BIOMECHANICAL, PHYSIOLOGICAL AND PERCEPTUAL RESPONSES OF THREE DIFFERENT ATHLETE GROUPS TO THE CYCLE-RUN TRANSITION.

BY

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ABSTRACT

The transition from cycling to running has been identified as one of the key determinants of success in triathlon, as it has been suggested that the cycle may affect subsequent running efficiency such that running performance is significantly altered or reduced. It is also suggested that athletes more adapted to the transition itself, rather than purely running or cycling, may be more efficient during the post-cycle running bout. The current study sought to investigate the effects of prior cycling on subsequent selected biomechanical, physiological and perceptual responses of three different athlete groups. Subjects were selected on the basis of their sporting background, and were divided into three groups – triathletes, cyclists and runners. Experimentation required subjects to perform a seven minute treadmill running protocol at 15km.h^{-1}, during which biomechanical (EMG, Stride rate, Stride length, Vertical acceleration), physiological (HR, VO_2, EE) and perceptual (RPE) responses were recorded. After resting, subjects were required to perform a twenty minute stationary cycle at 70% of maximal aerobic power (previously determined), immediately followed by a second seven minute treadmill running protocol during which the same data were collected and compared to those collected during the first run.

Biomechanical responses indicate that the cycle protocol had no effect on the muscle activity or vertical acceleration responses of any of the three subject groups, while the triathlete group significantly altered their gait responses in order to preserve running economy. The triathlete group was the least affected when considering the physiological responses, as running economy was preserved for this group. The runner and cyclist groups were significantly affected by the transition, as running economy decreased significantly for these groups. Perceptual responses indicate that athletes more experienced with the transition may find the transition from cycling to running to be easier than those inexperienced in this transition.

It is apparent that a high intensity cycle protocol has limited statistical impact on selected biomechanical responses, while physiological and perceptual responses were altered, during a subsequent run, regardless of athlete type. That said, the ability of transition-trained athletes to transition comfortably between disciplines was highlighted, which may have important performance implications.

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CHAPTER I

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Multisport endurance races such as triathlon, duathlon and biathlon provide athletes with challenges which are unique to such events. Athletes competing in these races are required to compete across a series of disciplines while performing optimally in each code (Chapman *et al.,* 2008). The transition from one discipline to the next, whether from swimming to cycling, cycling to running, or swimming to running, require the athletes to adapt to each new discipline. This will present new challenges both biomechanically and physiologically which they need to overcome in order to achieve success (Bentley *et al.,* 2008).

A competitive triathlon is comprised of a successive swim, cycle and run, and can be held over a variety of distances, the most common being the Sprint (750m swim, 20km cycle and 5km run), Olympic (1.5km swim, 40 km cycle and 10km run), half-Ironman (1.9km swim, 90km cycle and 21.1km run) and Ironman (3.8km swim, 180km cycle and 42.2km run). Each of these distances presents its own challenges with regards to training, preparation and race strategies. In order to maximise performance in triathlon, the athlete needs to complete each discipline at an optimal level and, importantly, needs to be able to make the transition from one code to the next without experiencing any adverse effects from the previous discipline (Millet and Vleck, 2000). The athlete's ability to limit energy expenditure across three disciplines while maintaining a high average speed has been identified as one of the key determinants of multisport performance (Vercruyssen *et al.,* 2001).

While the swim is an integral part of any triathlon, both research and anecdotal evidence within previous literature support the notion that it is the athletes ability to transition smoothly from the cycle to the run, and then run at maximum efficiency that is a key determinant of triathlon performance (Millet and Vleck, 2000; Chapman *et al.,* 2008). Since the run is the final stage of the triathlon it is likely that running performance is further complicated by the athlete's preceding effort in the swim and cycle stages of the race (Bentley *et al.,* 2008). In order to run effectively and efficiently, the triathlete is required to use muscle activity patterns that are running specific and are therefore not adversely affected by the demands of the previous cycle discipline (Chapman *et al.,* 2008).

However, according to Chapman *et al.,* (2008), most triathletes report a perception of impaired coordination when running after cycling. This impaired coordination during the ‘transition run’ can be associated with a change in the athlete’s running efficiency and economy. The effects of the prior cycle bout on running efficiency have been shown by Hue *et al.*(1998) to significantly increase the energy cost of running after cycling, as opposed to running only. The increase in energy cost of triathlon running may be linked to biomechanical alterations which occur as a direct result of the effects of the prior cycling exercise (Guezennec *et al.,* 1996; Millet *et al.,* 2000). Similarly, Marino and Goegan, (1993) reported an increase in mechanical work for triathlon running compared to a control run, coupled with a decrease in total running speed. However, most triathletes report impaired leg muscle coordination and overall performance at the onset of the run discipline, possibly related to fatigue brought on while cycling. Recent findings suggest that interference with the neuromuscular control of movement and muscle activity, resulting from repeated prior performance of the muscle activity patterns associated with cycling, may be responsible. It is likely that the above factors may result in changes in the gait mechanics of the athlete while running, which have a concomitant effect on the athlete’s efficiency and economy of motion (Bentley *et al.,* 2008).

The current study therefore chose to investigate the impact of a prior high intensity cycling bout on running performance during a triathlon. Although knowledge of the influence of the cycle-run transition on movement and muscle recruitment in highly performing triathletes is incomplete, it is likely that high intensity cycling can have a detrimental effect on subsequent running performance. These detrimental effects may be dependent on the experience level of the athlete, with greater effects on athletes new to the sport of triathlon or those without any experience in a multidisciplinary sport requiring the transition from cycling to running than on their experienced or elite counterparts (Bentley *et al.,* 2008; Chapman *et al.,* 2007). Due to the recent growth in triathlon as a sport, many athletes are changing from lone running or cycling to multisport. The result of this is there are expected to be differences between these groups and those experienced at triathlon. Furthermore, it is highly likely that differences between these groups of former single sport athletes exist.

The focus of this study is to determine the effects of a prior high-intensity cycling bout on the running performance of elite level triathletes, and to compare these effects to those experienced by single sport athletes skilled in either of the two key triathlon events – cycling or running.

1.2 STATEMENT OF THE PROBLEM

The athletes' ability to run effectively and efficiently after completing the swim and cycle disciplines is a key determinant of overall performance in triathlon. At present, the impact of a prior cycling bout on leg muscle recruitment, neuromuscular adaptations and running kinematics is poorly understood. Recent findings, however, suggest that the increased demands of transition running on both the neuromuscular and cardiorespiratory systems may have a significant impact on running performance, and hence on overall performance in any multisport endurance event requiring a cycle-run transition. Furthermore, the impact of athlete type (triathlete, runner or cyclist) and consequently the level of experience with the cycle-run transition have received limited scientific attention. The present study, therefore investigated the possible reasons for the perception of impaired coordination while running, as well as to determine the effects of triathlon competition level and experience on the severity and duration of the alterations which occur when running after a previous high-intensity cycling bout. A further goal of this research was to establish whether single-sport cyclists or single-sport runners are more affected by the biomechanical alterations associated with the cycle-run transition, thus giving an indication as to which of the two would be able to cross over into competitive triathlon with the most success.

1.3 RESEARCH HYPOTHESIS

Most triathletes report impaired leg muscle coordination when running after a previous high intensity cycling bout. The purpose of this research was to determine the effects of this cycling exercise on the athlete's muscle activity while running; to ascertain any changes in running mechanics which occur as a result of prior cycling; to determine the effect of the transition on the athlete's cardiorespiratory system, and to assess the influence of transition experience on the above variables. It was hypothesised that a prior bout of high intensity cycling will affect the leg muscle recruitment of the athletes while running, which would have a detrimental effect on the running kinematics of athletes at all ability levels. It was further hypothesised that experienced triathletes would display greater adaptation to the demands of prior cycling than their inexperienced counterparts, and would thus display either smaller alterations in muscle activity, running mechanics and cardiorespiratory function or would experience these changes for a shorter duration. It is also hypothesised that experienced triathletes, who have conditioned themselves for this transition, would also have a lower Rating of Perceived Exertion (RPE) for the transition run than the inexperienced athletes. Due to the lack of available literature regarding the effects of transition running on trained single sport cyclists or runners, this hypothesis was purely non-directional.

1.4 STATISTICAL HYPOTHESES

IMPACT OF THE TRANSITION

Biomechanical variables (muscle activity and running kinematics) will be the same for experienced triathletes, single sport cyclists and single sport runners between a control run and a transition run.

H_o: $\mu_{\text{CONT Triathletes \& Cyclists \& Runners}} = \mu_{\text{TRAN Triathletes \& Cyclists \& Runners}}$

H_a: $\mu_{\text{CONT Triathletes \& Cyclists \& Runners}} \neq \mu_{\text{TRAN Triathletes \& Cyclists \& Runners}}$

CONT = Control Run; TRAN = Transition Run

Physiological responses (heart rate, VO^2 and energy expenditure) will be the same for experienced triathletes, single sport cyclists and single sport runners between a control run and a transition run.

H_o: $\mu_{\text{CONT Triathletes \& Cyclists \& Runners}} = \mu_{\text{TRAN Triathletes \& Cyclists \& Runners}}$

H_a: $\mu_{\text{CONT Triathletes \& Cyclists \& Runners}} \neq \mu_{\text{TRAN Triathletes \& Cyclists \& Runners}}$

CONT = Control Run; TRAN = Transition Run

Perceptual responses (RPE) will be the same for experienced triathletes, single sport cyclists and single sport runners between a control run and a transition run.

