There is also a requirement to not only calculate the aerobic energy cost (as majority of studies calculate $\dot{V}O_2$ or oxygen cost), but also to include the anaerobic energy

cost in order to assess the total energy cost of running. It was demonstrated that 6 participants in the current study cohort ran with an *improved* economy, i.e. utilised less energy aerobically following cycling. These athletes also tended to change their mechanics to a greater extent following cycling compared to others who utilised more energy aerobically. However, as the athletes' anaerobic contribution was not known, it cannot be concluded with absolute certainly that the *improved* subgroup enhanced their *total* energy cost following cycling. Nor can it be concluded with absolute certainly that changing technique following is the desired outcome to maintain running economy, as the true energy cost was not calculated. Therefore, future studies are required to investigate the anaerobic component and calculate the total energy cost to examine with more specificity, the overall influence of a cycling bout on subsequent running economy.

Furthermore, a comprehensive investigation of the running gait is essential in order to understand the effect of preceding cycling locomotion on the efficiency (i.e. the total amount of work and the true energy cost) of subsequent running. This includes the assessment of more specific kinetic analysis with a particular focus on computing the total (i.e. external and internal) mechanical work of running, where the external work is the work performed to sustain the movement of the centre of mass relative to the ground; and the internal work is the work performed moving the limbs relative to the body's centre of mass. Together with calculating the total energy cost, measuring the internal and external work will allow the computation of running efficiency during overground running, and will allow much greater insight of how efficiency differs and how triathletes adapt their locomotor movement patterns following cycling exercise. Moreover, the examination of the external force transfer during the running gait and the landing and take-off symmetry (the applied force and time during initial foot landing vs. the applied force and time during the foot push-off) of a running stride has not been conducted to the author's knowledge, and requires further investigation. This is important to provide better understanding on the optimal way to apply force for improved running performance. These recommendations will add to the knowledge of the effects of a preceding task on a following task and also provide knowledge and practical applications on optimal strategies and techniques to improve triathlon running performances.

The scope of the current thesis applied to triathlon running performance, yet it is unknown whether these findings can translate to other sports or clinical settings. For example future research may examine the influence of prior locomotor tasks on the efficiency of subsequent tasks with a particular focus on the aging or physically disabled population groups.

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CHAPTER SIX - APPENDICES

APPENDIX INDEX

APPENDIX A ETHICS APPROVAL

Dear Chantelle

Project Number: 12035 DU PLESSIS
Project Name: Influence of a simulated Olympic distance cycle on subsequent running biomechanics and running economy in triathletes

Chief Investigator: Chantelle DU PLESSIS
Supervisors:
- Jodie Wilkie
- Anthony Blazevich
- Chris Abbiss

Ethics approval for your research project was granted from 16 December 2014 to 31 October 2016.

The *National Statement on Ethical Conduct in Human Research* requires that all approved projects are subject to monitoring conditions. This includes completion of an annual report (for projects longer than one year) and completion of a final report at the completion of the project.

A **FINAL REPORT** is due on **31 October 2016**.

A copy of the ethics report form can be found on the Ethics Website

Please complete the ethics report form and return the signed form to the Research Ethics Office. For further information, please contact the Research Ethics Office, email: research.ethics@ecu.edu.au

Ethics approval is required for both the collection and use (analysis) of identifiable data. If no further contact with participants is required and all data have been made non-identifiable, a Final Report can be submitted. Non-identifiable data may be used for write-up and/or publication without requiring further ethics approval.

If the project is still continuing, please complete the form and apply for an extension of ethics approval.

APPENDIX B INFORMED CONSENT

INFORMED CONSENT DOCUMENT

Influence of a simulated Olympic distance cycle on subsequent running biomechanics and running economy in triathletes

Researchers and Contact details

Name	Miss Chantelle du Plessis	Dr. Jodie Wilkie	A/Prof. Tony Blazevich	Dr. Chris Abbiss
Email	c.duplessis@ecu.edu.au	j.wilkie@ecu.edu.au	a.blazevich@ecu.edu.au	c.abbiss@ecu.edu.au
Phone	[redacted]	6304-5860	6304-5472	6304-5740

Statement confirming 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 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:
  - Three lab sessions with at least 48 hours between sessions.
  - Various cycling and running testing within each session.
  - An incremental cycling test until voluntary exhaustion
    - Where measurements of heart rate, expired gases (oxygen consumption) and perceived exertion will be taken.
  - Cycling for a period of 60 min, completing a high intensity and variable power output protocol
  - Run on a treadmill.
    - Where measurements of heart rate, expired gases (oxygen consumption) and perceived exertion will be taken.
  - Run over ground in a laboratory.
    - Where measurements of 3-dimentional motion and force output, and running velocity measures will be taken.
    - Where 39 reflective markers will be placed on the skin.
  - Wearing cycling shorts.
  - Filling out a medical questionnaire before participation commencement.
  - Providing a training and dietary diary 24 h prior to the testing commencement.
  - Recording and replicating my nutrition and training sessions as closely as possible before each test.
  - Limiting my training session to 1 h and intensity to 'somewhat hard' (a sessional rating of perceived exertion score below 13), 24 h prior to the testing session
  - Providing my own racing bicycle (for the first testing session) as well as my own pedals, cleats, cycling and running shoes for each testing session
- I understand that my information provided will be kept confidential, and that my identity will not be

disclosed without consent

- I understand that the information provided will only be used for the purposes of this research project, and I understand how the information is to be used
- 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

Participant **Signature** **Date**

____

Signed by member of research team **Date**

____

APPENDIX C INFORMATION LETTER

INFORMATION LETTER FOR PARTICIPANTS

Influence of a simulated Olympic distance cycle on subsequent running biomechanics and running economy in triathletes

Chief investigator: Chantelle du Plessis
School of Exercise, Biomedical and Health Sciences
Edith Cowan University
270 Joondalup Drive, Joondalup WA 6027
Phone: [redacted] *Email:* c.duplessis@ecu.edu.au

Thank you for expressing interest in this study. This document provides you with information on the study that you may participate in. Please read all the information carefully, and please feel welcome to contact the investigators if you have any questions or concerns you wish to raise.

Purpose of the Study

The aim of the proposed research is to examine the effect of the cycle component on the running component in triathlon. We will assess the running economy and running technique following cycling and compare this to running without prior cycling to understand how cycling affect these. Understanding running economy is very important as it is the ability to run with good form in which you expend minimum energy and reduce or limit fatigue. The aim of this study is to identify if athletes change their technique in a certain way after cycling, particularly those whose running economy is affected more. This may provide us with valuable information on running techniques which are more ideal to reduce energy expenditure and fatigue in the initial part of the run and improve an athlete’s overall performance.

Background

Triathlon success is largely dependent on an athlete’s ability to run efficiently following the cycle, particularly in an Olympic distance event. However, the cycle component that is performed prior to the run, may affect the running performance adversely, especially the initial part of the run. Some researchers have shown that the cycle affects the runner’s technique, when compared to running where a cycle exercise is not performed prior to it. Yet other studies have shown that the triathlete's technique is not altered under similar circumstances, but that the time to complete the run (and also the speed of the run) is still slower compared to a run where cycling is not performed prior to it. This research study therefore strives to investigate the changes in running economy (or the energy expenditure) and running biomechanics (or technique) using comprehensive biomechanical analysis before and after a prolonged cycling exercise. Valuable information will be obtained to identify whether there are specific changes in the runner’s technique after the cycle protocol, causing the triathlete to exert more energy. Identifying these aspects will allow us to potentially improve the triathlete’s running performance. Since the running component is essential to overall finishing position, improvement in running performance may lead to greater success in overall triathlon performance.

Description of the Study

This study consists of three laboratory testing sessions separated by at least 48 h, with each lasting approximately 3 h. Testing will be conducted at the Biomechanics laboratory of Edith Cowan University (ECU), Joondalup. The testing sessions will be supervised and will comprise of a Baseline, Biomechanics and Physiology testing session. In the first testing session (Baseline testing) you will undergo a DXA scan (see details below) which is located at the Vario clinic at ECU. Several measurements will be taken and you will be required to fill in necessary forms (including pre-exercise medical questionnaires, food diary and training history) prior to testing commencement. You will also perform an incremental cycle test to exhaustion (VO_{2max}) on an ergometer. Several measurements will be taken before, during and after exercise that includes measurements of heart rate, expired gases (oxygen consumption) and perceived exertion. Following a sufficient rest period, you will undergo a 60-min cycle protocol that is based on a protocol that simulates an Olympic distance cycle component on a stationary cycle ergometer. Thereafter, you will perform a run inside the Biomechanics laboratory and running velocity will be measured. The next two testing sessions, i.e. the Biomechanics and Physiology testing, will be randomized. During the Biomechanics testing session, you will run before and after the 60-min cycle protocol during which a number of biomechanical variables (i.e. your running technique) will be measured via 3-dimentional motion analysis and force platforms. This will be done to compare the possible adverse effects of the cycle on the running technique. During the Physiology testing session, you will run before and after the 60-min cycle protocol, but this will be done on a treadmill during which your running economy will be measured and for comparison purposes.

Table 1. Experimental procedures used in each testing session

TESTING SESSION	EXPERIMENTAL PROTOCOL						
Baseline testing session	Anthropometric measurements Questionaries DXA and full body 3-D scans	Warm-up	VO_{2max} test	Rest 30 min	60-min cycle protocol	Change into running shoes	Post-cycle run
Physiology testing session		Warm-up	Pre-cycle treadmill run	Rest 30 min	60-min cycle protocol	Change into running shoes	Post-cycle treadmill run
Biomechanics testing session	Retro-reflective marker placement according to 3-D motion analysis model	Warm-up	Pre-cycle overground run	Rest 30 min	60-min cycle protocol	Change into running shoes	Post-cycle overground run

Baseline testing session (3 h)

DXA scan: Your body composition will be measured using dual energy X-ray absorptiometry (DXA). This procedure is the gold standard or measuring body composition. You will be required to wear

clothing free of metallic material and will assume a supine position (lying on your back) with your arms by your side. This will provide an accurate measurement of your total mass, muscle mass, fat mass and bone mineral density of your entire body. This information will also be used to calculate the centre of mass of each limb required for calculations of the energy you exert and the work you do when you run by swinging your arms and legs. The radiation experienced during this procedure will be for a short duration only (2 min) and is insignificant (0.2-0.37µSv) when compared with daily natural background radiation levels (10µSv).

VO_{2max} test: You will then proceed to complete the cycle test to exhaustion (VO_{2max} test). The cycle ergometer will be adjusted to replicate your seat and handlebar position. Therefore, we require you to bring **your race bicycle for this session**. You will be using your **own pedals, cleats and cycling and running shoes** in all the testing sessions. You will start cycling at a comfortable 125 W for 10 min. The workload will be increased to 160 W and will be increased by 5 W every 15 s 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 which usually lasts 10-15 min. Throughout the test, a mouthpiece will be in place to monitor respiratory oxygen and carbon dioxide content to determine your individual maximal aerobic capacity and power output.

Cycle and run protocol: Following a rest period of 30 min, you will perform a high and variable intensity cycle protocol for 60 min. This protocol is based on 65% of your peak power output and is based on a previously validated protocol by Etxebarria et al. (2013) that simulates a 40-km cycle of an Olympic distance triathlon event. Your perceived exertion and effort scores will be recorded at the conclusion of the cycle protocol. Following the cycle, you will have 60 s to change into your running shoes and commence a run in the Biomechanics laboratory during which your running velocity will be measured using timing gates.

Biomechanics testing session (3 h)

During this session you, retro-reflective markers will be fixed on your skin on specific bony landmarks with fixumull and double-sided tape. You will then be required to complete a 10-min self-selected warm up followed by a run in the Biomechanics laboratory where your running velocity, 3-D motion analysis and force platform data will be collected. After 30 min of rest, you will complete the 60-min cycle protocol. Rating of perceived exertion and perception of effort will be obtained immediately at the conclusion of the cycle exercise. Within 60 s you will run over ground where your running velocity, 3-D motion analysis and force platform data will be collected. This run is performed following the fatiguing cycle to compare the possible changes in technique of the run after to the run before the cycle protocol.

Physiology testing session (3 h)

During this session you will replicate the same warm-up performed during the Biomechanics testing session. You will then run for 4-10 min on a treadmill until a steady state oxygen consumption level is achieved. Running economy will be calculated during this run to assess the energy expenditure when cycling is not performed prior to running. After 30 min of rest, you will complete the 60-min cycle protocol. Rating of perceived exertion and perception of effort will be obtained immediately at the conclusion of the cycle exercise. Within 60 s you will run for 4-10 min on the treadmill to record running economy to compare the energy expenditure of the run following the cycle to the run before

the cycle protocol was performed. This is done to assess the effect of the cycle exercise on the running performance.

Requirements

Please bring with you to the testing session your racing bicycle (only for the first session), your own pedals, cleats, cycling and running shoes and cycling shorts. You will be required to complete the testing sessions as explained above. To participate in this study it is required that you are male, between the ages of 18-45, free from any injury or illness, competed in triathlons for at least 2 years and have completed at least 2 Olympic distance triathlons in the last year. You will be asked to maintain your normal dietary practices (including caffeine) as closely as possible throughout the duration of the testing, particularly 24 h prior to testing. Twenty four hours prior to the testing sessions you should; avoid alcohol, record your dietary intake, limit your training duration to 1 h and limit the training intensity to somewhat hard (13 on the Borg scale). You will be allowed to undertake normal training throughout the testing duration, except for the limitation 24 h prior to testing. You will also be asked to outline your training and competition history for the past 2 years, which includes describing your training sessions for the past 2 weeks prior to the start of 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 and injury free at the time of testing. All testing sessions will be supervised by First Aid/CPR qualified personnel. Safety procedures for physical exercise testing will be followed as previously conducted in our laboratory. You will also undergo a safety induction of the lab prior to testing commencement.