H_o: $\mu_{\text{CONT Triathletes \& Cyclists \& Runners}} = \mu_{\text{TRAN Triathletes \& Cyclists \& Runners}}$

H_a: $\mu_{\text{CONT Triathletes \& Cyclists \& Runners}} \neq \mu_{\text{TRAN Triathletes \& Cyclists \& Runners}}$

CONT = Control Run; TRAN = Transition Run

IMPACT OF ATHLETE GROUP

Biomechanical variables (muscle activity and running kinematics) will be the same between triathletes, single sport cyclists or single sport runners for a control run and a transition run.

H_o: $\mu_{\text{Triathletes CONT}} = \mu_{\text{Runners CONT}} = \mu_{\text{Cyclists CONT}}$

H_a: $\mu_{\text{Triathletes CONT}} \neq \mu_{\text{Runners CONT}} \neq \mu_{\text{Cyclists CONT}}$

H_o: $\mu_{\text{Triathletes TRAN}} = \mu_{\text{Runners TRAN}} = \mu_{\text{Cyclists TRAN}}$

H_a: $\mu_{\text{Triathletes TRAN}} \neq \mu_{\text{Runners TRAN}} \neq \mu_{\text{Cyclists TRAN}}$

CONT = Control Run; TRAN = Transition Run

Physiological responses (VO_2 and energy expenditure) will be the same between triathletes, single sport cyclists and single sport runners for a control run and a transition run.

H_o: $\mu_{\text{Triathletes CONT}} = \mu_{\text{Runners CONT}} = \mu_{\text{Cyclists CONT}}$

H_a: $\mu_{\text{Triathletes CONT}} \neq \mu_{\text{Runners CONT}} \neq \mu_{\text{Cyclists CONT}}$

H_o: $\mu_{\text{Triathletes TRAN}} = \mu_{\text{Runners TRAN}} = \mu_{\text{Cyclists TRAN}}$

H_a: $\mu_{\text{Triathletes TRAN}} \neq \mu_{\text{Runners TRAN}} \neq \mu_{\text{Cyclists TRAN}}$

CONT = Control Run; TRAN = Transition Run

Perceptual responses (RPE) will be the same between triathletes, single sport cyclists and single sport runners for a control run and a transition run.

$H_o: \mu_{\text{Triathletes CONT}} = \mu_{\text{Runners CONT}} = \mu_{\text{Cyclists CONT}}$
$H_a: \mu_{\text{Triathletes CONT}} \neq \mu_{\text{Runners CONT}} \neq \mu_{\text{Cyclists CONT}}$
$H_o: \mu_{\text{Triathletes TRAN}} = \mu_{\text{Runners TRAN}} = \mu_{\text{Cyclists TRAN}}$
$H_a: \mu_{\text{Triathletes TRAN}} \neq \mu_{\text{Runners TRAN}} \neq \mu_{\text{Cyclists TRAN}}$

CONT = Control Run; TRAN = Transition Run

1.5 DELIMITATIONS

Although the investigation was undertaken with the utmost effort to control any extraneous variables, the following factors presented limitations to the study and should be considered when examining the results.

The test sample was drawn from the triathlon team based at the University of Pretoria High Performance Centre, as well as from the student body at Rhodes University. As every effort was made to ensure that all subjects met the required performance criteria, only a small number of athletes were deemed suitable. In the case of the runner and cyclist groups drawn from the Rhodes University student body, performance criteria were reduced slightly to include athletes who could be considered ‘highly-trained’ or ‘habitual’ runners or cyclists, rather than ‘elite’. Unfortunately, due to the stringent performance requirements chosen for the current research, there was a lack of appropriate subjects available on a volunteer basis. This lead to a reduced number of subjects being tested within each category, which may have had an effect on the subsequent statistical results.

Due to the nature of the test protocols, subjects were required to be healthy enough to take part in moderate- to high-intensity exercise. Subjects should not have had a history of respiratory disorders or musculoskeletal disorders of the lower extremity, but were not required to undergo medical clearance. As all subjects were chosen on a volunteer basis, testing was limited to just two sessions per subject.

1.6 LIMITATIONS

Despite the researcher’s best efforts, the network causality of all the individual factors (such as biomechanical, physiological and perceptual) rendered it impossible to control for all eventualities. However, every effort was made to ensure rigorous control of as many extraneous factors as possible. The following limitations remained and should be taken into consideration when examining the results.

Subjects were volunteers, and were thus self-motivated to perform optimally, although researchers made every effort possible to motivate the subjects throughout the study.

Besides the requested dietary compliance, subjects followed normal eating, drinking and exercise habits during the course of the study, with no researcher control over these external factors.

Clear and detailed instructions were given on the use and interpretation of the perceptual scales, however, “self reports” continue to be problematic, and the validity of these results must be appraised with this consideration in mind.

CHAPTER II

REVIEW OF RELATED LITERATURE

Triathlon is a multidisciplinary endurance sport encompassing the three disciplines of swimming, cycling and running. Multidisciplinary sports place unique demands on individuals as they are required to adapt to the specific demands of each code in such a way as to optimise performance (Bentley *et al.,* 2008). Although the concept of multisport events is not a new one, there has been a significant rise in the popularity and precedence of these sports in recent times. This is largely due to the inclusion of competitive triathlon in the Olympic Games, with the inaugural Olympic triathlon event taking place at the Sydney Summer Olympics in 2000. Coupled with this, the advent of mass participation events, as well as the rising popularity of ultra-distance events, has seen multidiscipline sport, and particularly triathlon, gaining massive popularity in recent years.

Due to the increase in popularity of these sports and increased competitiveness, there has been an associated increase in the amount of research into the aspects which are unique to these events, as well as on the performance determinants which are required for multisport success. One of the primary factors involved in competitive multisport events is the transitions between sports. With specific reference to triathlon, it has been determined that the transition from cycling to running has an important effect on running performance, which may well be linked to overall triathlon success (Vercruyssen *et al.,* 2001).

Research into the cycle-run transition has focused on a variety of different aspects. Chapman *et al*., (2008) measured the effects of cycling on motor coordination of the leg while running, while Hue *et al*., (1998) focused on the biomechanical and cardiorespiratory responses of triathletes during running. There has also been extensive research in the physiological cost of transition (cycle-run) running as compared to lone running, as well as the concomitant effects on performance (Guezennec *et al.,* 1996; Millet and Vleck*.,* 2000; Chapman *et al.,* 2008)

2.1 PERFORMANCE DETERMINANTS FOR ENDURANCE SPORT

The desire of all athletes to be able to compete at the highest level, and to bridge the gap between novice and elite status, forms the basis of extensive research into the factors which influence endurance performance (Coyle, 1999; Chapman *et al.,* 2008; Joyner and Coyle, 2008). In order to achieve successful endurance performance it is necessary to take a multi-faceted approach to training, as there are numerous factors which can influence performance (Coyle, 1999). A similar approach must be taken when conducting research into endurance performance, as it is necessary to account for as many variables which may potentially affect the outcomes of a given performance test as possible, thereby affecting the results of any research. Although research into the identification of performance determinants has established the importance of nutritional, psychological and psychosocial factors, the majority of research is focussed on the physiological and biomechanical parameters related to endurance performance (Joyner and Coyle, 2008).

An individual's maximal oxygen uptake (VO_{2MAX}) is traditionally accepted as the best indicator of that individual's ability to perform in endurance activities (Millet *et al*., 2002). VO_{2MAX} is used as an indication of the cardiorespiratory abilities of the individual as it can be defined as the highest rate at which oxygen can be taken up during exercise (Coyle, 1999). However, further physiological variables such as peak power output, lactate threshold and fractional utilisation of VO_{2MAX} can also be positively related to successful endurance performance (Lindsay *et al*., 1996).

Biomechanical factors such as movement economy, movement kinematics and muscle activity relating to the specific endurance sport being undertaken are also important determinants of endurance performance (Pialoux *et al*., 2008). The key endurance performance determinant is related to an individual's economy of movement. The ability to exercise for sustained periods while minimising the caloric cost of the given exercise is vital to performance in long duration events (Joyner and Coyle, 2008). The interaction between biomechanical and physiological variables is important when considering the mechanical efficiency or economy of a particular movement pattern. Mechanical efficiency is a ratio of work done during a task to the energy expenditure of that task (Coyle, 1999). Hence, in order to successfully perform in endurance based activities, it is necessary to optimise this interaction such that the physiological cost of an activity is minimised through the management of biomechanical factors such that no reduction in overall race speed occurs (Vercruyssen *et al*., 2001).

PERFORMANCE DETERMINANTS SPECIFIC TO TRIATHLON

The current study focused on the key factors surrounding the cycle-run transition which may influence overall triathlon performance. Several authors have suggested that the main determinants of triathlon performance are a high maximal oxygen uptake (VO_{2MAX}),a high lactate threshold and maximum sustainable percentage of VO_{2MAX} (Zhou *et al.,* 1997; Millet and Vleck, 2000). These physiological variables need to be optimised in conjunction with biomechanical factors to ensure that performance in each discipline is maximised to the extent that the energy cost of each discipline is minimised (Millet and Vleck*,* 2000).

Triathlon, like most multidisciplinary sports, is a relatively new event which has seen a growth in popularity since its inclusion at the 2000 Sydney Summer Olympics. The linking together of the three disciplines of swimming, cycling and running provide athletes with challenges which are unique to this type of event (Friel, 2009). Although the swimming discipline is an integral part of the triathlon event, it is commonly accepted that overall triathlon performance is largely dependent on the athlete's performance in the cycle and run disciplines (Millet *et al.,* 2000; Bentley *et al.,* 2008). In the same light, several studies agree that it is the run discipline which is the key determinant of triathlon performance (Millet and Vleck*,* 2000; Chapman *et al.,* 2008). The relative importance of running in triathlon is emphasised by the greater variability in running performances in triathlons when compared to the swimming and cycle stages, where competitors are closer together (Vleck *et al.,*2008). However, the ability of the triathletes to link the three triathlon disciplines in an optimal manner remains an important determinant of success (Hue *et al*., 1998). Although it is suggested that running is the key discipline in triathlon, it must be noted that optimal performance in the run phase is affected by the prior swim and cycle. The cycle, in particular, has an important impact as fatigue and interference with muscle recruitment as a result of the cycling exertion are imperative to subsequent running efficiency (Millet and Vleck, 2000; Chapman *et al.,* 2008). The current study, therefore, focused on the effects of the cycle on triathlon performance, with specific reference to the cycle-run transition. This transition has been identified as the key transition between disciplines during triathlon, and is therefore the most pertinent to success (Millet and Vleck, 2000).

PERFORMANCE DETERMINANTS SPECIFIC TO RUNNING

Critical physiological factors for performance in running are VO_{2MAX}, fractional VO_{2MAX} utilisation and running economy; as such, high correlations have been demonstrated between VO_{2MAX} and running performance in groups of runners of different abilities (Larsen, 2003). However, when athletes of similar performance abilities or within a narrow VO_{2MAX} range are compared, VO_{2MAX} becomes a less sensitive predictor of performance. In this case, it is an individual's running economy that has been shown to be a better predictor of running performance (Conley and Krahenbul, 1980; Bonacci *et al.,* 2010). Furthermore, it has been reported by several investigations that the fractional utilisation of VO_{2MAX} during running plays a crucial role in middle to long distance run performance (Hausswirth *et al.,*1996; Pialoux *et al.,* 2008)

The majority of factors that may explain a superior ability to exercise at a high percentage of VO_{2MAX} are related to the specific characteristics of the muscles involved in the running action. A moderate to strong relationship exists between middle to long distance running performance and the proportion of type I muscle fibres (Sjodin and Jacobs, 1981). The same authors reported that the percentage of type I muscle fibres may be an indicator of the potential 'trainability' of the individual's musculature, as endurance training has been demonstrated to induce a high mitochondrial oxidative capacity of type I muscle fibres.

PERFORMANCE DETERMINANTS SPECIFIC TO CYCLING

The importance of cycling in triathlon performance, particularly considering triathlon running performance, is most apparent when considering the fact that both running and cycling place large demands on the musculature of the leg. Furthermore, being a long-term, endurance sport, cycling possesses similar physiological requirements for optimum performance to both single sport running and triathlon. The physiological performance of the cyclist is determined by physiological parameters such as maximum oxygen consumption (VO_{2MAX}), lactate threshold and peak aerobic power producing capacity (W_{max}) (Coyle, 1999). According to classifications suggested by

Jeukendrup *et al.,* (2000), well trained to elite level single sport cyclists should have a Vo_{2MAX} of 70 – 80 $ml.kg^{-1}.min^{-1}$, and a W_{max} of 300 – 500 W.

However, unlike running, cycling combines the physical abilities of humans with the technological abilities provided by the bicycle, thus the combination of these two factors allows for the creation of several permutations by which cycling performance and efficiency can be both modified and improved (Jeukendrup *et al*., 2000). The majority of these permutations relate to the interaction between the human and the machine, which allows for the use of mechanical interventions to ensure that the biomechanical efficiency of the athlete is maximised (Jeukendrup *et al*., 2000).

2.2 ECONOMY OF MOVEMENT

It is generally accepted that the most important factor which determines an individual's efficiency is the preservation of energy – i.e. maximisation of energy efficiency. It is suggested that for aerobic, steady state activities, individuals naturally choose movement strategies that are the most economical with regard to energy expenditure (Novacheck, 1998).

ECONOMY OF RUNNING

Running economy, described as the relationship between running speed and its associated oxygen consumption, has been shown to be an excellent predictor of endurance performance (Palmer and Sleivert, 2001). Within a homogenous group of athletes, running economy, and not VO_{2MAX}, is strongly related to performance, as the runner with the best running economy will consume less oxygen at a given submaximal workload, allowing them to run faster at the same relative intensity or to run for longer at the same speed (Palmer and Sleivert, 2001).

Essentially, any improvement in running economy will result in a decrease in oxygen consumption for the running task, as well as a concomitant decrease in the total energy expenditure for that task (Saunders *et al.,* 2004). Therefore, any increase in running economy will also result in an increase in performance (Palmer and Sleivert, 2001). As discussed previously, the running leg of a triathlon competition has been identified as integral to overall performance. As with any endurance running event, the athletes with the greater running economy will perform better in this phase.

However, in terms of triathlon, it is the athlete who is able to display the greatest running efficiency despite the effects of the prior swim and cycle phases that may produce the most optimal performance (Chapman *et al.,* 2008). Consequently the ability of the athlete to run at a better economy during a transition run becomes imperative in determining the ability of the athlete to perform during the running phase. Therefore the current study chose to investigate how the transition from cycling to running affects the running economy of the athlete, and also if any of the measured biomechanical variables played a role in influencing running economy.

FACTORS AFFECTING RUNNING ECONOMY

Measurement of steady-state aerobic demand (an indication of economy) amongst a randomised sample for any submaximal activity would show a considerable amount of inter-subject variability (Martin and Morgan, 1992).There are several explanations for these variations in movement economy between subjects, which can include intra-individual variations, physiological differences and biomechanical factors.

Intra-individual Variability

The understanding of intra-individual variability is an important consideration when assessing the aerobic cost of a given task (Morgan and Craib, 1992). It is necessary to account for possible day-to-day variations in running economy, as accurate knowledge of intra-individual variability can ensure that a stable criterion is established by which running economy can be measured across individuals (Morgan and Craib, 1992). Daniels (1985) measured running aerobic demand in 10 well trained male athletes, using 15 treadmill run protocols equally spaced over a period of seven months. Although running speed, footwear and test equipment were controlled, the study failed to control external variables that may influence running economy, such as circadian variation and training activity within the seven month period. These factors may thus have an effect on the results of the study, which showed an 11% intra-individual variation in the aerobic demand of running. A subsequent study by Morgan *et al*. (1991) recorded the running economy of 17 trained male athletes, across two treadmill protocols, and reported just 1.3% variation in intra-individual running economy. In this case, time of day, footwear and fatigue state were controlled.

Several other studies have found similar results. For example, Brisswalter and Legros (1994) showed a 4.7% intra-individual variation in running economy for 10 elite 800m runners, and Periera and Freedson (1997) reported an intra-individual variation of 1.8% for well trained athletes and 2% for moderately trained individuals. It can thus be concluded from the reviewed literature that intra-individual variability ranges from 1.3% to 11%, but the extent of variability may well be reduced by utilising strict experimental procedures which account for and control all extraneous variables. It was therefore necessary for the current research to ensure that as many extraneous variables were accounted for as possible.

Physiological Factors

It is generally accepted that running economy, defined as the aerobic demand of submaximal running, is related to endurance running performance among athletes with comparable VO_{2MAX} values (Daniels, 1985; Morgan *et al.,* 1989; Krahenbuhl *et al.,* 1989). Several physiological parameters have been identified explaining why individuals matched for fitness and performance backgrounds display variations in running economy.

According to Morgan and Craib (1992), inter-individual variation in running economy can be linked to differences in athlete's heart rate and ventilation, as these two physiological parameters reflect oxygen supply to the active muscles. Pate *et al.,* (1989) report that a positive correlation exists between heart rate, ventilation and oxygen consumption, indicating that better running economy can be associated with reduced heart rate and ventilation. This has obvious performance implications in that an athlete with lower cardiorespiratory responses will be able conserve energy for longer, and thus be more suited to endurance activities.

Gender

There is contrasting evidence in the reviewed literature as to the role that gender may have in determining an athlete's running economy. No significant differences in aerobic efficiency were found between male and female athletes for 30 minutes of level or downhill running (Westerlind *et al.,* 1994), while Bransford and Howley (1977) had earlier reported significantly increased running economy relative to body mass for male athletes relative to their female counterparts. Glace *et al.,* (1998) recorded a significant increase in submaximal oxygen consumption in males after two hours of submaximal running, which represented a decrease in running economy when compared to the female athletes, who recorded no increase in submaximal oxygen consumption.

Biomechanical Factors

Research by Williams and Cavanagh (1987) supports the hypothesis that biomechanical (both kinetic and kinematic) variables are significantly related to running economy, as running mechanics have an effect on metabolic demand. It has been shown that alterations in running mechanics that result in a runner using less energy at a given speed will ultimately result in improved running performance (Anderson, 1996). This is of particular interest within the unique world of triathlon as the prior cycling leg will have an effect on the mechanics of the running phase, which will consequently have an impact on the economy of movement. It is therefore apparent that for an athlete to obtain optimum performance it is necessary to reduce the effects of the prior cycle on subsequent running performance.