DXA scans emit radiation when performed. This will expose you to a very low-level of radiation. It is important to understand that DXA scanning is routinely performed in the clinical settings and produces exceedingly low levels of radiation dosages (1-6 μSv) and for a short period of time (2 min) per scan. Compared to the annual radiation what Western communities are typically exposed to (public is allowed 1000 mSv per year), the radiation obtained from a DXA scan is exceptionally low.

Potential benefits

As a participant of this study, you will gain insight into the comprehensive research process involved in sport science. You will be provided with valuable information regarding your maximal oxygen uptake readings, your running economy and also variable aspects of your running technique that will be collected and analysed using 3-D analysis systems. You will be able to use this information for your individual training purposes.

Results from the research study

The data collected in this study will be coded and de-identified, which means that your personal information cannot be identified. The data will be presented at conferences and as a scientific report to be published in an academic journal. Upon your request, you will receive a summary of your own personal information and a group summary explaining the findings of the study.

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, and will be stored electronically for a period of 5 years on a password protected hard drive and locked in a cabinet. It will subsequently be destroyed at the end of this period.

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.

Name	Miss Chantelle du Plessis	Dr. Jodie Wilkie	A/Prof. Tony Blazevich	Dr. Chris Abbiss
Email	c.duplessis@ecu.edu.au	j.wilkie@ecu.edu.au	a.blazevich@ecu.edu.au	c.abbiss@ecu.edu.au
Phone	[redacted]	6304-5860	6304-5472	6304-5740

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

APPENDIX D MEDICAL QUESTIONNAIRE

MEDICAL QUESTIONNAIRE

EDITH COWAN UNIVERSITY
School of Exercise and Health Science

Influence of a simulated Olympic distance cycle on subsequent running biomechanics and running economy in triathletes

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.

Name: **Age:** **yr** **Weight:** **kg** **Height:** **cm**

Briefly describe the type and amount of exercise you do.

Type:

____

____

____

Amount:

____

____

Do you smoke? YES NO

Have you smoked in the past? YES NO

Have you ever been diagnosed with:

Being overweight? YES NO

High blood pressure? YES NO

High cholesterol levels? YES NO

Diabetes? YES NO

Any bleeding disorders? YES NO

Asthma? YES NO

Have you ever had a serious asthma attack during exercise or do you have asthma that requires medication? YES NO

If YES please give details

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____

Do you have any reason to believe that you are more at risk of cardiovascular disease than a normal member of the population of the same age and sex? YES NO

If YES please give details

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____

Have you ever had rheumatic fever? YES NO

If YES please give details

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____

Have you ever experienced heat exhaustion or heat stroke? YES NO

If YES please give details

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____

Is there anything that you are aware of that may limit your capacity to exercise? (e.g., Chronic back pain and/or other joint pain, severe headaches?) YES NO

If YES please give details

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Do you have any allergies? YES NO

If YES please give details

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____

Are you currently on any prescribed or non-prescribed medications? YES NO

If YES please give details

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____
____
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Have you suffered from any viral infections, chronic tiredness or donated blood in the past two months? YES NO

If YES please give details

____
____
____
____

Do you have any other complaint or any other reason that you know of which you think may prevent you from participating in and completing this experiment? YES NO

If YES please give details

____
____
____
____

I believe that the information that I have supplied is true and correct.

Print Name	**Signed**	**Date**

APPENDIX E TRAINING HISTORY

TRAINING HISTORY

Influence of a simulated Olympic distance cycle on subsequent running biomechanics and running economy in triathletes

Name:____ **Date:_____________________**

You will be required to outline your training and competition history for the past 2 years, and also provide a detailed description of your training schedule two weeks prior to the testing commencement.

1. Please outline your training history for the past 2 years below.

On average, how many kilometres did you swim, cycle and run per week?

Year	Swim	Cycle	Run
2012-2013			
2013-2014			

Comments:____
____
____
____

2. Please outline your competition history below.

How many Olympic distance triathlons have you attempted/ competed in?

____

How many Olympic distance triathlons have you completed?

____

How many Olympic distance triathlons have you completed in the last 2 years?

____

What was your fastest time of completion?

____

What year was your first Olympic distance triathlon race?

____

Have you competed in any other distance events, i.e. Sprint, Half-Iron man, or Full-Iron man?

If yes, please specify which and how many times

____
____
____

3. Please outline your weekly training schedule for each discipline from the last 2 weeks

Week	**Swim**		**Cycle**		**Run**	
	Hours	Kilometres	Hours	Kilometres	Hours	Kilometres
1						
2						

Comments____
____
____
____

4. Which is your strongest discipline (swim, cycle or run)? _______________________________
5. Please list other sports you have participated in and the level and length of time.

Sport	**Highest level (e.g. recreational, state representative, national representative)**	**Frequency of training and competition**	**When and length of time**

Name: ____

Signature: ________________________________ Date: ______________________________

24 HOUR FOOD RECALL

Influence of a simulated Olympic distance cycle on subsequent running biomechanics and running economy in triathletes

Name:____ **Date:**____________________

Please document your dietary intake for the last 24 hours. This includes food, beverages and supplementations.

You will be required to replicate this dietary intake as closely as possible in the 24 h leading up to every testing session

Breakfast

Food/ fluid intake	Amount	Time

Snack

Food/ fluid intake	Amount	Time

Lunch

Food/ fluid intake	Amount	Time

Snack

Food/ fluid intake	Amount	Time

Dinner

Food/ fluid intake	Amount	Time

Other snacks/ workout intake **particularly caffeine and supplementation*

Food/ fluid intake	Amount	Time

Comments:____
____
____
____
____
____

Please ensure that you have included the amount of caffeine and also other supplementations in this diary.

YOU WILL BE REQUIRED TO REPLICATE THIS DIETARY INTAKE AS CLOSELY AS POSSIBLE IN THE 24 H LEADING UP TO EVERY TESTING SESSION.

APPENDIX G FINAL CHECKLIST

FINAL CHECKLIST FOR PARTICIPANTS

EDITH COWAN UNIVERSITY
School of Exercise and Health Science

Influence of a simulated Olympic distance cycle on subsequent running biomechanics and running economy in triathletes

	Please circle one	
1. Are you aware that if you feel uncomfortable with any testing procedure you should tell the researcher immediately, and that YOU CAN STOP your participation at any time?	**YES**	**NO**
2. Are you aware that, although very rare, maximal exercise can result in fainting, severe exhaustion or cardiac events leading to death?	YES	NO
3. Are you aware that the fatigue caused by the exercise can impair your ability to perform tasks such as driving for a short while after the cessation of exercise?	YES	NO
4. Have you been given the opportunity to view the equipment/ photos outlining the maximal exercise testing techniques?	YES	NO
5. Are you aware that this study requires you to complete 3 testing sessions that includes an incremental test, and running before and after a high intensity 60-min cycle protocol?	YES	NO
6. Are you aware that you are required to bring in your own racing bike to the first session and pedals, cleats and running shoes for each testing session?	YES	NO
7. Are you aware that you need to wear your cycling shorts? You will be wearing minimal clothing for the testing sessions.	YES	NO
8. Are you aware that 3-D motion analysis will involve reflective markers being placed on many locations of the body?	YES	NO
9. Are you aware there will be video recordings taken for some of the testing session?	YES	NO
10. Are you aware that data and images recorded may be used in publications and presentations?	YES	NO
11. Are you aware that you will be asked to record your dietary intake 24 h prior to the testing commencement?	YES	NO

12. Are you aware that you will be asked to replicate this 24 h dietary intake as closely as possible prior to each testing session?	YES	NO
13. Are you aware that you will be asked to resume normal training 24 h prior to the testing commencement, but the session should be limited to an hour and the intensity to somewhat hard (13 on the Borg scale)?	YES	NO
14. Have you had food within 2 to 6 hours?	YES	NO