Stride length and stride frequency have been identified as two of the primary kinematic variables that affect running economy (Morgan *et al.,* 1989). Several studies have demonstrated that the aerobic demands of running at a controlled speed tend to increase when stride length, and hence stride rate, is altered such that it differs from the individual's preferred stride rate or stride length (Cavanagh and Williams, 1982; Martin and Morgan, 1992). The basic assumption of this research is that longer stride length results in higher braking forces at heel strike, requiring increased power during propulsion that may invoke increased internal friction and stiffness. Conversely, running with a short stride length may increase internal work through increased frequency of reciprocal movement (Cavanagh *et al.,*1977). As early as 1922, Hill demonstrated that muscle efficiency varies with shortening velocity, hence, a most efficient velocity exists. It therefore follows, that changes in stride length or rate require concomitant changes in the rate of muscle shortening and lengthening, which will result in altered aerobic demand. In most cases, according to Martin and Morgan (1992), an individual's preferred stride rate and stride length combination equate to the optimal values for these parameters, while very few individuals show a preferred stride rate and stride length combination that greatly differs from optimal. The curvilinear relationship between the stride length-stride rate combination and running economy has the effect that running economy is not excessively sensitive to small variations in stride length or rate, while large scale deviations from the optimal stride length or rate will affect the running economy of the individual (Martin and Morgan, 1992). That said, the specific mechanisms associated with the curvilinear relationship between stride length, stride rate and running economy are unclear, but may be associated with fundamental muscle force and power generating abilities (Martin and Morgan, 1992).

The most apparent finding regarding stride length and running economy is that there is no one efficient stride length, as both intra-individual and inter-individual variability is high (Williams and Cavanagh, 1987). It has been established that the stride length (and hence stride rate) freely chosen by the athlete is the most economical, and therefore evokes the greatest mechanical efficiency (Morgan *et al.,* 1994). Deviations from the freely chosen stride length have consistently evoked increases in the oxygen cost of a given running task (Cavanagh and Williams, 1982; Morgan *et al.,* 1994). It has been suggested that runners are able to integrate all the relevant internal factors as well as perceived exertion in order to adjust their stride length to that which minimises energy cost (Cavanagh and Williams, 1982; Morgan *et al.,* 1994).

The influence of running skill on variability in the gait cycle was studied by Nakayama *et al.* (2010), who found that long term running practice can produce a stable and consistent gait cycle, due to a decrease in variability in inter-limb coordination. However the predominant differences in coordination between trained runners and untrained non-runners was caused by trained runners choosing a higher preferred running speed. When the variance due to running speed was accounted for, no significant effects of running training were found (Nakayama *et al,* 2010). To date, no studies have investigated the direct effect of the cycle-run transition on the stride-length and stride-rate relationship. If there is an effect of the transition upon the freely chosen or natural stride rate or length of an individual, it follows that there will be a concomitant decrease in running economy. The current study therefore chose to investigate the effects of the cycle-run transition on this variable.

Vertical displacement refers to the movement of an individual's centre of mass during locomotion. During normal walking, a high vertical displacement is evident due to the constant trade off between kinetic and potential energy with each step. During running however, this trade off is minimised due to the change in mechanics which occurs during running. As more flexion and extension of the knees occurs during running than walking, there is a reduced centre of mass displacement with each step. Hence, in order to be most efficient when running, it is important to reduce vertical displacement as much as possible, as while it is impossible to produce only horizontal force with each step, any vertical movement which occurs is essentially wasted energy. Cavanagh (1982) found that elite male distance runners had a lower vertical displacement than their sub-elite counterparts, although this difference was not significant and could not be related to economy as submaximal oxygen consumption was not measured. Subsequently, Williams and Cavanagh (1987) found a consistent relationship between lower vertical displacement and lower aerobic demand of running. Once again, however, these results were not significant. Although Dutton and Smith (2002) found an increase in the amount of vertical displacement as an athlete neared exhaustion, submaximal oxygen consumption was again not measured, thus giving no indication of the effects of these changes on running economy. It is thus inconclusive, based on the literature reviewed, whether or not the amount of vertical displacement while running has any effect on running economy. The current study investigated this further, in order to establish if any possible link between vertical displacement and running economy existed.

ECONOMY OF CYCLING

It has been previously stated by Ettema and Loras (2009) that several factors affecting cycling efficiency have been researched extensively, including task variations (load, chainring shape and body position), environmental conditions and subject characteristics such as training status. That said, it has been widely accepted that cadence has the biggest impact on cycling efficiency, and is also one of the few variables that the cyclist can modify during exercise in order to achieve the optimal combination between power output and physiological cost (Faria *et al.,* 1984; Bentley *et al.,* 2008).

Cadence and Cycling Efficiency

During running, the athlete naturally adopts the pattern of locomotion corresponding to the lowest energy cost (Cavanagh *et al*., 1982). This, however, is not necessarily the case with cycling. Although it has been shown by several studies that athletes adopt cadences that minimise either the oxygen demand, muscular activity, joint moments or pedal forces for a given power output (Patterson and Moreno, 1990; Marsh *et al.,* 2003). However, conflict has been observed between the energetically optimal cadence (cadence at which oxygen demand is minimised) and the freely chosen cadence (cadence spontaneously chosen by the athlete) (Marsh and Martin, 1993). The same authors have shown that the energetically optimal cadence is between 55 – 65 rpm, whereas most trained subjects choose to cycle at 80 – 95 rpm. The choice of higher cadences has been linked to the minimisation of lower extremity stress and forces applied to the pedal cranks (Takaishi *et al.,* 1994).

Unlike running and walking, where efficiency is determined by the gait pattern that corresponds to the lowest aerobic demand (Cavanagh *et al.,* 1982), the criteria that determine efficiency in cycling tend to be related more to the reduction in neuromuscular and biomechanical responses than the associated metabolic costs (Vercruyssen and Brisswalter, 2009).

2.3 THE INFLUENCE OF THE CYCLE-RUN TRANSITION

Due to the fact that the first transition in a triathlon (swim-cycle) is seen as having a negligible effect on the athlete’s overall performance, little research has been conducted in this area (Borchers and Buckenmeyer*,* 1987). Traditionally, the second transition (cycle-run) has been regarded as being the most important to performance, and has therefore been more extensively researched (Millet and Vleck*,* 2000). Most research, however, focuses on the Olympic distance event (1.5km Swim, 40km Bike, 10km Run). That said, many of the adaptations inherent to high performance triathlon competition are both necessary and apparent in both the shorter (Sprint) and longer (Half-Ironman, Ironman) distance events.

EFFECT OF CYCLE PACING STRATEGY

Much emphasis has been placed on researching the effects of different pacing strategies on subsequent running performance. Suriano *et al.,* (2007) aimed to investigate the effects of constant versus variable power output cycling on the subsequent treadmill run time to exhaustion. Subjects performed 30 minutes of cycling either utilising a constant or stochastic pacing strategy, with the same average power output. Each cycling bout was immediately followed by a high intensity treadmill run to exhaustion, with a significant improvement in running performance following the variable intensity cycling protocol. However, an earlier study by Palmer *et al.,* (1999) found no differences in 20km cycling time trial performance following 140minutes of either stochastic or constant intensity cycling. Furthermore, Lepers *et al.,* (2008) reported that although sprint triathletes perform high intensity cycling at the beginning and end of the cycle leg of the race, these variations in intensity have no influence on the neuromuscular fatigue of the knee extensors. It has been suggested that it is the amount of high intensity cycling during the final minutes of the cycle leg that may determine subsequent exercise performance (Suriano *et al.,* 2001). It is therefore inconclusive as to whether or not a constant or stochastic pacing strategy is ideal for triathlon performance. The current study chose to focus on a constant pacing strategy in order to ensure that overall power output could be related to total demand of triathlon, rather than focus on a pacing strategy which may be route/course specific.

PHYSIOLOGICAL INFLUENCES

Previous studies have indicated that triathlon running (i.e. running after a prior cycling bout) is harder than control running at the same speed (Millet and Vleck, 2000). Oxygen consumption, breathing frequency, ventilation rate and heart rate have all been shown to increase during a transition run when compared to a control run (Millet and Vleck, 2000). The increase in physiological variables may be due to the cycle to run transition inducing leg muscle fatigue, resulting in a redistribution of muscle blood flow between the different muscle groups (Hausswirth *et al.,* 1996;Millet and Vleck, 2000). In a previous study, Hausswirth *et al.* (1999) found that the energy cost of running was between 1.6% and 11.6% higher for a transition run than for a control run, although this study did not make use of trained triathletes.

Pialoux *et al.,* (2008) assessed the decrease in running efficiency that occurs during transition running, finding that the increase in VO_2 generally observed during running post-cycling may be explained by increased lipid oxidation as a metabolic substrate caused by a depletion of muscle glycogen.

The extent to which the energy cost of running is increased is dependent on the conditions under which the athlete completed the preceding cycle leg (Hausswirth *et al.,* 1999). Further research on the topic by the same authors found that completing the cycling protocol alone or in a sheltered position (as seen in draft-legal races) had a significant effect on the post-cycle run performance. Athletes' physiological responses to the running protocol were significantly higher for the draft-legal protocol than for the non-draft protocol, yet the associated average running speed was also significantly higher. Hausswirth *et al.,* (1999) hypothesised that the triathletes were able to save a significant amount of energy when cycling in the draft legal protocol, which allowed them to expend more energy on the subsequent run. A later study by Gottschall and Palmer (2002) found that triathletes who utilised a high cadence for a cycling protocol were able to improve on their subsequent 3200m run time without any increased physiological responses compared to either a self-selected cadence or a slow cadence protocol.

BIOMECHANICAL MODIFICATIONS

The increase in energy cost of the transition run may be related to changes in the athlete's biomechanics, as the athlete adjusts to the different demands of running as opposed to cycling (Millet and Vleck*,* 2000). These biomechanical alterations were shown by Marino and Goegan (1993), who filmed athletes during a 10km transition run and a 10km control run, showing an increase in mechanical work despite a 38% decrease in running speed. An 8% decrease in running efficiency was also reported by Guezennec *et al.* (1996) for a transition run compared to a control run. This finding was later confirmed by Hausswirth *et al.* (1996), who suggested that kinematic variables such as stride length, trunk gradient, knee angle in the non-support phase and knee extension during the stance phase could partly explain differences in running economy. Although some authors (Quigley and Richards*,* 1996; Hue *et al*, 1998) report that stride length is unchanged in runners after a prior cycling bout, other authors have noted a significant decrease in stride length during a transition run, and have attributed it to local muscle fatigue resulting from the previous cycle (Hausswirth *et al.,* 1996). During eccentric contractions, this muscle fatigue results in a decrease in the energy stored in the muscle and lowers the efficiency of resultant stretch shortening movements such as running (Nicol *et al.,* 1996).

Nicol *et al.* (1996) reported disruptions in the electromyographic (EMG) activity of the vastus lateralis, tibialis and tensor fascia latae muscles as a result of the change from concentric muscle contractions in cycling to the stretch shortening activity in running, and caused by an alteration in motor unit recruitment. An increase in forward leaning posture, which may affect running economy, has also been reported by Hausswirth *et al.*(1996) during a transition run. This change in trunk gradient has been attributed to differences in lumbar and abdominal muscle contractions induced by the change in body position between cycling and running (Hausswirth *et al.,* 1996). More recently, Bini *et al.,* (2008) investigated the EMG responses to a 40km cycling time trial. Subjects were required to complete the time trial in the fastest possible time, utilising a freely chosen pacing strategy. Importantly, the results of this study confirmed those of an earlier study by Duc *et al.,* (2005) which suggested that a muscular 'steady state' is achieved after 30minutes of cycling, even in the course of a 40km time trial. This 'steady state' was observed for all assessed muscles, apart from vastus lateralis, which is a key force producer, and is most likely an attempt to avoid premature muscle fatigue (Duc *et al.,* 2005).

INFLUENCE OF TRIATHLETE ABILITY LEVEL

Several studies have suggested that the extent to which the energy cost of running is increased during a transition run is reflective of the ability level of the triathlete (De Vito *et al.,* 1995; Hue *et al*., 1998). According to Millet and Vleck (2000), the more experienced the triathlete, the less physiological and biomechanical alterations appear to occur during the transition run. It has been proposed by Millet *et al.* (2000) that elite level triathletes have reduced responses to the cycle-run transition as a result of their specified training which takes this transition into account. The same study found that although the running mechanics for a transition run were different between elite and middle-level triathletes, these differences were transient as they only lasted for approximately six minutes. These factors are important in the context of the current study, which investigated the effects of transition experience on athlete performance. Furthermore, the current study expanded on the effects of differing ability levels by including both single sport runners and single sport cyclists in the sample group, the intention of which was to highlight the role that transition experience may play in triathlon performance.

2.4 MUSCLE ACTIVITY

MUSCLE ACTIVITY DURING CYCLING

Unlike running, cycling is a more standardised movement as a result of the bicycle itself restricting the movement of the legs to the circular path of the pedal stroke (Hug and Dorel, 2007). The crank cycle, or pedal cycle, is characterised by three distinct phases, namely the power/propulsive phase, the pulling/recovery phase and the pushing phase (So *et al.,* 2005). The majority of the propulsive work done by the cyclist occurs during the power phase, which occurs on the down-stroke from slightly in front of the crank's upper vertical alignment, through the horizontal alignment, to slightly before the crank's lowest vertical alignment (Gregor and Rugg, 1986). The next most effective phase of the pedal cycle is the pulling phase, which occurs on the up-stroke from slightly after the crank's lowest vertical alignment to slightly before the crank's upper vertical alignment (Gregor and Rugg, 1986). The least effective phase of the pedal cycle occurs at the cranks upper and lower vertical alignments, referred to as the top and bottom dead centre (So *et al.,* 2005).

The knee extensors are the predominant muscles used to generate force during the power phase of the pedal stroke (Raasch *et al.,* 1997). During the first half of this phase (upper vertical alignment to 90°) the vastus medialis, vastus lateralis, tibialis anterior, rectus femoris, biceps femoris and gluteus maximus all contract at greater than 50% of their maximal voluntary contraction. During the final part of the push phase (90° to lower vertical alignment), the vastii muscles decrease their contribution, while the biceps femoris, rectus femoris and gluteus maximus maintain force application, in conjunction with the gastrocnemius muscle (Gregor and Rugg, 1986). Tibialis anterior, which is responsible for both ankle stabilisation and flexion, is active throughout the pedalling range of motion (So *et al.,* 2005).

ELITE VERSUS NOVICE ATHLETES

Chapman *et al.* (2007) have shown that differences in leg muscle recruitment exist between novice and elite cyclists. In this study, novice cyclists were found to possess greater variability in muscle recruitment (individual variance) as well as greater variability between cyclists (population variance) than their elite counterparts. It is well documented that the continued practise of a movement pattern creates an internal representation of that movement, which enhances the accuracy of the movement and decreases the stiffness of the movement, which would be expressed as decreased amplitude and duration of muscle activity associated with that action (Osu *et al.,* 2002). It is therefore likely that the variability in muscle activity seen in novice cyclists is related, in part, to a less defined internal representation of the given movement pattern, resulting in less skilled muscle recruitment (Chapman *et al.,* 2007).

EFFECTS OF CADENCE

Due to the high angular velocities associated with the pedal stroke, it has been concluded that muscle activity can be minimised at a given power output by increasing the cadence (rpm) at which the athlete is cycling, and as power output increases, the unique cadence at which muscle activity is minimised gradually increases (Macintosh *et al*., 2000). As cadence increases, the recovery phase of the pedal stroke decreases in duration, requiring more positive work from the leg in the push phase in order maintain the high angular velocity. This increase in positive work thus affects the muscle recruitment pattern during cycling (Sanderson *et al*., 2000).

Increased cadence is associated with increased activity in the gluteus maximus, gluteus medius, vastus medialis, semimembranosus, tibialis anterior and gastrocnemius muscles, while co-activation of antagonist muscles such as biceps femoris would also increase with increasing cadence (Timmer, 1991; Miller *et al*., 2000).

MUSCLE ACTIVITY DURING RUNNING

The gait cycle begins when one foot comes into contact with the ground and ends when the same foot contacts the ground again (initial contact). The stance phase refers to the period of time in which the foot is in contact with the ground, and thus extends from initial contact to toe off, which also signifies the onset of the swing phase. Running is characterised by a change in the gait cycle which involves a shift from the periods of double support (both feet in contact with the ground simultaneously) associated with walking, to two periods of float at either end of the swing phase, when neither foot is in contact with the ground (Novacheck, 1998).

During running, muscles are more active in anticipation of and just after initial contact. It follows thus that EMG activity is greater at the transition from swing to stance rather than from stance to swing (Novacheck,1998). Muscle activity during running is specific to each of the above mentioned phases. During the stance phase, the biceps femoris, hip extensors, rectus femoris, quadriceps, soleus and anterior tibial muscles are all active, with the majority of activity seen within the biceps femoris and anterior tibial muscles. Only the rectus femoris and anterior tibial muscles are active during the swing phase, as rectus femoris is responsible for restraining the posterior movement of the tibia as the knee flexes, and anterior tibialis dorsiflexes the ankle to provide clearance for the foot in mid-swing, to allow initial contact to take place heel first, and finally contracts eccentrically to control the lowering of the forefoot to the ground during the initial parts of the stance phase (Novacheck, 1998).

Based on the above, it is possible to determine that there is a high degree of overlap between the muscles utilised for cycling, and the muscles recruited for running. As the current study focused on the effects of cycling on run performance, these overlapping muscles are of particular importance.

2.5 NEUROMUSCULAR FATIGUE

Muscle fatigue is a complex phenomenon which occurs as a result of simultaneously occurring physiological and neurological processes (Barry and Enoka, 2007). Neuromuscular fatigue is defined as any reduction in maximal voluntary contraction (MVC) force, usually as the result of prolonged exercise, which leads to a reduction in performance (Lepers *et al*., 2002). The onset of muscular fatigue, however, is an ongoing process that begins from the start of a muscle contraction, resulting in a progressive decline in the muscle's force producing capabilities which begins well before the muscle reaches failure (So *et al*., 2005; Hug and Dorel, 2007). For instance, during a sustained maximal contraction, force will decline steadily and fatigue can be observed from the start of exercise, while during repeated submaximal contractions, performance may be maintained at the target intensity for a longer duration (Vollestad, 1997).