Name of volunteer:____

Signature of volunteer: ______________________________ Date: ___________

Name of witness: ____

Signature of witness: ________________________________ Date: ___________

Name of emergency contact 1:____

Contact Number: ____

Name of emergency contact 2:____

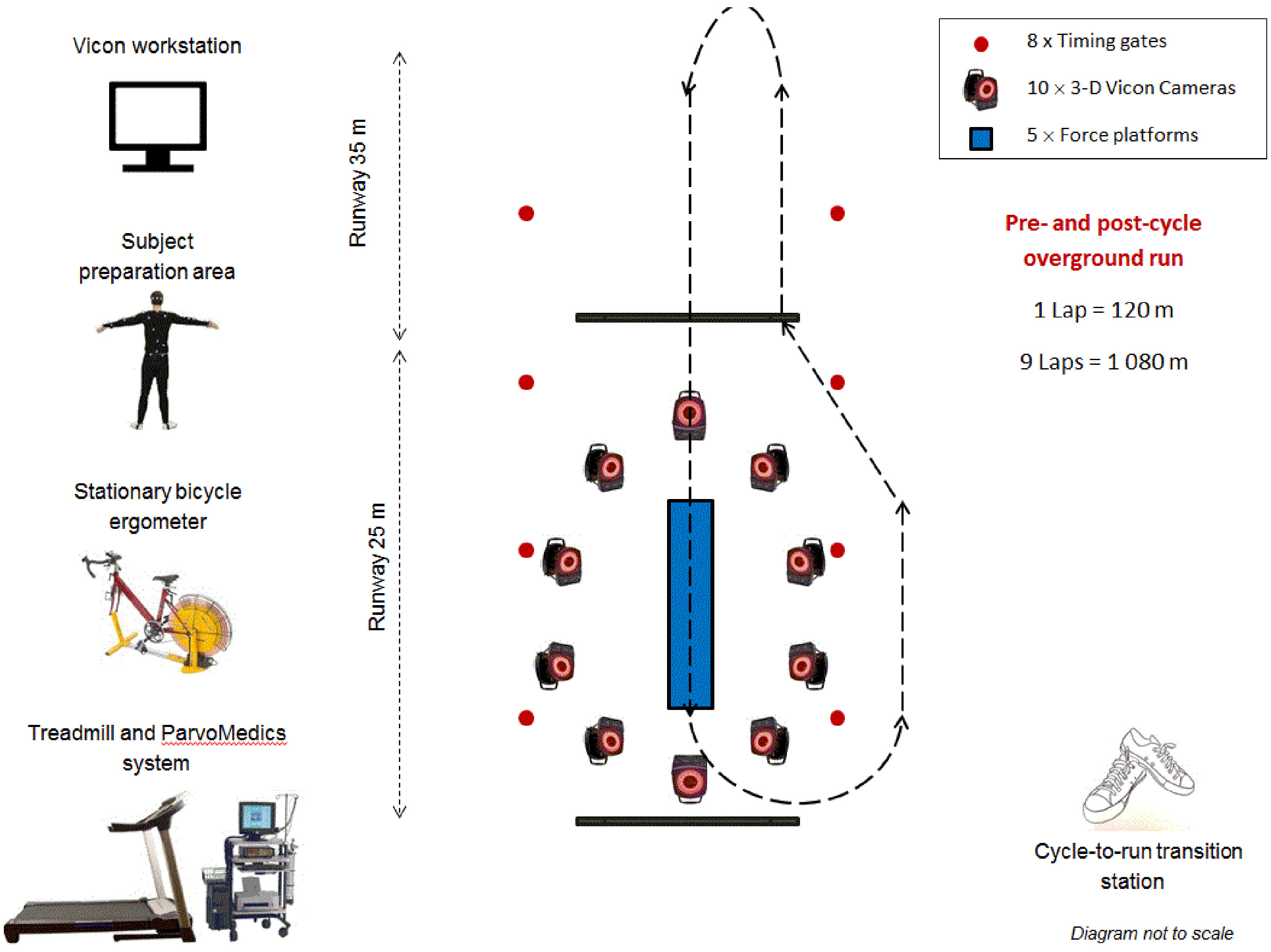
Contact Number: ____

APPENDIX H BORG SCALE

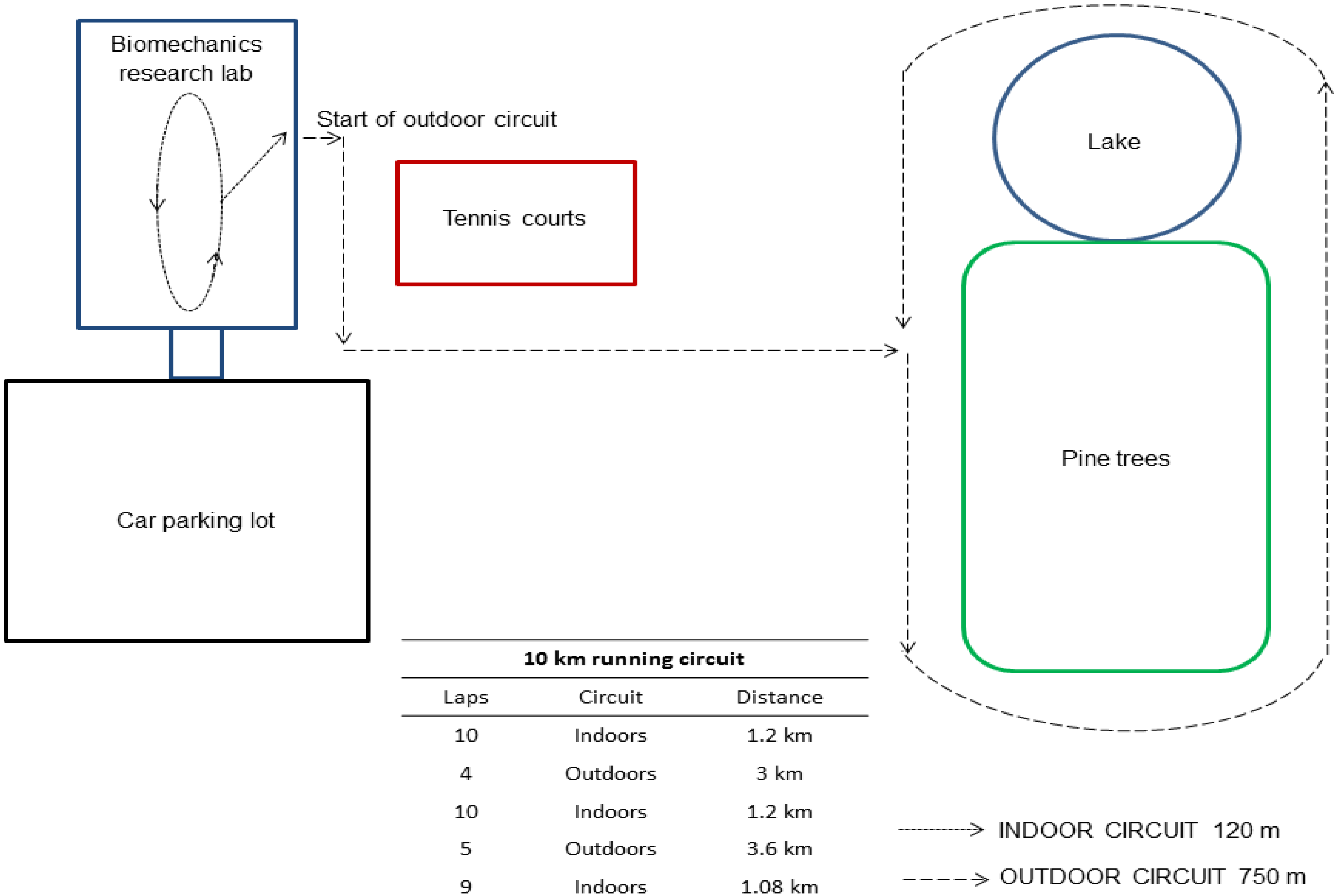
RATING OF PERCEIVED EXERTION

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

APPENDIX I AERIAL VIEW OF THE LABORATORY SET UP FOR THE INDOOR RUNNING TRACK



APPENDIX J DIAGRAMMATIC REPRESENTATION OF 10 KM RUNNING COURSE



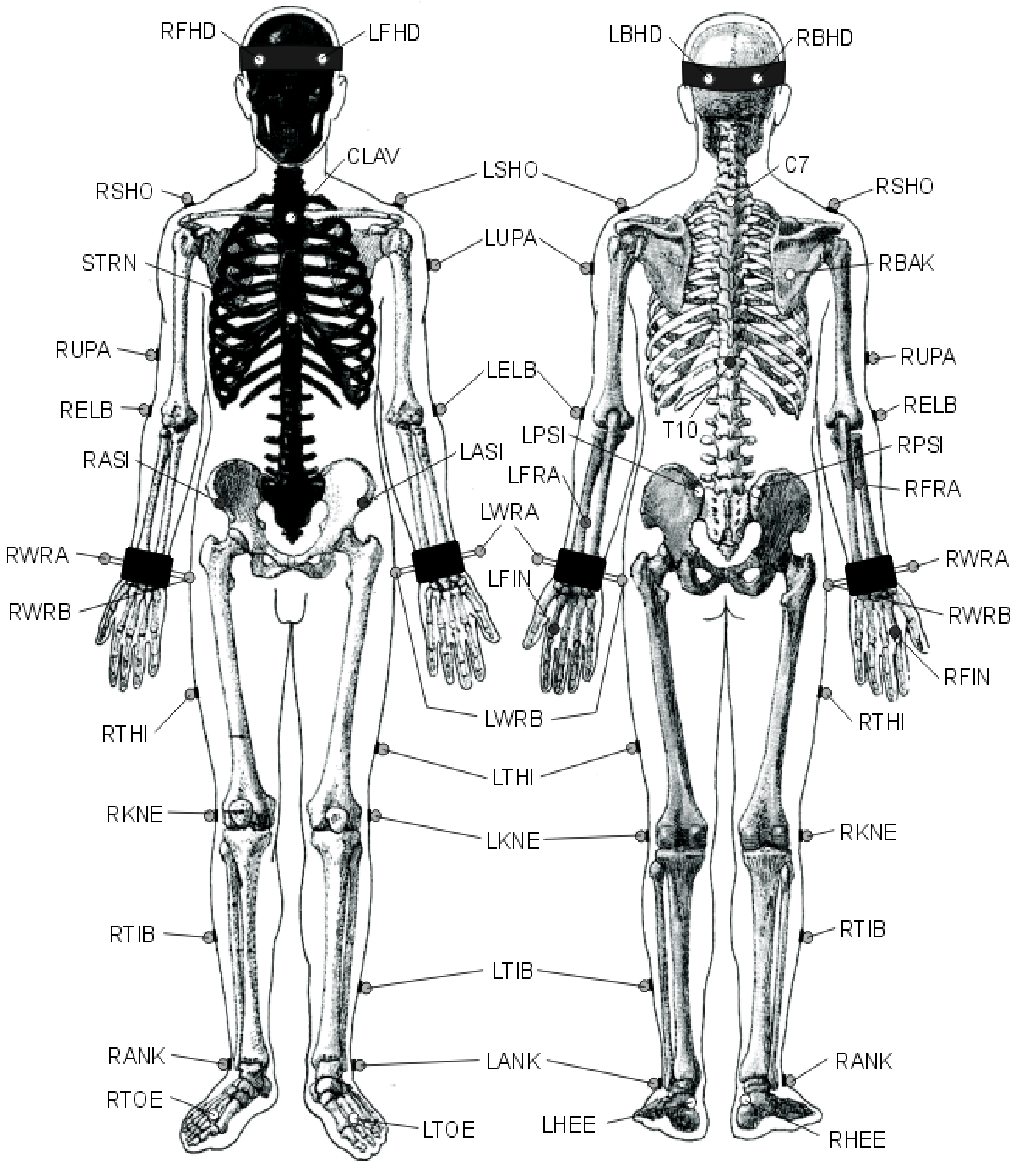
10 km running circuit

Laps	Circuit	Distance
10	Indoors	1.2 km
4	Outdoors	3 km
10	Indoors	1.2 km
5	Outdoors	3.6 km
9	Indoors	1.08 km

APPENDIX K PLUG-IN-GAIT-FULL-BODY-Ai MARKER SET

Plug-in-Gait Upper-and-Lower Arm Model

The locations of the retro-reflective markers for the 3-dimentional motion analysis are as follows:



APPENDIX L MATLAB CODE

MATLAB CODE FOR STUDY TWO

Analysing the kinematic data using the MATLAB-VICON interphase

This code has been designed to calculate the stride parameters and joint angles across the whole time-phase. This script initially uses the MATLAB-VICON interphase to import the required variables, where the specific trial of interest should be open. Repeat steps 1-5 for all trials of a particular participant. The following code was subsequently written to analyse and export the selected variables.

STEP 1: USE THE MATLAB-VICON INTERPHASE

```
vicon = ViconNexus ();
```

STEP 2: IMPORT KEY INFORMATION FROM OPENED NEXUS TRIAL

```
Subject = vicon.GetSubjectNames; % get the subject name
Subjects = Subject {1}; %convert it to a char format
BodyMass= vicon.GetSubjectParam (Subjects, 'Bodymass');
Height= vicon.GetSubjectParam (Subjects, 'Height');
Fs= vicon.GetFrameRate;
[FilePath,FileName]= vicon.GetTrialName ();
i = input('What colum is foot plant ----> input number');
fileName(i) = {FileName};
```

STEP 3: IMPORTING EVENTS FOR BOTH LEFT AND RIGHT FEET

```
% Right and Left Heelstrike and Toe-Off
Kinematics.(FileName).Events.RHS(1,:) = vicon.GetEvents
(Subjects, 'Right','Foot Strike'); % Right heel strike
Kinematics.(FileName).Events.RTO(1,:) = vicon.GetEvents
(Subjects, 'Right', 'Foot Off'); % Right toe off
Kinematics.(FileName).Events.LHS = vicon.GetEvents (Subjects,
'Left','Foot Strike'); % Left heel strike
Kinematics.(FileName).Events.LTO = vicon.GetEvents (Subjects,
'Left', 'Foot Off'); % Left toe off
```

STEP 4: FIND THE Y AXIS OF THE HEEL MARKER TO DETERMINE STRIDE LENGTH

```
[~,Kinematics.(fileName{i}).Data.Raw.Right.RHEEy,~,~] =
vicon.GetTrajectory (Subjects,'RHEE'); % import the Y axis of
the right heel marker to find the distance to determine SL
Kinematics.(fileName{i}).Data.Raw.Right.RHEEy=Kinematics.(fileNa
me{i}).Data.Raw.Right.RHEEy'; %Transpose vector
[~,Kinematics.(fileName{i}).Data.Raw.Left.LHEEy,~,~] =
vicon.GetTrajectory (Subjects,'LHEE'); % import the Y axis of
the right heel marker to find the distance to determine SL
Kinematics.(fileName{i}).Data.Raw.Left.LHEEy=Kinematics.(fileNam
e{i}).Data.Raw.Left.LHEEy'; %Transpose the vector
```

STEP 5: IMPORT THE KINEMATIC DATA OF THE RIGHT AND LEFT LEGS BY FIRST IDENTIFYING MODEL OUTPUTS, IMPORT AND SAVE FOR EACH SUBJECT

```
% DATA: Ankle, Knee, Hip, Pelvis, Thorax, COM
ModelOutputs = {'RAnkleAngles'; 'RKneeAngles'; 'RHipAngles';
'RPelvisAngles'; 'RThoraxAngles';'CentreOfMass'};
     for j = 1:length (ModelOutputs)
     Kinematics.(FileName).Data.Raw.Right.(ModelOutputs {j})=
     (vicon.GetModelOutput (Subjects, ModelOutputs {j}))';
     end
ModelOutputsL = {'LAnkleAngles'; 'LKneeAngles'; 'LHipAngles';
'LPelvisAngles'; 'LThoraxAngles';'CentreOfMass'};
     for j = 1:length (ModelOutputsL)
     Kinematics.(FileName).Data.Raw.Left.(ModelOutputsL {j})=
     (vicon.GetModelOutput (Subjects, ModelOutputsL {j}))';
     end
```

STEP 6: DIVIDE THE KINEMATICS (MODEL OUTPUTS) INTO STRIDES

```
% Data needs to be cropped according to events
for i=1:length (fileName)

Kinematics.(fileName{i}).nStrideR=length(Kinematics.(fileName{i}
).Events.RHS)-1; % number of strides = number of steps-1 in this
case; i.e 2 HS= 1 stride
     for n =1:Kinematics.(fileName{i}).nStrideR % for the
     number of strides, and model outputs, crop that trial
     accordingly
          for j= 1:length (ModelOutputs)
Kinematics.(fileName{i}).Data.Cropped.Right.(ModelOutputs{j}).(s
trcat('Stride',num2str(n)))=Kinematics.(fileName{i}).Data.Raw.Ri
ght.(ModelOutputs{j})(Kinematics.(fileName{i}).Events.RHS(n)+1:K
inematics.(fileName{i}).Events.RHS (n+1)+1,:);
          end
     end
Kinematics.(fileName{i}).nStrideL=length(Kinematics.(fileName{i}
).Events.LHS)-1; % number of strides = number of steps-1 in this
case; i.e 2 HS= 1 stride
     for n =1:Kinematics.(fileName{i}).nStrideL % for the
     number of strides, and model outputs, crop that trial
     accordingly
          for j= 1:length (ModelOutputsL)
Kinematics.(fileName{i}).Data.Cropped.Left.(ModelOutputsL{j}).(s
trcat('Stride',num2str(n)))=Kinematics.(fileName{i}).Data.Raw.Le
ft.(ModelOutputsL{j})(Kinematics.(fileName{i}).Events.LHS(n)+1:K
inematics.(fileName{i}).Events.LHS (n+1)+1,:);
          end
     end
```