Neuromuscular fatigue can be further classified as either 'central fatigue', originating within the central nervous system, which includes the brain, spinal cord and sites proximal to the neuromuscular junction, or 'peripheral fatigue', which originates within the peripheral nervous system, which includes all sites distal to the neuromuscular junction (Lepers *et al*., 2008). Central fatigue is described as a decrease in neural drive or motor command to the muscle resulting in a decline in force or tension development (Enoka and Stuart, 1992 ; Kay *et al.,*2000). Peripheral fatigue is defined as a reduction in the force generating capacity of the skeletal muscle due to action potential failure, excitation contraction coupling failure or impairment of cross-bridge cycling in the presence of unchanged or increased neural drive (Taylor *et al.,* 1997; Kay *et al.,* 2000).

Gandevia *et al.* (1995) argue for a distinction to be made between the MVC and the Maximum Evocable Force (MEF) due to the fact that even with strong encouragement, it is often not possible to eliminate the fact that force generated voluntarily may be limited by a lack of motivation and inhibitory effects in the central nervous system. MEF is determined by the electrical stimulation of the muscle or nerve and is defined as the force generated by a muscle or group of muscles when electrical stimulation does not augment force (Vollestad, 1997). Thus, if muscle fatigue is defined as the exercise-induced fall in force generating capacity, 'central fatigue' can be classified as the reduction in voluntary maximal contraction force occurring during exercise which is not accompanied by a fall in MEF (Vollestad, 1997).

ELECTRICAL ACTIVITY IN THE FATIGUING MUSCLE

EMG analysis of the fatiguing muscle shows a progressive increase in EMG activity as the force producing capabilities of the muscle decrease (Hug and Dorel, 2007). Several theories attempt to explain this increase in EMG activity. The most commonly accepted theory is that the increased EMG amplitude occurs as a result of the recruitment of additional motor units in order to compensate for the reduced force generation of the fatigued muscle fibers (Hug and Dorel, 2007). An alternative hypothesis is that the increased EMG amplitude can be attributed to an increased firing frequency or synchronisation of motor unit recruitment (Gandevia *et al.,* 2001).

2.6 NEURAL CONTROL OF MOVEMENT

Through sustained contraction or alternating contraction and relaxation, skeletal muscle tissue allows for the coordination of body movements and stabilisation of body positions (Tortora and Grabowski, 2003). Skeletal muscle functions primarily on a voluntary basis as its activity can be consciously controlled by neurons that are part of the somatic division of the nervous system (Tortora and Grabowski, 2003).

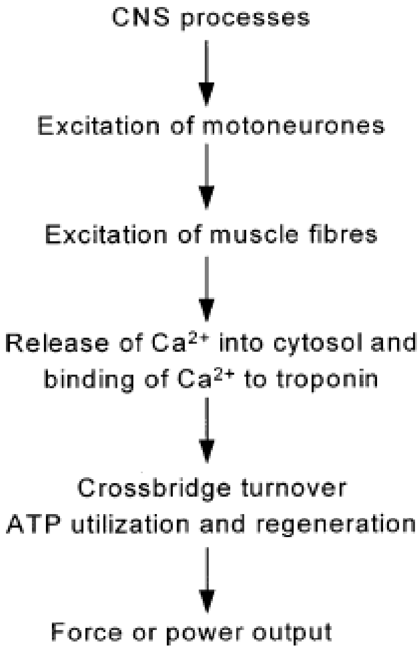

Figure 1: Schematic illustration of processes involved in generation of muscle force (Adapted from Vollestad, 1997)

In order to facilitate movement, a nerve impulse (somatic motor neuron) is propagated from the Central Nervous System (CNS) to the involved muscle fibers, via the complex structures of the Peripheral Nervous System (PNS). The neuromuscular junction serves as the synapsis between the somatic motor neuron and the muscle fibre (McArdle *et al.,* 2001). A neurotransmitter (Acetylcholine) is released at this point which allows for the nerve impulse to travel across the synaptic cleft, thereby setting off a series of chemical reactions which results in the development of a muscle action potential which allows for the innervations of the skeletal muscle fibre causing the muscle contraction to occur (McArdle *et al.,* 2001).

ORDER OF RECRUITMENT OF MUSCLE FIBERS

Submaximal muscle contractions are generated by a certain fraction of the total motor unit population. The sequence of recruitment is governed by each muscle fiber types threshold for activation. In this regard type I fibers (Slow twitch) are recruited first, followed by type IIA (Fast, fatigue resistant) and finally type IIx fibers (Fast, fatigable) are recruited (Vollestad, 1997). When submaximal contractions are performed until exhaustion, Type I fibers, and some type IIA fibers, are recruited from the start. As exercise progresses, an increasing number of fresh type II fibers will be recruited until exhaustion, where all motor units have been activated (Vollestad, 1997).

CHAPTER III

METHODOLOGY

In long distance endurance activities, and particularly multidisciplinary events such as triathlon, minimising energy expenditure while maintaining a high average speed for the race is seen as an important determinant of successful performance (Vercruyssen *et al.,*2002). A unique aspect of multisport activities is the change of sport codes and consequent demands on the athlete with each transition. Previous research has identified numerous factors that may influence cycling or running performance during triathlon, while it is commonly accepted that overall triathlon performance, while not independent of the swim discipline, is largely dependent on the athletes' ability to run effectively and efficiently after the previous cycle discipline (Bentley *et al.,* 2008). The current study aimed to assess the effects of a prior cycling bout on running performance, which required measurement of several variables as well as the establishment of a test protocol that could provide the relevant data while being influenced by as few extraneous variables as possible.

3.1 PILOT TEST PROTOCOL

In order to determine the viability and logistical working of the proposed research, extensive pilot work was undertaken in the Department of Human Kinetics and Ergonomics at Rhodes University. During pilot work, trials were conducted in conditions that were reflective of the intended testing environment. These preliminary simulations served to refine the testing protocol and establish the suitability of the equipment being used, and the variables being assessed. Volunteers participated in trial protocols in which different combinations of both cycle and run duration and intensity were tested to establish appropriate combinations for the research. The pilot phase ensured that the researcher was familiar with all equipment and psychophysical scales to be used during the testing phase of this research.

During pilot testing, subjects were exposed to the Lamberts and Lambert Submaximal Cycle test (Lamberts *et al.,* 2009) to ensure that the use of this warm up protocol would allow subjects to warm up sufficiently before the commencement of the Maximal Aerobic Power (MAP) test. The MAP test was then conducted according to the criteria and instructions laid out by Lamberts *et al.,* (2009), with subjects starting at a power output of 2.50W.kg^{-1} body mass, after which the load increased by 20W each minute until the subject could not sustain a cadence greater than 70rpm or was volitionally exhausted. From the results of the pilot research it was possible to determine that the Lamberts and Lambert Submaximal Cycle test provided sufficient warm up for subjects prior to the commencement of the MAP test.

The researcher was also required to pilot run duration, running speed, cycle duration and cycle intensity for use in the test protocols. It was necessary to test the above durations and intensities in order to ensure that the run intensity was high enough to test the subjects, but without inducing unnecessary fatigue, as well as to ensure that the combination of intensity and duration for the cycle protocol would be enough to induce fatigue similar to that which may be experienced during a competitive triathlon. Based on the reviewed literature, it was determined that a running speed of 15km.h^{-1} for a duration of 7 minutes should be piloted (Chapman *et al.,* 2008; Pialoux *et al.,* 2008; Le Meur *et al.,* 2009). In terms of the cycle protocol, research by Pialoux *et al.,* (2008) and Le Meur *et al.,* (2009) found that in order to mimic the effects of the cycle leg of a competitive triathlon, it was necessary for subjects to cycle at a average power output of 63% - 75% of maximal aerobic power (MAP). For the purposes of this study, it was decided to pilot the effects of cycling at 70% of MAP for a duration of 20 minutes. Finally, pilot testing was utilised to ascertain the viability of testing the proposed muscles – tibialis anterior, gastrocnemius, biceps femoris, rectus femoris and vastus lateralis. Time observation of the pilot study protocols showed that subjects would have to attend two laboratory sessions, with session 1 lasting approximately 1 hour, and session 2 lasting approximately 2 hours.

3.2 EXPERIMENTAL DESIGN

The current research project aimed to establish the effect of a prior cycling bout on the physical responses of subsequent running, to identify the severity of any alterations in running mechanics caused by prior cycling as well their concomitant effect on athletes' physiological responses while running . A further objective of the experiment was to determine the influence of triathlon experience on the above responses, when compared to athletes who compete in lone cycling or running. The variables of interest related specifically to muscle activity, running kinematics, heart rate, oxygen consumption and energy expenditure, while measures of ratings of perceived exertion were considered to be key psychophysical measures.

3.3 DESIGN MATRIX

In order to identify the changes in running biomechanics and physiological demand which occur when running after cycling, subjects were required to complete a short control run (run only) to which the transition run (cycle-run) results could be compared.

Table I: Design matrix for the current study

	BIOMECHANICAL, PHYSIOLOGICAL AND PERCEPTUAL VARIABLES		
	TRIATHLETES	*CYCLISTS*	*RUNNERS*
CONTROL RUN	1	2	3
TRANSITION RUN	4	5	6

In order to accurately identify the changes in the above-mentioned variables, the experimental design was characterised by three subject groups (triathletes, cyclists and runners).As depicted in Table I each group was required to complete the same test protocol which included a control condition and a transition condition. The control condition involved running only, while the transition condition required subjects to perform a cycling bout before completing the run protocol. Further explanation of the experimental conditions follows in the sections below.

3.4 SELECTION OF EXERCISE INTENSITY AND DURATION

The focus of the current study was on the influence of a prior cycling bout on subsequent running performance. It was thus necessary to ensure that the relationship between exercise duration and intensity is taken into account for both the cycle and run protocols.

CYCLE PROTOCOL

Several studies have investigated aspects of the triathlon cycle-run transition utilising different test procedures.

In order to accurately measure the effects of cycling on running in the current context, it was necessary to ensure that the effects of the cycle experienced in the experimental procedures mimic those encountered in a competitive scenario to enhance applicability. Thus, it was imperative that subjects complete the cycle protocol at an intensity that is relative to that which they would maintain for a competitive race.

Based on the literature reviewed, it is apparent that given the cycle is performed at a sufficient intensity, it is not necessary for the duration to exceed 30 minutes (Duc *et al.,* 2005, Bini *et al.,* 2008). Bini *et al.,* (2008) investigated the EMG responses to a 40km cycling time trial. Subjects were required to complete the time trial in the fastest possible time, utilising a freely chosen pacing strategy. Importantly, the results of this study confirmed those of an earlier study Duc *et al.,* (2005) which suggested that a muscular 'steady state' is achieved after 30minutes of cycling, even in the course of a 40km time trial. This 'steady state' was observed for all assessed muscles, apart from vastus lateralis, which is a key force producer, and is most likely an attempt to avoid premature muscle fatigue.

Le Meur *et al.,* (2009) found that elite triathletes achieved an average power output of 265W (3.96W.kg^{-1}) during the cycle leg of world cup (elite level) triathlon. This corresponds to approximately 63.4% of Maximal Aerobic Power (MAP) which was maintained for 66 minutes. Pialoux *et al.,* (2008) assessed the physiological effects of running after a cycle-run transition, requiring athletes to cycle submaximally at 75% of MAP for 30 minutes.

Although some form of pacing strategy may be required to mimic the fluctuations in pacing that occur during normal cycling in race conditions, where changes in speed, cadence and intensity are apparent (Chapman *et al.,* 2005), there are contrasting opinions about the effects of utilising a pacing strategy in triathlon. Several authors have demonstrated a discrepancy between factors affecting performance and those identified in experimental conditions (Vogt *et al.,* 2006; Bernard *et al.,* 2009). One of the main differences occurs as a result of the constant power output adopted for experimental studies as opposed to the variations in force application observed in competitive situations (Vogt, 2006). Contrastingly, Bernard *et al.,* (2009) found that varying power output from 5% to 15% of mean power during 20km of cycling in a triathlon resulted in a decreased performance in the subsequent 5km run when compared to a constant power output cycling strategy. Due to the varying nature of the cycle profiles in triathlon races around the world, it is difficult to identify a set pacing strategy utilised by experienced athletes. Thus, based on reviewed literature, it was decided that a constant pacing strategy would be maintained throughout the protocol, which would be 20 minutes in duration, with athletes cycling at 70% of MAP. Although this duration is slightly shorter than the stated literature, the effects of a shorter duration are counteracted by a higher required intensity.

Alterations in cadence can also be utilised as a form of pacing strategy during the cycling phase of a competitive triathlon. That said, it has been identified by several authors that triathletes naturally adopt a cadence of between 85 – 95 rpm (Suriano *et al.,* 2007; Candotti *et al.,* 2008; Le Meur *et al.,* 2009). In order to minimise the variance that could be directly attributed to changes in cadence, it was decided to limit the range to between 90 – 95rpm. This was done based on reviewed literature as well as pilot studies.

RUN PROTOCOL

Previous studies have utilised various methods of investigating the run phase, with a range of intensities and durations being employed. For example, Chapman *et al.,* (2008) utilised a 10 minute control run at a self selected pace that the athlete could hold for 30 minutes without fatiguing, followed by a 30 minute transition run that was preceded by 20 minutes of cycling. Millett *et al.,* (2000) tested the effects of triathlete ability level (elite versus sub-elite) on the external mechanical cost of running before and after a maximal cycling bout. Subjects were required to perform two seven minute runs (one control, one post-cycle) at a speed which corresponded with that which they could maintain for an actual triathlon event. The results of this study showed that differences in running mechanics had disappeared after approximately six minutes of starting the transition run. Pialoux *et al.,* (2008) performed three different running protocols when assessing the decrease in running efficiency that occurs during transition running. Subjects were first required to undergo an incremental test to determine their Maximum Aerobic Speed (MAS), after which they performed two 13 minute trials at 75% of their determined MAS. The first of these was a control run, while the second was preceded by 30minutes of cycling at 75% of heart rate reserve.

In order to accurately compare the effects of cycling on running between subjects and subject groups, it was necessary to select a constant pace which was not only relative to that which is maintained during a competitive triathlon, but can be maintained by all subjects taking part in the current study. Le Meur *et al.,* (2009) observed the pacing strategies adopted by elite triathletes during a world cup (elite) event. The results of this study found that elite male triathletes were able to maintain an average speed of 18.4km.h^{-1}, which equates to 3:16 minutes per kilometre. An earlier study by Millet *et al.,* (2000) required athletes to run at a pace that corresponded to that which would be held during a competitive Olympic triathlon event (10km run). Elite level subjects recorded an average speed of 18.5km.h^{-1} while ‘middle level’ subjects averaged 17.6km.h^{-1}, equating to an average pace of 3:14 minutes per kilometre and 3:25 minutes per kilometre respectively. During a laboratory study by Chapman *et al.,* (2008), elite triathletes were requested to run at a self selected pace that would be comfortable and non-fatiguing for 30minutes. Participants in this study selected an average running speed of 13.8km.h^{-1}, which is relative to 4:21 minutes per kilometre.

It was imperative in the context of the current study that the effects of running fatigue were minimised, such that the biomechanical and physiological effects of the cycle bout are isolated. Similarly, it was necessary to adopt a run speed that would be achievable for all three subject groups. Based on the above literature as well as pilot studies, it was decided that a running speed of 15km.h^{-1} adequately met the requirements of the study, as the intensity was high enough to be applicable to the race context while not inducing unnecessary fatigue.

3.5 SELECTION OF DEPENDENT VARIABLES OF INTEREST

ELECTROMYOGRAPHY

Due to the fact that this study focused on the effects of cycling on running responses, it was important to isolate muscles which are not only crucial to running performance, but are also sufficiently taxed by the cycling motion. This would aid in ensuring that any alterations in muscular activity resulting from the cycling bout were adequately presented while running.

Chapman *et al.,* (2008) investigated the effects of cycling on motor coordination during cycling in elite triathletes, utilising the tibialis anterior muscle, as not only is it the most superficial muscle in the leg, but it is also crucial to both running and cycling. Earlier research by Witt *et al.,* (1993) reported that changes in stride length in a transition run may occur as a result of perturbations in the EMG activity of the vastus lateralis, anterior tibialis and tensor fascia latae, caused by the change from the concentric muscular contraction in cycling to the stretch-shortening activity observed in running.

Candotti *et al.,* (2008) compared the cycling techniques of triathletes to those of competitive cyclists, analysing the rectus femoris, biceps femoris and vastus lateralis muscles. These authors concluded that vastus lateralis and rectus femoris muscle activity was similar between cyclists and triathletes, while the only difference was that triathletes activated the biceps femoris muscle for a greater percentage of the pedal cycle. Importantly, Candotti *et al.,* (2008) suggest that this may be as a result of the triathletes attempting to improve muscle efficiency in preparation for the subsequent running phase of a triathlon race.

Taking both the above literature and extensive pilot testing into account, it was decided that the EMG activity in five muscles would be tested in the current study. The muscles of the thigh (vastus lateralis, rectus femoris and biceps femoris) were tested as they are both primary movers and primary force producers in both running and cycling. The leg muscles (tibialis anterior and gastrocnemius) were selected due to their ease of access, as well as a result of the crucial role that both play in both running and cycling.

RUNNING KINEMATICS

Several studies have reported the effects of muscle fatigue on running kinematics and running efficiency (Cavanagh and Williams, 1982; Morgan *et al.,* 1989; Morgan *et al.,* 1994). The current research assessed the specific effects of cycling exercise on subsequent running kinematics. Two of the primary kinematic variables affecting running efficiency which have been identified are stride length and stride rate (Morgan *et al.,* 1989). The basic assumption of previous research is that longer stride length results in higher braking forces at heel strike, requires increased power during propulsion and may invoke increased internal friction and stiffness. Conversely, running with a short stride length may increase internal work through increased frequency of reciprocal movement (Cavanagh *et al.,*1977).

Further variables of interest include vertical displacement and centre of mass movement as it seems plausible that all movements diverging from the running direction will affect running economy negatively. Previous research into the relationship between vertical displacement and running performance and efficiency has been inconclusive, however there is a consistent link between increased vertical displacement and lower efficiency while running (Williams and Cavanagh, 1987; Dutto and Smith, 2002). Thorstenson (1984) reported that movements in the medio-lateral directions are smaller than in the vertical direction and therefore have a smaller influence on running economy. Further kinematic variables which may explain changes in running economy include trunk gradient, knee angle in the non-support phase and knee angle during the stance phase (Millet and Vleck, 2000).