STEP 7: IDENTIFY THE KEY VALUES

```
% Max, mins and averages during the STRIDE
     for n = 1:Kinematics.(fileName{i}).nStrideR
          for j= 1:length (ModelOutputs)
Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{j}).
Max(n,:)=max(Kinematics.(fileName{i}).Data.Cropped.Right.(ModelO
utputs {j}).(strcat ('Stride', num2str (n)))); % find a max for
the x, y and z
```

```
Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{j}).
Min(n,:)=min(Kinematics.(fileName{i}).Data.Cropped.Right.(ModelO
utputs{j}).(strcat ('Stride', num2str (n)))); % find a min for
the x, y and z
Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{j}).
Mean(n,:)=mean(Kinematics.(fileName{i}).Data.Cropped.Right.(Mode
lOutputs{j}).(strcat ('Stride', num2str (n)))); % find a mean
for the x, y and z
                if n == Kinematics.(fileName{i}).nStrideR &&
                Kinematics.(fileName{i}).nStrideR >=1
Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{j}).
Average = []; %Pre-allocating a variable
Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{j}).
Average(1,:)=mean(Kinematics.(fileName{i}).Data.KeyValues.Right.
(ModelOutputs {j}).Max(:,1:3)); % the average max values for the
x plane(flexion extension)
Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{j}).
Average(2,:)=mean(Kinematics.(fileName{i}).Data.KeyValues.Right.
(ModelOutputs {j}).Min(:,1:3));
Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{j}).
Average(3,:)=mean(Kinematics.(fileName{i}).Data.KeyValues.Right.
(ModelOutputs {j}).Mean(:,1:3));
                elseif Kinematics.(fileName{i}).nStrideR ==0
disp ('only one step for right')
                end
            end
        end

% Left foot
        for n = 1:Kinematics.(fileName{i}).nStrideL
            for j= 1:length (ModelOutputsL)
Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{j}).
Max(n,:)=max(Kinematics.(fileName{i}).Data.Cropped.Left.(ModelOu
tputsL {j}).(strcat ('Stride', num2str (n)))); % find a max for
the x, y and z values
Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{j}).
Min(n,:)=min(Kinematics.(fileName{i}).Data.Cropped.Left.(ModelOu
tputsL {j}).(strcat ('Stride', num2str (n)))); % find a min for
the x, y and z values
Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{j}).
Mean(n,:)=mean(Kinematics.(fileName{i}).Data.Cropped.Left.(Model
OutputsL {j}).(strcat ('Stride', num2str (n)))); % find a mean
for the x, y and z values
                if n == Kinematics.(fileName{i}).nStrideL &&
                Kinematics.(fileName{i}).nStrideL >= 1
Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL
{j}).Average = []; %Pre-allocating a variable
Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{j}).
Average(1,:)=mean(Kinematics.(fileName{i}).Data.KeyValues.Left.(
ModelOutputsL {j}).Max(:,1:3)); % the average max values for the
x plane(flexion extension)
Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{j}).
Average(2,:)=mean(Kinematics.(fileName{i}).Data.KeyValues.Left.(
ModelOutputsL {j}).Min(:,1:3));
```

```
Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{j}).
Average(3,:)=mean(Kinematics.(fileName{i}).Data.KeyValues.Left.(
ModelOutputsL {j}).Mean(:,1:3));
                elseif Kinematics.(fileName{i}).nStrideL ==0
disp ('only one step for left')
                end
           end
      end
```

STEP 8: IDENTIFY THE SPECIFIC EVENTS DURING THE STEP

```
% Angles at Heel strike
      for j= 1:length (ModelOutputs)
           for l= 1:length(Kinematics.(fileName{i}).Events.RHS);
                if l >= 1
Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{j}).
Landing(l,:)=Kinematics.(fileName{i}).Data.Raw.Right.(ModelOutpu
ts {j})(Kinematics.(fileName{i}).Events.RHS(1,l));
                elseif i<1
disp ('no right step')
                end
           end
      end
% Angles at TO
      for j= 1:length (ModelOutputs)
           for l= 1:length(Kinematics.(fileName{i}).Events.RTO);
                if l >= 1
Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{j}).
ToeOff(l,:)=Kinematics.(fileName{i}).Data.Raw.Right.(ModelOutput
s{j})(Kinematics.(fileName{i}).Events.RTO(1,l));
                elseif i<1
disp ('no right step')
                end
           end
      end
% Average and stdev for HS and TO
      for j= 1:length (ModelOutputs)
Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{j}).
MeanLanding=mean(Kinematics.(fileName{i}).Data.KeyValues.Right.(
ModelOutputs {j}).Landing(l,:));
Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{j}).
MeanToeOff=mean(Kinematics.(fileName{i}).Data.KeyValues.Right.(M
odelOutputs {j}).ToeOff(l,:));
      end
% Velocity of the COM at landing
      for n = Kinematics.(fileName{i}).nStrideR
           if Kinematics.(fileName{i}).nStrideR >=1
Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.v =
diff(Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.(s
trcat ('Stride', num2str (n)))(:,1:3)); %changes in the
displacement (vertical direction)
Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.velocit
y=(Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.v./0
.004)./1000; %v= displacement/time/ 1000 (to get m/s, from mm/s)
Kinematics.(fileName{i}).Data.KeyValues.Right.CentreOfMass.COMVH
S=(Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.velo
```

```
city(1,1)); %Centre of mass velocity at heel strike- the first
point
           elseif Kinematics.(fileName{i}).nStrideR ==0
disp ('only one step for right')
           end
      end
% Acceleration of the COM at landing
           if Kinematics.(fileName{i}).nStrideR >=1
Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.a=diff(
Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.velocit
y);
Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.acceler
ation=(Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.
a./0.004);
Kinematics.(fileName{i}).Data.KeyValues.Right.CentreOfMass.COMAH
S=(Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.acce
leration(1,1)); %centre of mass acceleration at heel strike
           elseif Kinematics.(fileName{i}).nStrideR ==0
disp ('only one step for right')
           end
% Distance between HS and COM location
      for n =1:Kinematics.(fileName{i}).nStrideR
           if Kinematics.(fileName{i}).nStrideR >= 1
Kinematics.(fileName{i}).Data.Cropped.Right.RHEEy.(strcat
('Stride',
num2str(n)))=Kinematics.(fileName{i}).Data.Raw.Right.RHEEy(Kinem
atics.(fileName{i}).Events.RHS
(n)+1:Kinematics.(fileName{i}).Events.RHS (n+1)+1,:); %crop the
trial
Kinematics.(fileName{i}).Data.KeyValues.Right.COMdistancefromHee
l=[]; % creating an 'open' variable
Kinematics.(fileName{i}).Data.KeyValues.Right.COMdistancefromHee
l(n)=Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.(s
trcat ('Stride', num2str (n)))(1,2)-
(Kinematics.(fileName{i}).Data.Cropped.Right.RHEEy.(strcat
('Stride', num2str (n)))(1,1)); %difference between the point of
com and heel marker
Kinematics.(fileName{i}).Data.KeyValues.Right.COMdistancefromHee
lav=mean(Kinematics.(fileName{i}).Data.KeyValues.Right.COMdistan
cefromHeel(n));
           elseif Kinematics.(fileName{i}).nStrideR == 0
display ('only one step for this foot')
           end
      end
% SPECIFIC POINTS IN THE STRIDE
      for n = 1:Kinematics.(fileName{i}).nStrideR
% Knee flexion of support leg (first peak of the graph)
      [Data.pks,loc]=findpeaks(Kinematics.(fileName{i}).Data.Cro
      pped.Right.RKneeAngles.(strcat ('Stride', num2str
      (n)))(:,1)); %find the peak and its locations of the
      graph, for the X axis
      findpeaks(Kinematics.(fileName{i}).Data.Cropped.Right.RKne
      eAngles.(strcat ('Stride', num2str (n)))(:,1)) %plots the
      peaks on the graph
```

```
    Kinematics.(fileName{i}).Data.KeyValues.Right.RKneeAngles.
    MaxKneeFlexSup= mean (Data.pks(1,:)); % average of the max
    knee flexion during the stance
% Knee extension on toe off (typically at or just after toe
off), a few frames after TO (initial peak in the flipped graph)
    Kinematics.(fileName{i}).Data.Cropped.Right.Inverted.RKnee
    Angles.(strcat('Stride',num2str(n)))=-
    (Kinematics.(fileName{i}).Data.Cropped.Right.RKneeAngles.(
    strcat ('Stride', num2str (n)))(:,1));
    [Data.pks1,~]=findpeaks(Kinematics.(fileName{i}).Data.Crop
    ped.Right.Inverted.RKneeAngles.(strcat ('Stride', num2str
    (n))));% instead of finding the mins, I flipped the graph
    and found the peaks again
    findpeaks(Kinematics.(fileName{i}).Data.Cropped.Right.Inve
    rted.RKneeAngles.(strcat ('Stride', num2str (n))))
    Kinematics.(fileName{i}).Data.KeyValues.Right.RKneeAngles.
    MaxKneeExtTO = mean (Data.pks1 (1,:)).*-1; % Max knee
    extension
% Hip flexion during the swing (similar to the Max Hip flex
angle)
    Kinematics.(fileName{i}).Data.KeyValues.Right.RHipAngles.M
    axHipFlexSwing(n)=max(Kinematics.(fileName{i}).Data.Croppe
    d.Right.RHipAngles.(strcat ('Stride', num2str (n)))(:,1));
    % maximum hip flexion angle during swing
    Kinematics.(fileName{i}).Data.KeyValues.Right.RHipAngles.M
    axHipFlexSwing=mean(Kinematics.(fileName{i}).Data.KeyValue
    s.Right.RHipAngles.MaxHipFlexSwing);
% Pelvis height during support of support leg (y axis), first
peak on the graph
    Data.RPelvisAngles.(strcat ('Stride', num2str (n)))=[];
    [Data.RPelvisAngles.(strcat('Stride',num2str(n))).pks,~]=
    findpeaks(Kinematics.(fileName{i}).Data.Cropped.Right.RPel
    visAngles.(strcat ('Stride', num2str (n)))(:,2));
    Kinematics.(fileName{i}).Data.KeyValues.Right.RPelvisAngle
    s.MaxPelHeightSup(n)=(Data.RPelvisAngles.(strcat('Stride',
    num2str (n))).pks (1,:));%
    Kinematics.(fileName{i}).Data.KeyValues.Right.RPelvisAngle
    s.MaxPelHeightSupAv=mean(Kinematics.(fileName{i}).Data.Key
    Values.Right.RPelvisAngles.MaxPelHeightSup);
% Pelvis drop during swing (right leg, How much the pelvis drops
when it is swinging through on the next step, so during left
support
    Kinematics.(fileName{i}).Data.Cropped.Right.Inverted.RPelv
    isAngles.(strcat ('Stride', num2str (n)))=-
    (Kinematics.(fileName{i}).Data.Cropped.Right.RPelvisAngles
    .(strcat ('Stride', num2str (n)))(:,2));
    Data.RPelvisAngles.inverted.(strcat('Stride',num2str(n)))=
    [];
    [Data.RPelvisAngles.inverted.(strcat ('Stride', num2str
    (n))).pks,~]
    =findpeaks(Kinematics.(fileName{i}).Data.Cropped.Right.Inv
    erted.RPelvisAngles.(strcat ('Stride', num2str (n))));
    Kinematics.(fileName{i}).Data.KeyValues.Right.RPelvisAngle
    s.MaxPelDropSwing(n)= (Data.RPelvisAngles.inverted.(strcat
    ('Stride', num2str (n))).pks (2,:));%
```

```
      Kinematics.(fileName{i}).Data.KeyValues.Right.RPelvisAngle
      s.MaxPelDropSwingAv=mean(Kinematics.(fileName{i}).Data.Key
      Values.Right.RPelvisAngles.MaxPelDropSwing).*(-1);
      end

% LLEFT foot
% Angles at Heel strike
      for j= 1:length (ModelOutputsL)
            for l= 1:length(Kinematics.(fileName{i}).Events.LHS);
Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{j}).
Landing(l,:)=Kinematics.(fileName{i}).Data.Raw.Left.(ModelOutput
sL{j})(Kinematics.(fileName{i}).Events.LHS(:,l));
            end
      end
% Angles at TO
      for j= 1:length (ModelOutputsL)
            for l= 1:length(Kinematics.(fileName{i}).Events.LTO);
Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{j}).
ToeOff(l,:)=Kinematics.(fileName{i}).Data.Raw.Left.(ModelOutputs
L{j})(Kinematics.(fileName{i}).Events.LTO(:,l));
            end
      end
% Average and stdev for HS and TO
      for j= 1:length (ModelOutputsL)
            if Kinematics.(fileName{i}).nStrideL >=1
Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{j}).
MeanLanding=mean(Kinematics.(fileName{i}).Data.KeyValues.Left.(M
odelOutputsL {j}).Landing);
Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{j}).
MeanToeOff=mean(Kinematics.(fileName{i}).Data.KeyValues.Left.(Mo
delOutputsL {j}).ToeOff);
            elseif Kinematics.(fileName{i}).nStrideL == 0
disp ('only one step for left')
            end
      end
% Velocity of the COM L
      for n = Kinematics.(fileName{i}).nStrideL
            if Kinematics.(fileName{i}).nStrideL >=1
Kinematics.(fileName{i}).Data.Cropped.Left.CentreOfMass.v=diff(K
inematics.(fileName{i}).Data.Cropped.Left.CentreOfMass.(strcat
('Stride', num2str (n)))(:,1:3)); %changes in the displacement
(vertical direction)
Kinematics.(fileName{i}).Data.Cropped.Left.CentreOfMass.velocity
=(Kinematics.(fileName{i}).Data.Cropped.Left.CentreOfMass.v./0.0
04)./1000; %v= displacement/time/ 1000 (to get m/s, from mm/s)
            elseif Kinematics.(fileName{i}).nStrideL == 0
disp ('only one step for left')
            end
      end
% Acceleration of the COM at landing
      for n = Kinematics.(fileName{i}).nStrideL
            if Kinematics.(fileName{i}).nStrideL >=1
Kinematics.(fileName{i}).Data.Cropped.Left.CentreOfMass.a=diff(K
inematics.(fileName{i}).Data.Cropped.Left.CentreOfMass.velocity)
;
```

```
Kinematics.(fileName{i}).Data.Cropped.Left.CentreOfMass.accelera
tion=(Kinematics.(fileName{i}).Data.Cropped.Left.CentreOfMass.a.
/0.004);
Kinematics.(fileName{i}).Data.KeyValues.Left.CentreOfMass.COMAHS
=(Kinematics.(fileName{i}).Data.Cropped.Left.CentreOfMass.accele
ration(1,1)); %centre of mass acceleration at heel strike
           elseif Kinematics.(fileName{i}).nStrideL == 0
disp ('only one step for left')
           end
      end
% Distance between HS and COM location
      for n =1:Kinematics.(fileName{i}).nStrideL
           if Kinematics.(fileName{i}).nStrideL >= 1
Kinematics.(fileName{i}).Data.Cropped.Left.LHEEy.(strcat('Stride
',num2str(n)))=Kinematics.(fileName{i}).Data.Raw.Left.LHEEy(Kine
matics.(fileName{i}).Events.LHS(n)+1:Kinematics.(fileName{i}).Ev
ents.LHS (n+1)+1,:); %crop the trial
Kinematics.(fileName{i}).Data.KeyValues.Left.COMdistancefromHeel
=[]; % creating an 'open' variable
Kinematics.(fileName{i}).Data.KeyValues.Left.COMdistancefromHeel
(n)=Kinematics.(fileName{i}).Data.Cropped.Left.CentreOfMass.(str
cat('Stride',num2str(n)))(1,2)-
(Kinematics.(fileName{i}).Data.Cropped.Left.LHEEy.(strcat('Strid
e', num2str (n)))(1,1)); %difference between the point of com
and heel marker
Kinematics.(fileName{i}).Data.KeyValues.Left.COMdistancefromHeel
av=mean(Kinematics.(fileName{i}).Data.KeyValues.Left.COMdistance
fromHeel(n));
           elseif Kinematics.(fileName{i}).nStrideL == 0
display ('only one step for this foot')
           end
      end
% SPECIFIC POINTS IN THE STRIDE
      for n = 1:Kinematics.(fileName{i}).nStrideL
% Knee flexion of support leg (first peak of the graph)
      [Data.pksL,~]=findpeaks(Kinematics.(fileName{i}).Data.Crop
      ped.Left.LKneeAngles.(strcat ('Stride',num2str(n)))(:,1));
      %find the peak and its locations of the graph, for the X
      axis
      findpeaks(Kinematics.(fileName{i}).Data.Cropped.Left.LKnee
      Angles.(strcat ('Stride', num2str (n)))(:,1)) %plots the
      peaks on the graph
      Kinematics.(fileName{i}).Data.KeyValues.Left.LKneeAngles.M
      axKneeFlexSup= mean (Data.pksL(1,:)); % average of the max
      knee flexion during the stance
% Knee extension on toe off typically at or just after toe off),
a few frames after TO (inital peak in the flipped graph)
      Kinematics.(fileName{i}).Data.Cropped.Left.Inverted.LKneeA
      ngles.(strcat ('Stride',num2str(n)))=-
      (Kinematics.(fileName{i}).Data.Cropped.Left.LKneeAngles.(s
      trcat('Stride', num2str (n)))(:,1));
      [Data.pks1L,~]=findpeaks(Kinematics.(fileName{i}).Data.Cro
      pped.Left.Inverted.LKneeAngles.(strcat ('Stride', num2str
      (n))));% instead of finding the mins, I flipped the graph
      and found the peaks again
```

```
        findpeaks(Kinematics.(fileName{i}).Data.Cropped.Left.Inver
        ted.LKneeAngles.(strcat ('Stride', num2str (n))))
        Kinematics.(fileName{i}).Data.KeyValues.Left.LKneeAngles.M
        axKneeExtTO=mean (Data.pks1L (1,:)).*-1; % Max knee
        extension (
% Hip flexion during the swing (similar to the Max Hip flex
angle)
        Kinematics.(fileName{i}).Data.KeyValues.Left.LHipAngles.Ma
        xHipFlexSwing(n)=max(Kinematics.(fileName{i}).Data.Cropped
        .Left.LHipAngles.(strcat ('Stride', num2str (n)))(:,1)); %
        maximum hip flexion angle during swing
        Kinematics.(fileName{i}).Data.KeyValues.Left.LHipAngles.Ma
        xHipFlexSwing=mean(Kinematics.(fileName{i}).Data.KeyValues
        .Left.LHipAngles.MaxHipFlexSwing);
% Pelvis height during support of support leg (y axis)
        Data.LPelvisAngles.(strcat ('Stride', num2str (n)))=[];
        [Data.LPelvisAngles.(strcat('Stride',num2str(n))).pks,~]=
        findpeaks(Kinematics.(fileName{i}).Data.Cropped.Left.LPelv
        isAngles.(strcat ('Stride', num2str (n)))(:,2));
        Kinematics.(fileName{i}).Data.KeyValues.Left.LPelvisAngles
        .MaxPelHeightSup(n)= (Data.LPelvisAngles.(strcat('Stride',
        num2str (n))).pks (1,:));%
        Kinematics.(fileName{i}).Data.KeyValues.Left.LPelvisAngles
        .MaxPelHeightSupAv=mean(Kinematics.(fileName{i}).Data.KeyV
        alues.Left.LPelvisAngles.MaxPelHeightSup);% Maximum pelvis
        height of the support leg, first peak on the graph
% Pelvis drop during swing (right leg)
% How much the pelvis drops when it is swinging through on the
next step, so during left support
        Kinematics.(fileName{i}).Data.Cropped.Left.Inverted.LPelvi
        sAngles.(strcat ('Stride', num2str (n)))=-
        (Kinematics.(fileName{i}).Data.Cropped.Left.LPelvisAngles.
        (strcat ('Stride', num2str (n)))(:,2));
        Data.LPelvisAngles.inverted.(strcat('Stride',num2str(n)))=
        [];
        [Data.LPelvisAngles.inverted.(strcat('Stride',num2str(n)))
        .pks,~]=findpeaks(Kinematics.(fileName{i}).Data.Cropped.Le
        ft.Inverted.LPelvisAngles.(strcat ('Stride',num2str(n))));
        Kinematics.(fileName{i}).Data.KeyValues.Left.LPelvisAngles
        .MaxPelDropSwing(n)= (Data.LPelvisAngles.inverted.(strcat
        ('Stride', num2str (n))).pks (2,:));
        Kinematics.(fileName{i}).Data.KeyValues.Left.LPelvisAngles
        .MaxPelDropSwingAv=mean(Kinematics.(fileName{i}).Data.KeyV
        alues.Left.LPelvisAngles.MaxPelDropSwing).*(-1);
        end

clearvars ('pks', 'locs', 'pks1', 'locs1', 'pks2', 'locs2',
'pks3', 'locs3', 'l', 'm');
```

STEP 8: FIND STRIDE LENGTH AND STRIDE RATE

```
% Contact time and SL
% Needs to be in 'double' format, otherwise it will simply round
up to 1 instead of in the format 0.xxx
Kinematics.(fileName{i}).Data.KeyValues.Right.ContactTime= [];
        for n = 1:Kinematics.(fileName{i}).nStrideR;
```

```
            if Kinematics.(fileName{i}).nStrideR >=1
Kinematics.(fileName{i}).Data.KeyValues.Right.ContactTime(n)=
(Kinematics.(fileName{i}).Events.RTO(n)-
Kinematics.(fileName{i}).Events.RHS(n));
            elseif Kinematics.(fileName{i}).nStrideR ==0
disp ('only one step for right')
            end
      end
      for n = 1:Kinematics.(fileName{i}).nStrideR;
            if Kinematics.(fileName{i}).nStrideR >=1
Kinematics.(fileName{i}).Data.KeyValues.Right.ContactTime(2,n)=(
Kinematics.(fileName{i}).Data.KeyValues.Right.ContactTime(1,n))/
Fs;
            elseif Kinematics.(fileName{i}).nStrideR == 0
disp ('only one step for right')
            end
      end
% Stride time, stride rate and cadence
Kinematics.(fileName{i}).Data.KeyValues.Right.StrideTime = [];
      for n = 1:Kinematics.(fileName{i}).nStrideR;
            if Kinematics.(fileName{i}).nStrideR >=1
Kinematics.(fileName{i}).Data.KeyValues.Right.StrideTime(n)=
(Kinematics.(fileName{i}).Events.RHS (n+1)-
Kinematics.(fileName{i}).Events.RHS (n)); %finding the
difference in frame number between HS and HS
            elseif Kinematics.(fileName{i}).nStrideR ==0
disp ('only one step for right')
            end
      end
      for n = 1:Kinematics.(fileName{i}).nStrideR;
            if Kinematics.(fileName{i}).nStrideR >=1
Kinematics.(fileName{i}).Data.KeyValues.Right.StrideTime (2,n)=
Kinematics.(fileName{i}).Data.KeyValues.Right.StrideTime(1,n)/Fs
;
Kinematics.(fileName{i}).Data.KeyValues.Right.Totaltime=Kinemati
cs.(fileName{i}).nStrideR.*(mean(Kinematics.(fileName{i}).Data.K
eyValues.Right.StrideTime(2,:))); %total time it takes to do the
number of strides
Kinematics.(fileName{i}).Data.KeyValues.Right.SR=Kinematics.(fil
eName{i}).nStrideR./Kinematics.(fileName{i}).Data.KeyValues.Righ
t.Totaltime; % number of strides per second
Kinematics.(fileName{i}).Data.KeyValues.Right.StrideRate=(Kinema
tics.(fileName{i}).Data.KeyValues.Right.SR).*60; % number of
strides per minute (single leg)
Kinematics.(fileName{i}).Data.KeyValues.Right.Cadence =
Kinematics.(fileName{i}).Data.KeyValues.Right.StrideRate *2;%
Both legs
% Stride Length
Kinematics.(fileName{i}).Data.KeyValues.Right.StrideLength=abs((
mean(Kinematics.(fileName{i}).Data.Cropped.Right.CentreOfMass.ve
locity(:,2)))/Kinematics.(fileName{i}).Data.KeyValues.Right.SR);
% since v = SR x SL
                for s = Kinematics.(fileName{i}).Data.KeyValues.
                Right.StrideLength
                      if s <1
disp ('Do not use SL: Stride length not calculated correctly')
```

```
                    end
                end
            elseif Kinematics.(fileName{i}).nStrideR ==0
disp ('only one step for right')
            end
        end
% Left
% Contact time
Kinematics.(fileName{i}).Data.KeyValues.Left.ContactTime= [];
        for n = 1:Kinematics.(fileName{i}).nStrideL;
            if Kinematics.(fileName{i}).nStrideL >=1
Kinematics.(fileName{i}).Data.KeyValues.Left.ContactTime(n)=(Kin
ematics.(fileName{i}).Events.LTO(n)-
Kinematics.(fileName{i}).Events.LHS(n));
            elseif Kinematics.(fileName{i}).nStrideL ==0
disp ('only one step for left')
            end
        end
        for n = 1:Kinematics.(fileName{i}).nStrideL;
            if Kinematics.(fileName{i}).nStrideL >=1
Kinematics.(fileName{i}).Data.KeyValues.Left.ContactTime(2,n)=
(Kinematics.(fileName{i}).Data.KeyValues.Left.ContactTime(1,n))/
Fs;
            elseif Kinematics.(fileName{i}).nStrideL == 0
disp ('only one step for left')
            end
        end
% Stride time, stride rate and cadence
Kinematics.(fileName{i}).Data.KeyValues.Left.StrideTime = [];
        for n = 1:Kinematics.(fileName{i}).nStrideL;
            if Kinematics.(fileName{i}).nStrideL >=1
Kinematics.(fileName{i}).Data.KeyValues.Left.StrideTime(n)=(Kine
matics.(fileName{i}).Events.LHS (n+1)-
Kinematics.(fileName{i}).Events.LHS (n)); %finding the
difference in frame number between HS and HS
Kinematics.(fileName{i}).Data.KeyValues.Left.StrideTime(2,n)=
Kinematics.(fileName{i}).Data.KeyValues.Left.StrideTime(n)/Fs;
Kinematics.(fileName{i}).Data.KeyValues.Left.Totaltime=Kinematic
s.(fileName{i}).nStrideL.*
mean(Kinematics.(fileName{i}).Data.KeyValues.Left.StrideTime(2,:
)); %total time it takes to do the number of strides
Kinematics.(fileName{i}).Data.KeyValues.Left.SR=Kinematics.(file
Name{i}).nStrideL./Kinematics.(fileName{i}).Data.KeyValues.Left.
Totaltime; % number of strides per second
Kinematics.(fileName{i}).Data.KeyValues.Left.StrideRate=((Kinema
tics.(fileName{i}).Data.KeyValues.Left.SR).*60)./n; % number of
strides per minute (single leg)
Kinematics.(fileName{i}).Data.KeyValues.Left.Cadence =
Kinematics.(fileName{i}).Data.KeyValues.Left.StrideRate *2;
%Both legs
% Stride Length
Kinematics.(fileName{i}).Data.KeyValues.Left.StrideLength=abs((m
ean(Kinematics.(fileName{i}).Data.Cropped.Left.CentreOfMass.velo
city (1:end-
1,2)))./Kinematics.(fileName{i}).Data.KeyValues.Left.SR); %
since v = SR x SL
```

```
                for s =Kinematics.(fileName{i}).Data.KeyValues.
                Left.StrideLength
                    if s <1
disp ('Do not use SL: Stride length not calculated correctly')
                    end
                end
            elseif Kinematics.(fileName{i}).nStrideL == 0
disp ('only one step for left')
            end
        end
end
```

STEP 9: EXPORT THE KINEMATIC DATA TO EXCEL

```
% RIGHT
Name = {'Name', 'Trial'};
Subject = {Subjects};
Trial= {fileName};
%Trial = {FileName};
KinData={'RContactTime','RStrideTime','RStrideLength','RStrideRa
te','RCadence'};
Ankle={'RAnkleAngleMaxX','RAnkleAngleMaxY','RAnkleAngleMaxZ','RA
nkleAngleMinX','RAnkleAngleMinY','RAnkleAngleMinZ','RAnkleAngleM
eanX','RAnkleAngleMeanY','RAnkleAngleMeanZ','RAnkleMeanHSX','RAn
kleMeanTOX'};
Knee={'RKneeAngleMaxX','RKneeAngleMaxY','RKneeAngleMaxZ','RKneeA
ngleMinX','RKneeAngleMinY','RKneeAngleMinZ','RKneeAngleMeanX','R
KneeAngleMeanY','RKneeAngleMeanZ','RKneeMeanHSX','RKneeMeanTOX',
'RMaxKneeFlexSup','RMaxKneeExtTO'};
Hip={'RHipAngleMaxX','RHipAngleMaxY','RHipAngleMaxZ','RHipAngleM
inX','RHipAngleMinY','RHipAngleMinZ','RHipAngleMeanX','RHipAngle
MeanY','RHipAngleMeanZ','RHipMeanHSX','RHipMeanTOX','RMaxHipFlex
SwingX'};
Pelvis={'RPelvisAngleMaxX','RPelvisAngleMaxY','RPelvisAngleMaxZ'
,'RPelvisAngleMinX','RPelvisAngleMinY','RPelvisAngleMinZ','RPelv
isAngleMeanX','RPelvisAngleMeanY','RPelvisAngleMeanZ','RPelvisMe
anHSX','RPelvisMeanTOX','RMaxPelHeightSupY','RMaxPelDropSwingY'}
;
Thorax={'RThoraxAngleMaxX','RThoraxAngleMaxY','RThoraxAngleMaxZ'
,'RThoraxAngleMinX','RThoraxAngleMinY','RThoraxAngleMinZ','RThor
axAngleMeanX','RThoraxAngleMeanY','RThoraxAngleMeanZ','RThoraxMe
anHSX','RThoraxMeanTOX','RCOMMaxX'};
CentreOfMass={'RCOMMaxX','RCOMMaxY','RCOMMaxZ','RCOMMinX','RCOMM
inY','RCOMMinZ','RCOMMeanX','RCOMMeanY','RCOMMeanZ','RCOMMeanHSX
','RCOMMeanTOX','RCOMdistancefromHS','RCOMVHS','RCOMAHS'};
Kinetics = {'RPosWork', 'LPosWork'};
Column={'A', 'B', 'C', 'D', 'E', 'F', 'G', 'H', 'I', 'J', 'K',
'L', 'M', 'N', 'O', 'P','Q', 'R', 'S','T', 'U', 'V','W', 'X',
'Y','Z'};
Row=['0','1','2','3','4','5','6','7','8','9','0','1','2','3','4'
,'5','6','7','8','9','0','1','2','3'];
xlswrite (strcat('_AngleData_'), Name, (Subjects), 'A1');
xlswrite (strcat('_AngleData_'), Subject, (Subjects), 'A2:A23');
xlswrite (strcat('_AngleData_'), KinData, (Subjects), 'C1');
xlswrite (strcat('_AngleData_'), Ankle, (Subjects), 'H1');
xlswrite (strcat('_AngleData_'), Knee, (Subjects), 'S1');
```

```
xlswrite (strcat('_AngleData_'), Hip, (Subjects), 'AF1');
xlswrite (strcat('_AngleData_'), Pelvis, (Subjects), 'AR1');
xlswrite (strcat('_AngleData_'), Thorax, (Subjects), 'BE1');
xlswrite (strcat('_AngleData_'), CentreOfMass, (Subjects),
'BP1');

for i= 1:length(fileName);
     for m = 1:length (ModelOutputs)
          if i >0 && i <= 8 % only for trial 1-8
xlswrite (strcat('_AngleData_'), fileName(i),(Subjects), (char
(strcat(Column(2), Row(i+2)))));
          end
               if i >= 9 && i <=18 % for trial 9 to trial 18
xlswrite (strcat('_AngleData_'), fileName(i),(Subjects), (char
(strcat(Column(2), Row(2), Row(i+2)))));
               end
                    if i >= 19 && i <=22 % For trial 19 to 22
xlswrite (strcat('_AngleData_'), fileName(i),(Subjects), (char
(strcat(Column(2), Row(3), Row(i+2)))));
                    end
     end
end
% Trial 1-11 will be 'Pre-cyle' and trial 12-22 will be 'Post-
cycle'
for i= 1:length(fileName);
     for m = 1:length (ModelOutputs)
          for n =1:Kinematics.(fileName{i}).nStrideR
               if Kinematics.(fileName{i}).nStrideR >=1
                    if i >0 && i <=8 % only for trial 1-8
% Contacts
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.ContactTime(2,1)),(Subjects),
(char(strcat(Column(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.StrideTime (2,1)),(Subjects),
(char(strcat(Column(4), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.StrideLength),(Subjects), (char(strcat(Column(5),
Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.StrideRate),(Subjects), (char(strcat(Column(6),
Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.Cadence),(Subjects),  (char(strcat(Column(7),
Row(i+2)))));
% Ankle
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{1}).Max (1,:)),(Subjects),
(char(strcat(Column(8), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{1}).Min (1,:)),(Subjects),
(char(strcat(Column(11), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{1}).Mean (1,:)),(Subjects),
(char(strcat(Column(14), Row(i+2)))));
```

```
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{1}).MeanLanding),(Subjects),
(char(strcat(Column(17), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{1}).MeanToeOff),(Subjects),
(char(strcat(Column(18), Row(i+2)))));
% Knee
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).Max(1,:)),(Subjects),
(char(strcat(Column(19), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).Min(1,:)),(Subjects),
(char(strcat(Column(22), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).Mean(1,:)),(Subjects),
(char(strcat(Column(25), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).MeanLanding),(Subjects),
(char(strcat(Column(1),Column (2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).MeanToeOff),(Subjects),
(char(strcat(Column(1),Column (3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).MaxKneeFlexSup),(Subjects),
(char(strcat(Column(1),Column (4), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).MaxKneeExtTO),(Subjects),
(char(strcat(Column(1),Column (5), Row(i+2)))));
% Hip
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).Max(1,:)),(Subjects),
(char(strcat(Column(1),Column (6), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).Min(1,:)),(Subjects),
(char(strcat(Column(1),Column (9), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).Mean(1,:)),(Subjects),
(char(strcat(Column(1),Column (12), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).MeanLanding),(Subjects),
(char(strcat(Column(1),Column (15), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).MeanToeOff),(Subjects),
(char(strcat(Column(1),Column (16), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).MaxHipFlexSwing),(Subjects),
(char(strcat(Column(1),Column (17), Row(i+2)))));
% Pelvis
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{4}).Max(1,:)),(Subjects),
(char(strcat(Column(1),Column (18), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{4}).Min(1,:)),(Subjects),
(char(strcat(Column(1),Column (21), Row(i+2)))));
```

```
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{4}).Mean(1,:)),(Subjects),
(char(strcat(Column(1),Column (24), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{4}).MeanLanding),(Subjects),
(char(strcat(Column(2),Column (1), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{4}).MeanToeOff),(Subjects),
(char(strcat(Column(2),Column (2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{4}).MaxPelHeightSup),(Subjects),
(char(strcat(Column(2),Column (3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{4}).MaxPelDropSwing),(Subjects),
(char(strcat(Column(2),Column (4), Row(i+2)))));
% Thorax
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{5}).Max(1,:)),(Subjects),
(char(strcat(Column(2),Column (5), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{5}).Min(1,:)),(Subjects),
(char(strcat(Column(2),Column (8), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{5}).Mean(1,:)),(Subjects),
(char(strcat(Column(2),Column (11), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{5}).MeanLanding),(Subjects),
(char(strcat(Column(2),Column (14), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{5}).MeanToeOff),(Subjects),
(char(strcat(Column(2),Column (15), Row(i+2)))));
% CentreOfMass
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).Max(1,:)),(Subjects),
(char(strcat(Column(2),Column (16), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).Min(1,:)),(Subjects),(char(strca
t(Column(2),Column (19), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).Mean(1,:)),(Subjects),
(char(strcat(Column(2),Column (22), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).MeanLanding),(Subjects),
(char(strcat(Column(2),Column (25), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).MeanToeOff),(Subjects),
(char(strcat(Column(2),Column (26), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.COMdistancefromHeelav),(Subjects),
(char(strcat(Column(3),Column (1), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).COMVHS),(Subjects),
(char(strcat(Column(3),Column (2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).COMAHS),(Subjects),
(char(strcat(Column(3),Column (3), Row(i+2)))));
```

```
                    end
                         if i >= 9 && i <=18
% Contacts
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.ContactTime(2,1)),(Subjects),
(char(strcat(Column(3), Row(2),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.StrideTime (2,1)),(Subjects),
(char(strcat(Column(4), Row(2),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.StrideLength),(Subjects), (char(strcat(Column(5),
Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.StrideRate),(Subjects), (char(strcat(Column(6),
Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.Cadence),(Subjects),  (char(strcat(Column(7),
Row(2), Row(i+2)))));
% Ankle
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{1}).Max(1,:)),(Subjects),
(char(strcat(Column(8), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{1}).Min(1,:)),(Subjects),
(char(strcat(Column(11), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{1}).Mean(1,:)),(Subjects),
(char(strcat(Column(14), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{1}).MeanLanding),(Subjects),
(char(strcat(Column(17), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{1}).MeanToeOff),(Subjects),
(char(strcat(Column(18), Row(2), Row(i+2)))));
% Knee
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{2}).Max(1,:)),(Subjects),
(char(strcat(Column(19), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{2}).Min(1,:)),(Subjects),
(char(strcat(Column(22),Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{2}).Mean(1,:)),(Subjects),
(char(strcat(Column(25), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{2}).MeanLanding),(Subjects),
(char(strcat(Column(1),Column (2),Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{2}).MeanToeOff),(Subjects),
(char(strcat(Column(1),Column (3), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{2}).MaxKneeFlexSup),(Subjects),
(char(strcat(Column(1),Column (4), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{2}).MaxKneeExtTO),(Subjects),
(char(strcat(Column(1),Column (5), Row(2), Row(i+2)))));
```

```
% Hip
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).Max(1,:)),(Subjects),
(char(strcat(Column(1),Column (6), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).Min(1,:)),(Subjects),
(char(strcat(Column(1),Column (9), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).Mean(1,:)),(Subjects),
(char(strcat(Column(1),Column (12), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).MeanLanding),(Subjects),
(char(strcat(Column(1),Column (15), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).MeanToeOff),(Subjects),
(char(strcat(Column(1),Column (16), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).MaxHipFlexSwing),(Subjects),
(char(strcat(Column(1),Column (17), Row(2), Row(i+2)))));
% Pelvis
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{4}).Max(1,:)),(Subjects),
(char(strcat(Column(1),Column (18), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{4}).Min(1,:)),(Subjects),
(char(strcat(Column(1),Column (21), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{4}).Mean(1,:)),(Subjects),
(char(strcat(Column(1),Column (24), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{4}).MeanLanding),(Subjects),
(char(strcat(Column(2),Column (1), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{4}).MeanToeOff),(Subjects),
(char(strcat(Column(2),Column (2), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{4}).MaxPelHeightSup),(Subjects),
(char(strcat(Column(2),Column (3), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{4}).MaxPelDropSwing),(Subjects),
(char(strcat(Column(2),Column (4), Row(2), Row(i+2)))));
% Thorax
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{5}).Max(1,:)),(Subjects),
(char(strcat(Column(2),Column (5), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{5}).Min(1,:)),(Subjects),
(char(strcat(Column(2),Column (8), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{5}).Mean(1,:)),(Subjects),
(char(strcat(Column(2),Column (11), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{5}).MeanLanding),(Subjects),
(char(strcat(Column(2),Column (14), Row(2), Row(i+2)))));
```

```
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{5}).MeanToeOff),(Subjects),
(char(strcat(Column(2),Column (15), Row(2), Row(i+2)))));
% CentreOfMass
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{6}).Max(1,:)),(Subjects),
(char(strcat(Column(2),Column (16), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{6}).Min(1,:)),(Subjects),(char(strcat(Column(2),Column (19), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{6}).Mean(1,:)),(Subjects),
(char(strcat(Column(2),Column (22), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{6}).MeanLanding),(Subjects),
(char(strcat(Column(2),Column (25), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{6}).MeanToeOff),(Subjects),
(char(strcat(Column(2),Column (26), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.COMdistancefromHeelav),(Subjects),
(char(strcat(Column(3),Column (1), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{6}).COMVHS),(Subjects),
(char(strcat(Column(3),Column (2), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{6}).COMAHS),(Subjects),
(char(strcat(Column(3),Column (3), Row(2), Row(i+2)))));
                            end
                                  if i >= 19 && i <=22
% Contacts
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.ContactTime(2,1)),(Subjects),
(char(strcat(Column(3), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.StrideTime (2,1)),(Subjects),
(char(strcat(Column(4), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.StrideLength),(Subjects), (char(strcat(Column(5), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.StrideRate),(Subjects), (char(strcat(Column(6), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.Cadence),(Subjects),  (char(strcat(Column(7), Row(3), Row(i+2)))));
% Ankle
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{1}).Max(1,:)),(Subjects),
(char(strcat(Column(8), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{1}).Min(1,:)),(Subjects),
(char(strcat(Column(11), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{1}).Mean(1,:)),(Subjects),
(char(strcat(Column(14), Row(3), Row(i+2)))));
```

```
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{1}).MeanLanding),(Subjects),
(char(strcat(Column(17), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{1}).MeanToeOff),(Subjects),
(char(strcat(Column(18), Row(3), Row(i+2)))));
% Knee
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).Max(1,:)),(Subjects),
(char(strcat(Column(19), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).Min(1,:)),(Subjects),
(char(strcat(Column(22), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).Mean(1,:)),(Subjects),
(char(strcat(Column(25), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).MeanLanding),(Subjects),
(char(strcat(Column(1),Column (2), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).MeanToeOff),(Subjects),
(char(strcat(Column(1),Column (3), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).MaxKneeFlexSup),(Subjects),
(char(strcat(Column(1),Column (4), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{2}).MaxKneeExtTO),(Subjects),
(char(strcat(Column(1),Column (5), Row(3), Row(i+2)))));
% Hip
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).Max(1,:)),(Subjects),
(char(strcat(Column(1),Column (6), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).Min(1,:)),(Subjects),
(char(strcat(Column(1),Column (9), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).Mean(1,:)),(Subjects),
(char(strcat(Column(1),Column (12), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).MeanLanding),(Subjects),
(char(strcat(Column(1),Column (15), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).MeanToeOff),(Subjects),
(char(strcat(Column(1),Column (16), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{3}).MaxHipFlexSwing),(Subjects),(char(strcat(Column(1),Column (17), Row(3), Row(i+2)))));
% Pelvis
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{4}).Max(1,:)),(Subjects),
(char(strcat(Column(1),Column(18), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Right.(ModelOutputs{4}).Min(1,:)),(Subjects),
(char(strcat(Column(1),Column(21), Row(3), Row(i+2)))));
```

```
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{4}).Mean(1,:)),(Subjects),
(char(strcat(Column(1),Column (24), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{4}).MeanLanding),(Subjects),
(char(strcat(Column(2),Column (1), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{4}).MeanToeOff),(Subjects),
(char(strcat(Column(2),Column (2), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{4}).MaxPelHeightSup),(Subjects),
(char(strcat(Column(2),Column (3), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{4}).MaxPelDropSwing),(Subjects),
(char(strcat(Column(2),Column (4), Row(3), Row(i+2)))));
% Thorax
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{5}).Max(1,:)),(Subjects),
(char(strcat(Column(2),Column (5), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{5}).Min(1,:)),(Subjects),
(char(strcat(Column(2),Column (8), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{5}).Mean(1,:)),(Subjects),
(char(strcat(Column(2),Column (11), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{5}).MeanLanding),(Subjects),
(char(strcat(Column(2),Column (14), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{5}).MeanToeOff),(Subjects),
(char(strcat(Column(2),Column (15), Row(3), Row(i+2)))));
% CentreOfMass
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).Max(1,:)),(Subjects),
(char(strcat(Column(2),Column (16), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).Min(1,:)),(Subjects),(char(strca
t(Column(2),Column (19), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).Mean(1,:)),(Subjects),
(char(strcat(Column(2),Column (22), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).MeanLanding),(Subjects),
(char(strcat(Column(2),Column (25), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).MeanToeOff),(Subjects),
(char(strcat(Column(2),Column (26), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.COMdistancefromHeelav),(Subjects),
(char(strcat(Column(3),Column (1), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).COMVHS),(Subjects),
(char(strcat(Column(3),Column (2), Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Right.(ModelOutputs{6}).COMAHS),(Subjects),
(char(strcat(Column(3),Column (3), Row(3), Row(i+2)))));
```

```
                                end
                elseif Kinematics.(fileName{i}).nStrideR ==0
disp ('only one step for right')

                end
            end
        end
end

% LEFT
KinDataL={'LContactTime','LStrideTime','LStrideLength','LStrideR
ate','LCadence'};
AnkleL={'LAnkleAngleMaxX','LAnkleAngleMaxY','LAnkleAngleMaxZ','L
AnkleAngleMinX','LAnkleAngleMinY','LAnkleAngleMinZ','LAnkleAngle
MeanX','LAnkleAngleMeanY','LAnkleAngleMeanZ','LAnkleMeanHSX','LA
nkleMeanTOX'};
KneeL={'LKneeAngleMaxX','LKneeAngleMaxY','LKneeAngleMaxZ','LKnee
AngleMinX','LKneeAngleMinY','LKneeAngleMinZ','LKneeAngleMeanX','
LKneeAngleMeanY','LKneeAngleMeanZ','LKneeMeanHSX','LKneeMeanTOX'
,'LMaxKneeFlexSup','LMaxKneeExtTO'};
HipL={'LHipAngleMaxX','LHipAngleMaxY','LHipAngleMaxZ','LHipAngle
MinX','LHipAngleMinY','LHipAngleMinZ','LHipAngleMeanX','LHipAngl
eMeanY','LHipAngleMeanZ','LHipMeanHSX','LHipMeanTOX','LMaxHipFle
xSwingX'};
PelvisL={'LPelvisAngleMaxX','LPelvisAngleMaxY','LPelvisAngleMaxZ
','LPelvisAngleMinX','LPelvisAngleMinY','LPelvisAngleMinZ','LPel
visAngleMeanX','LPelvisAngleMeanY','LPelvisAngleMeanZ','LPelvisM
eanHSX','LPelvisMeanTOX','LMaxPelHeightSupY','LMaxPelDropSwingY'
};
ThoraxL={'LThoraxAngleMaxX','LThoraxAngleMaxY','LThoraxAngleMaxZ
','LThoraxAngleMinX','LThoraxAngleMinY','LThoraxAngleMinZ','LTho
raxAngleMeanX','LThoraxAngleMeanY','LThoraxAngleMeanZ','LThoraxM
eanHSX','LThoraxMeanTOX','LCOMMaxX'};
CentreOfMassL={'LCOMMaxX','LCOMMaxY','LCOMMaxZ','LCOMMinX','LCOM
MinY','LCOMMinZ','LCOMMeanX','LCOMMeanY','LCOMMeanZ','LCOMMeanHS
X','LCOMMeanTOX','LCOMdistancefromHS','LCOMVHS','LCOMAHS'};

for i= 1:length(fileName);
      for m = 1: length (ModelOutputsL)
xlswrite (strcat('_AngleData_'), KinDataL,(Subjects), 'CD1');
xlswrite (strcat('_AngleData_'), AnkleL,(Subjects), 'CI1');
xlswrite (strcat('_AngleData_'), KneeL,(Subjects), 'CT1');
xlswrite (strcat('_AngleData_'), HipL,(Subjects), 'DG1');
xlswrite (strcat('_AngleData_'), PelvisL,(Subjects), 'DS1');
xlswrite (strcat('_AngleData_'), ThoraxL,(Subjects), 'EF1');
xlswrite (strcat('_AngleData_'), CentreOfMassL,(Subjects),
'EQ1');
           if i >0 && i <=8  % only for trial 1-8
xlswrite (strcat('_AngleData_'), fileName(i),(Subjects), (char
(strcat(Column(2), Row(i+2)))));
           end
                if i >= 9 && i <=18 % for trial 9 to trial 18
xlswrite (strcat('_AngleData_'), fileName(i),(Subjects), (char
(strcat(Column(2), Row(2), Row(i+2)))));
                end
```

```
                    if i >= 19 && i <=22 % For trial 19 to 22
xlswrite (strcat('_AngleData_'), fileName(i),(Subjects), (char
(strcat(Column(2), Row(3), Row(i+2)))));
                    end
      end
end

for i= 1:length(fileName);
      for m = 1: length (ModelOutputsL)
            for n =1:Kinematics.(fileName{i}).nStrideL
                  if Kinematics.(fileName{i}).nStrideL >=1
                        if i >0 && i <=8
% Contacts
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.ContactTime(2,1)),(Subjects),(char(strcat(Column(3)
,Column(4), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.StrideTime(2,1)),(Subjects),(char(strcat(Column(3),
Column(5), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.StrideLength),(Subjects),
(char(strcat(Column(3),Column (6), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.StrideRate),(Subjects),
(char(strcat(Column(3),Column (7), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.Cadence),(Subjects), (char(strcat(Column(3),Column
(8), Row(i+2)))));
% Ankle
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{1}).Max(1,:)),(Subjects),(char(strca
t(Column(3),Column (9), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{1}).Min(1,:)),(Subjects),(char(strca
t(Column(3),Column (12), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{1}).Mean(1,:)),(Subjects),(char(strc
at(Column(3),Column (15), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{1}).MeanLanding),(Subjects),(char(st
rcat(Column(3),Column (18), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{1}).MeanToeOff),(Subjects),
(char(strcat(Column(3),Column (19), Row(i+2)))));
% Knee
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{2}).Max(1,:)),(Subjects),(char(strca
t(Column(3),Column (20), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{2}).Min(1,:)),(Subjects),(char(strca
t(Column(3),Column (23), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{2}).Mean(1,:)),(Subjects),(char(strc
at(Column(3),Column (26), Row(i+2)))));
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xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{2}).MeanLanding),(Subjects),(char(strcat(Column(4),Column (3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{2}).MeanToeOff),(Subjects),(char(strcat(Column(4),Column (4), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{2}).MaxKneeFlexSup),(Subjects),(char(strcat(Column(4),Column (5), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{2}).MaxKneeExtTO),(Subjects),(char(strcat(Column(4),Column (6), Row(i+2)))));
% Hip
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3}).Max(1,:)),(Subjects),(char(strcat(Column(4),Column (7), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3}).Min(1,:)),(Subjects),(char(strcat(Column(4),Column (10), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3}).Mean(1,:)),(Subjects),(char(strcat(Column(4),Column (13), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3}).MeanLanding),(Subjects),(char(strcat(Column(4),Column (16), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3}).MeanToeOff),(Subjects),(char(strcat(Column(4),Column (17), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3}).MaxHipFlexSwing),(Subjects),(char(strcat(Column(4),Column (18), Row(i+2)))));
% Pelvis
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).Max(1,:)),(Subjects),(char(strcat(Column(4),Column (19), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).Min(1,:)),(Subjects),(char(strcat(Column(4),Column (22), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).Mean(1,:)),(Subjects),(char(strcat(Column(4),Column (25), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MeanLanding),(Subjects),(char(strcat(Column(5),Column (2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MeanToeOff),(Subjects),(char(strcat(Column(5),Column (3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MaxPelHeightSup),(Subjects),(char(strcat(Column(5),Column (4), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MaxPelDropSwing),(Subjects),(char(strcat(Column(5),Column (5), Row(i+2)))));
% Thorax
```

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xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).Max(1,:)),(Subjects),(char(strcat(Column(5),Column (6), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).Min(1,:)),(Subjects),(char(strcat(Column(5),Column (9), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).Mean(1,:)),(Subjects),
(char(strcat(Column(5),Column (12), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).MeanLanding),(Subjects),(char(strcat(Column(5),Column (15), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).MeanToeOff),(Subjects),(char(strcat(Column(5),Column (16), Row(i+2)))));
% CentreOfMass
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).Max(1,:)),(Subjects),(char(strcat(Column(5),Column (17), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).Min(1,:)),(Subjects),(char(strcat(Column(5),Column (20), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).Mean(1,:)),(Subjects),(char(strcat(Column(5),Column (23), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).MeanLanding),(Subjects),(char(strcat(Column(5),Column (26), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).MeanToeOff),(Subjects),(char(strcat(Column(6),Column (1), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.COMdistancefromHeelav),(Subjects),(char(strcat(Column(6),Column (2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).COMAHS),(Subjects),(char(strcat(Column(6),Column (4), Row(i+2)))));
                      end
                            if i >= 9 && i <=18
% Contacts
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.ContactTime(2,1)),(Subjects),
(char(strcat(Column(3),Column (4), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.StrideTime (2,1)),(Subjects),
(char(strcat(Column(3),Column (5), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.StrideLength),(Subjects),
(char(strcat(Column(3),Column (6), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.StrideRate),(Subjects),
(char(strcat(Column(3),Column (7), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.Cadence),(Subjects), (char(strcat(Column(3),Column (8), Row(2), Row(i+2)))));
% Ankle
```

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xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{1}).Max(1,:)),(Subjects),(char(strca
t(Column(3),Column (9), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ky
Values.Left.(ModelOutputsL{1}).Min(1,:)),(Subjects),(char(strcat
(Column(3),Column (12), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{1}).Mean(1,:)),(Subjects),(char(strc
at(Column(3),Column (15), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{1}).MeanLanding),(Subjects),(char(st
rcat(Column(3),Column (18), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{1}).MeanToeOff),(Subjects),(char(str
cat(Column(3),Column (19), Row(2), Row(i+2)))));
% Knee
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{2}).Max(1,:)),(Subjects),(char(strca
t(Column(3),Column (20), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{2}).Min(1,:)),(Subjects),(char(strca
t(Column(3),Column (23), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{2}).Mean(1,:)),(Subjects),(char(strc
at(Column(3),Column (26), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{2}).MeanLanding),(Subjects),(char(st
rcat(Column(4),Column (3), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{2}).MeanToeOff),(Subjects),(char(str
cat(Column(4),Column (4), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{2}).MaxKneeFlexSup),(Subjects),(char
(strcat(Column(4),Column (5), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{2}).MaxKneeExtTO),(Subjects),(char(s
trcat(Column(4),Column (6), Row(2), Row(i+2)))));
% Hip
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{3}).Max(1,:)),(Subjects),(char(strca
t(Column(4),Column (7), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{3}).Min(1,:)),(Subjects),(char(strca
t(Column(4),Column (10), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{3}).Mean(1,:)),(Subjects),(char(strc
at(Column(4),Column (13), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{3}).MeanLanding),(Subjects),(char(st
rcat(Column(4),Column (16), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{3}).MeanToeOff),(Subjects),(char(str
cat(Column(4),Column (17), Row(2),  Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.Ke
yValues.Left.(ModelOutputsL{3}).MaxHipFlexSwing),(Subjects),(cha
r(strcat(Column(4),Column (18), Row(2), Row(i+2)))));
```

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% Pelvis
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).Max(1,:)),(Subjects),(char(strcat(Column(4),Column (19), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).Min(1,:)),(Subjects),(char(strcat(Column(4),Column (22), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).Mean(1,:)),(Subjects),(char(strcat(Column(4),Column (25), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MeanLanding),(Subjects),(char(strcat(Column(5),Column (2), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MeanToeOff),(Subjects),(char(strcat(Column(5),Column (3), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MaxPelHeightSup),(Subjects),(char(strcat(Column(5),Column (4), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MaxPelDropSwing),(Subjects),(char(strcat(Column(5),Column (5), Row(2), Row(i+2)))));
% Thorax
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).Max(1,:)),(Subjects),(char(strcat(Column(5),Column (6), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).Min(1,:)),(Subjects),(char(strcat(Column(5),Column (9), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).Mean(1,:)),(Subjects),(char(strcat(Column(5),Column (12), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).MeanLanding),(Subjects),(char(strcat(Column(5),Column (15), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).MeanToeOff),(Subjects),(char(strcat(Column(5),Column (16), Row(2), Row(i+2)))));
% CentreOfMass
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).Max(1,:)),(Subjects),(char(strcat(Column(5),Column (17), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).Min(1,:)),(Subjects),(char(strcat(Column(5),Column (20), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).Mean(1,:)),(Subjects),(char(strcat(Column(5),Column (23), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).MeanLanding),(Subjects),(char(strcat(Column(5),Column (26), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).MeanToeOff),(Subjects),(char(strcat(Column(6),Column (1),Row(2),  Row(i+2)))));
```

```
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.COMdistancefromHeelav),(Subjects),(char(strcat(Column(6),Column (2), Row(2), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).COMAHS),(Subjects),(char(strcat(Column(6),Column (4), Row(2), Row(i+2)))));
                           end
                                if i >= 19 && i <=22
% Contacts
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.ContactTime(2,1)),(Subjects),
(char(strcat(Column(3),Column (4), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.StrideTime (2,1)),(Subjects),
(char(strcat(Column(3),Column (5), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.StrideLength),(Subjects),
(char(strcat(Column(3),Column (6), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.StrideRate),(Subjects),(char(strcat(Column(3),Column(7),Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.Cadence),(Subjects), (char(strcat(Column(3),Column(8), Row(3),Row(i+2)))));
% Ankle
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{1}).Max(1,:)),(Subjects),
(char(strcat(Column(3),Column (9), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{1}).Min(1,:)),(Subjects),
(char(strcat(Column(3),Column (12), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{1}).Mean(1,:)),(Subjects),
(char(strcat(Column(3),Column (15),Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{1}).MeanLanding),(Subjects),
(char(strcat(Column(3),Column (18), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{1}).MeanToeOff),(Subjects),
(char(strcat(Column(3),Column (19), Row(3),Row(i+2)))));
% Knee
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{2}).Max(1,:)),(Subjects),(char(strcat(Column(3),Column (20), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{2}).Min(1,:)),(Subjects),(char(strcat(Column(3),Column (23), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{2}).Mean(1,:)),(Subjects),(char(strcat(Column(3),Column (26), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{2}).MeanLanding),(Subjects),(char(strcat(Column(4),Column (3), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{2}).MeanToeOff),(Subjects),(char(strcat(Column(4),Column (4), Row(3),Row(i+2)))));
```

```
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{2}).MaxKneeFlexSup),(Subjects),(char(strcat(Column(4),Column (5),Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{2}).MaxKneeExtTO),(Subjects),(char(strcat(Column(4),Column (6),Row(3), Row(i+2)))));
% Hip
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3}).Max(1,:)),(Subjects),(char(strcat(Column(4),Column (7), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3}).Min(1,:)),(Subjects),(char(strcat(Column(4),Column (10), Row(3),Row(i+2)))));
xlswrite (strcat('_AngleData_'),
(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3})
.Mean(1,:)),(Subjects),(char(strcat(Column(4),Column(13),Row(3),
Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3}).MeanLanding),(Subjects),(char(strcat(Column(4),Column (16),Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3}).MeanToeOff),(Subjects),(char(strcat(Column(4),Column (17), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{3}).MaxHipFlexSwing),(Subjects),(char(strcat(Column(4),Column (18), Row(3),Row(i+2)))));
% Pelvis
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).Max(1,:)),(Subjects),(char(strcat(Column(4),Column (19), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).Min(1,:)),(Subjects),(char(strcat(Column(4),Column (22), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).Mean(1,:)),(Subjects),(char(strcat(Column(4),Column (25),Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MeanLanding),(Subjects),(char(strcat(Column(5),Column (2),Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MeanToeOff),(Subjects),(char(strcat(Column(5),Column (3), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MaxPelHeightSup),(Subjects),(char(strcat(Column(5),Column (4),Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{4}).MaxPelDropSwing),(Subjects),(char(strcat(Column(5),Column (5),Row(3), Row(i+2)))));
% Thorax)
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).Max(1,:)),(Subjects),(char(strcat(Column(5),Column (6),Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).Min(1,:)),(Subjects),(char(strcat(Column(5),Column (9), Row(3),Row(i+2)))));
```

```
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).Mean(1,:)),(Subjects),(char(strcat(Column(5),Column (12),Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).MeanLanding),(Subjects),(char(strcat(Column(5),Column (15), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{5}).MeanToeOff),(Subjects),(char(strcat(Column(5),Column (16), Row(3),Row(i+2)))));
% CentreOfMass
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).Max(1,:)),(Subjects),(char(strcat(Column(5),Column (17),Row(3), Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).Min(1,:)),(Subjects),(char(strcat(Column(5),Column (20), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).Mean(1,:)),(Subjects),(char(strcat(Column(5),Column (23), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).MeanLanding),(Subjects),(char(strcat(Column(5),Column (26), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).MeanToeOff),(Subjects),(char(strcat(Column(6),Column (1), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.COMdistancefromHeelav),(Subjects),(char(strcat(Column(6),Column (2), Row(3),Row(i+2)))));
xlswrite(strcat('_AngleData_'),(Kinematics.(fileName{i}).Data.KeyValues.Left.(ModelOutputsL{6}).COMAHS),(Subjects),(char(strcat(Column(6),Column (4), Row(3),Row(i+2)))));
                                end
                elseif Kinematics.(fileName{i}).nStrideL ==0
disp ('only one step for left')
                end
           end
      end
end
```

STEP 10: TIME NORMALISED TO 101 POINTS

```
% Data needs to be cropped according to events
% Data= 1 stride, therefore 2 HS are required to define a stride
for i=1:length (fileName)
% Right foot
Kinematics.(fileName{i}).nStrideR=length(Kinematics.(fileName{i}).Events.RHS)-1; % number of strides = number of steps-1 in this case; i.e 2 HS= 1 stride
      for n =1:Kinematics.(fileName{i}).nStrideR % for the number of strides, and model outputs, crop that trial accordingly
           for j= 1:length (ModelOutputs)
Kinematics.(fileName{i}).Data.Cropped.Right.(ModelOutputs{j}).(strcat('Stride',num2str(n)))=Kinematics.(fileName{i}).Data.Raw.Right.(ModelOutputs{j})(Kinematics.(fileName{i}).Events.RHS (n)+1:Kinematics.(fileName{i}).Events.RHS (n+1)+1,:);
```

```
            end
        end
    % Left foot
    Kinematics.(fileName{i}).nStrideL=length(Kinematics.(fileName{i}
    ).Events.LHS)-1; % number of strides = number of steps-1 in this
    case; i.e 2 HS= 1 stride
        for n =1:Kinematics.(fileName{i}).nStrideL % for the
    number of strides, and model outputs, crop that trial
    accordingly
            for j= 1:length (ModelOutputsL)
    Kinematics.(fileName{i}).Data.Cropped.Left.(ModelOutputsL
    {j}).(strcat('Stride',num2str(n)))=Kinematics.(fileName{i}).Data
    .Raw.Left.(ModelOutputsL{j})(Kinematics.(fileName{i}).Events.LHS
    (n)+1:Kinematics.(fileName{i}).Events.LHS (n+1)+1,:);
            end
        end
    end
    % For the right leg only, finding the 101 normalised data points
    for i=1:length (fileName)
        for j= 1:length (ModelOutputs)
            for n = 1:Kinematics.(fileName{i}).nStrideR
                for r= 1:3
    Kinematics.(fileName{i}).Data.TimeNorm.Right.(ModelOutputs
    {j}).(strcat('Stride',num2str(n)))(:,r)...
     = spline (1:1:length
    (Kinematics.(fileName{i}).Data.Cropped.Right.(ModelOutputs
    {j}).(strcat ('Stride', num2str (n)))(:,r)),...
    Kinematics.(fileName{i}).Data.Cropped.Right.(ModelOutputs
    {j}).(strcat ('Stride', num2str (n)))(:,r),...
    0:length(Kinematics.(fileName{i}).Data.Cropped.Right.(ModelOutpu
    ts {j}).(strcat ('Stride', num2str (n)))(:,r))/100: ...
    length(Kinematics.(fileName{i}).Data.Cropped.Right.(ModelOutputs
    {j}).(strcat ('Stride', num2str (n)))(:,r)));
                end
            end
        end
    end
    % For the left leg
    ModelOutputsL = {'LAnkleAngles'; 'LKneeAngles'; 'LHipAngles';
    'LPelvisAngles'; 'LThoraxAngles';'CentreOfMass'};
    for i=1:length (fileName)
        for j= 1:length (ModelOutputsL)
            for n = 1:Kinematics.(fileName{i}).nStrideL
                for r= 1:3
    Kinematics.(fileName{i}).Data.TimeNorm.Left.(ModelOutputsL
    {j}).(strcat('Stride',num2str(n)))(:,r)...
    = spline (1:1:length
    (Kinematics.(fileName{i}).Data.Cropped.Left.(ModelOutputsL
    {j}).(strcat ('Stride', num2str (n)))(:,r)),...
    Kinematics.(fileName{i}).Data.Cropped.Left.(ModelOutputsL
    {j}).(strcat ('Stride', num2str (n)))(:,r),...
    0:length(Kinematics.(fileName{i}).Data.Cropped.Left.(ModelOutput
    sL {j}).(strcat ('Stride', num2str (n)))(:,r))/100: ...
    length(Kinematics.(fileName{i}).Data.Cropped.Left.(ModelOutputsL
    {j}).(strcat ('Stride', num2str (n)))(:,r)));
                end
```

```
            end
        end
    end
```

STEP 11: AVERAGE THE TIME NORMALISED CURVES

```
Coord = {'X', 'Y', 'Z'};
% Right leg
for i=1:length (fileName)
      for j= 1:length (ModelOutputs)
            for r= 1:3
                  for n = 1:Kinematics.(fileName{i}).nStrideR
Data.(fileName{i}).TimeNorm.Right.(ModelOutputs{j}).(Coord{r})(:
,n)=Kinematics.(fileName{i}).Data.TimeNorm.Right.(ModelOutputs
{j}).(strcat('Stride',num2str(n)))(:,r);
                  end
            end
      end
end

for i= 19:22
      for j= 1:length (ModelOutputs)
            for r= 1:3
Data.GM.Right.(ModelOutputs {j}).(Coord{r})(:,i)=
Data.(fileName{i}).TimeNorm.Right.(ModelOutputs
{j}).(Coord{r})(:,1);
            end
      end
end
% Left Leg
for i=1:length (fileName)
      for j= 1:length (ModelOutputsL)
            for r= 1:3
                  for n = 1:Kinematics.(fileName{i}).nStrideL
Data.(fileName{i}).TimeNorm.Left.(ModelOutputsL{j}).(Coord{r})(:
,n)=Kinematics.(fileName{i}).Data.TimeNorm.Left.(ModelOutputsL{j
}).(strcat('Stride',num2str(n)))(:,r);
                  end
            end
      end
end

for i= 20:22
      for j= 1:length (ModelOutputsL)
            for r= 1:3
Data.GM.Left.(ModelOutputsL{j}).(Coord{r})(:,i)=Data.(fileName{i
}).TimeNorm.Left.(ModelOutputsL {j}).(Coord{r})(:,1);
            end
      end
end
```

STEP 12: WRTIE TO EXCEL

```
Row = {'Ankle'; 'Knee';'Hip'; 'Pelvis'; 'Thorax'; 'COM'};
```

```
RowHeader={'T01';'T02';'T03';'T04';'T05';'T06';'T07';'T08';'T09'
;'T10';'T11';'T12';'T13';'T14';'T15';'T16';'T17';'T18';'T19';'T2
0';'T21';'T22'};
ColHeader = {'X', 'Y', 'Z'};
     for r = 1:3
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Right.(ModelOutpu
ts {1}).(Coord{r}), strcat('RAnkleAngles_',(Coord{r})),'A2');
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Right.(ModelOutpu
ts {2}).(Coord{r}), strcat('RKneeAngles_',(Coord{r})),'A2');
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Right.(ModelOutpu
ts {3}).(Coord{r}), strcat('RHipAngles_',(Coord{r})),'A2');
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Right.(ModelOutpu
ts {4}).(Coord{r}), strcat('RPelvisAngles_',(Coord{r})),'A2');
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Right.(ModelOutpu
ts {5}).(Coord{r}), strcat('RTrunkAngles_',(Coord{r})),'A2');
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Right.(ModelOutpu
ts {6}).(Coord{r}), strcat('COM_',(Coord{r})),'A2');
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Left.(ModelOutput
sL {1}).(Coord{r}), strcat('RAnkleAngles_',(Coord{r})),'X2');
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Left.(ModelOutput
sL {2}).(Coord{r}), strcat('RKneeAngles_',(Coord{r})),'X2');
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Left.(ModelOutput
sL {3}).(Coord{r}), strcat('RHipAngles_',(Coord{r})),'X2');
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Left.(ModelOutput
sL {4}).(Coord{r}), strcat('RPelvisAngles_',(Coord{r})),'X2');
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Left.(ModelOutput
sL {5}).(Coord{r}), strcat('RTrunkAngles_',(Coord{r})),'X2');
xlswrite(strcat(Subjects,'_TimeNorm_'),Data.TH.Left.(ModelOutput
sL {6}).(Coord{r}), strcat('COM_',(Coord{r})),'X2');
     end
```