The measurement of changes in stride length, stride rate and vertical displacement in the context of the current study is important as any alterations, whether transient or permanent, which occur as a result of the prior cycling bout may well have a significant effect on performance and efficiency during a transition run.

HEART RATE

Heart rate increases with increasing exercise intensity, thus creating a direct relationship between these two responses. Exercise intensity, however, is not the only factor which may determine an individual’s heart rate. Day to day variations, cardiac drift, environmental changes and hydration levels may also contribute to heart rate variability (Jeukendrup, 2000). As it has been previously established (Hausswirth *et al.,* 1996;Millet and Vleck, 2000) that the transition from running to cycling has the effect of increasing exercise intensity, and thereby heart rate, measurement of the changes associated with this variable was deemed necessary in the current context.

ENERGY EXPENDITURE

Laboratory data indicate that triathlon running is harder than control running at the same speed (Millet and Vleck, 2000). Several studies have indicated an increase in the energy cost of running at the end of a triathlon as opposed to a control run performed at the same speed (Guezennac *et al.,* 1996; Hausswirth *et al.,* 1996). This increase in energy cost of transition running may be related to alterations in running biomechanics, and the measurement of increases in energy expenditure when running after cycling will give an indication of the effects of the biomechanical changes on running efficiency and economy.

OXYGEN CONSUMPTION

Running after cycling is associated with an increase in oxygen consumption (VO_2), as opposed to merely running alone (Millet and Vleck, 2000). Both Kreider *et al.,* (1988) and Guezennec *et al.,* (1996) have reported an increase in mean VO_2 for transition running as opposed to control running at the same speed. An increase in VO_2 of a task is associated with a decrease in movement efficiency, and is therefore an important consideration in the current study.

3.6 SELECTION OF SUBJECTS

The current study investigated the effects of cycling on subsequent running performance in competitive triathlon, and to compare the responses of seasoned multisport athletes to athletes who compete in single-discipline sports which contribute to triathlon, namely cycling and running. Although triathletes of all ability levels have reported a sense of impaired coordination when running after cycling, it appears that there is a difference in the extent to which any biomechanical alterations caused by cycling affect performance, dependent on the performance level of the athlete (Chapman *et al.,* 2008).

Millet *et al.,* (2000) tested the hypothesis that elite triathletes experience reduced negative effects compared to non-elite athletes when running after cycling. This study described their elite participants as international representatives all ranked in top 50 in the International Federation world rankings. Their middle-level triathletes had either regional or national level representation and were well-trained and experienced. Chapman *et al.,* (2008) utilised strict inclusion criteria to ensure the homogeneity of their elite sample group. Participants in this study had experienced either international or national level competition, and had been competing in triathlon for 6.6±1.9 years. During the previous three months, all participants had cycled 463.3±42.8km in 5.2±0.4 training sessions per week, and had run 63.9±14.2km in 5.5±0.3 training sessions per week.

For the purposes of the current study, the experienced triathlete sample group was drawn from athletes forming part of the University of Pretoria Triathlon team or those competing at a national level in the BSG Energade Triathlon Series. This series comprises the early part of the South African triathlon season and is made up of seven sprint triathlon events across the country. Although this series is open to triathletes of all ability levels, subjects were selected from those consistently competing at the highest level. In order to make comparisons to single sport runners and cyclists, these two control groups were made up of experienced runners and cyclists from within the Rhodes University Athletics Club and Rhodes University Cycling Club respectively. In order to match singe-sport athletes as closely as possible to their elite triathlete counterparts, it was necessary to account for factors such as age, gender and stature. Unfortunately, due to subject limitations, while the athletes in each control group could be considered trained in their specific discipline, they could only be classified as ‘sub-elite’, rather than reach the ‘elite’ classification of the triathlete group. Control subjects were required to be trained in their specific sport, but with no experience of the cycle-to-run transition. This was an important exclusion criterion as it maximised the variance between sample groups, allowing for accurate comparisons.

In total, 35 subjects were recruited to take part in the current study. Subjects were required to match the performance criteria in order to be deemed experienced in each of their respective disciplines and none of the subjects reported any serious recent (within the last 12 months) musculoskeletal injuries or illness which would affect their performance. Anthropometric and demographic data for each subject group is displayed in Table II below.

Table II: Anthropometric and demographic data for each subject group (Means with standard deviations on brackets, percentages indicate coefficient of variation).

	Age (years)	**Stature (cm)**	**Mass (kg)**
Triathletes (n = 11)	21.55 (± 2.77) 12.86%	180.07 (± 5.09) 2.83%	72.44 (± 4.76) 6.58%
Runners (n = 12)	20.82 (± 2.48) 11.93%	182.05 (± 6.45) 3.54%	78.28 (± 8.21) 10.49%
Cyclists (n = 11)	22.82 (± 2.23) 9.76%	180.21 (± 5.38) 2.99%	74.38 (± 5.70) 7.66%

3.7 EQUIPMENT AND MEASUREMENT TECHNIQUES

PHYSIOLOGICAL PARAMETERS

Oxygen consumption (VO_2) and energy expenditure were measured using a Cosmed™ K4b^2 portable Ergospirometer which provides a breath-by-breath analysis of cardiorespiratory function and physiological responses. The K4b^2 is a portable measurement unit which is connected to a mask which is placed over the subject's nose and mouth allowing for the collection of all metabolic data on a breath-by-breath basis. Data collected by the measurement unit were transferred via telemetry to a laptop for storage and data analysis. Before the start of every testing session the Cosmed™ K4b^2 had to be calibrated. Calibration involved gas calibration from a cylinder with a known concentration of gases (16% O_2, 5% CO_2), room air calibrations with the correct concentrations of room air (20.95% O_2, 0.03% CO_2), and a volume calibration using a 3-litre calibration syringe. Delay calibration was performed so that the time delay between air entering the mask from the subject's mouth and the air reaching the analysis unit is accounted for.

Figure 2: K4b^2 Ergospirometer face mask attached to subject.

Heart rate was measured in beats per minute (bt.min^{-1}) using a Polar™ heart rate monitor and telemetry strap. The strap was placed around the subject's torso and aligned with sternum, slightly below the pectoral muscles. The strap was tightened sufficiently so that it did not slip, but without being uncomfortable or constricting for the subject. The strap detected electrical impulses from the heart, transmitting them to the K4b^2 or the Polar heart rate watch.

BIOMECHANICAL PARAMETERS

Surface EMG was used to record muscle activity in the previously discussed muscles, during both the control and transition run protocols. Muscular activity was measured by attaching electrodes to the surface of the skin, directly over the muscle belly. The skin was cleanly shaved and prepped prior to application of the electrodes. The correct anatomical position for electrode placement was established by palpating the muscle. The EMG system recorded the changes in electrical activity in the muscle directly beneath the attached electrodes. The surface EMG device used for this investigation was the Biometrics Ltd DataLOG W4X 8 .The DataLOG has eight analogue channels and two digital channels which allow for a variety of data to be collected simultaneously. Five analogue channels were used to measure muscle activity, one for each of the selected muscles to be tested, while one digital channel was used to connect a neutral electrode which was placed on an uninvolved muscle. All information was transferred to a laptop via infrared telemetry for storage and data analysis.

Accelerometer

The accelerometer was connected to the Biometrics Ltd DataLOG W4X 8 using an analogue channel, and all information was transferred to a laptop via infrared telemetry. The accelerometer was attached to the right hand side of the subject’s lower back, proximal to the sacroiliac joint. The accelerometer provided information regarding the athlete’s vertical accelerations, which are indicative of their vertical displacement.

PSYCHOPHYSICAL PARAMETERS

Rating of Perceived Exertion

Perception of effort is a subjective evaluation of an individual’s response to physical demands and encompasses physiological, musculoskeletal and psychological aspects. The RPE scale was developed by Borg (1980) to provide a means to relate subjective responses to objective measurements.

The RPE scale consists of a 15-point scale ranging from a rating of six (minimal exertion) to a rating of 20 (maximal exertion). The present study focused on obtaining measures of ‘central’ cardiovascular responses and ‘local’ muscular responses for the leg muscles specifically. Subjects were required to give a ‘central’ and ‘local’ rating at minute four and minute seven for each test.

The RPE scale is depicted in Figure 3, along with verbal cues to accompany each intensity level.

RATINGS 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	

Figure 3: Rating of Perceived Exertion scale (Borg, 1980)

3.8 ETHICAL CONSIDERATIONS

Due to the fact that the research required the use of human subjects, approval from the Human Kinetics and Ergonomics department ethics committee was required before testing could begin. For this purpose an ethics form describing the project and the testing procedures that would take place was completed. Information on the study and the testing process was offered to the subjects both verbally and in writing prior to testing. This ensured that all procedures were clarified, were within the perceived capabilities of each subject, and that all procedures were accepted by the subject. The letter of information given to the subject also outlined the aims and expectations of the study, as well as any associated risks or benefits to the subject. Following this, each subject was required to sign a letter of informed consent. Both documents are included in the appendix to the current study.

All safety precautions possible were taken prior to testing to ensure that in the instance of a subject being unable to complete a protocol, all necessary measures were in place to assist the subject. Pre-test instructions were verbally explained to the subjects in advance to ensure that the procedures were understood and subjects were fully prepared for the testing session.

3.9 EXPERIMENTAL PROTOCOL

Subjects were required to attend two testing sessions, the first comprising of the pre-test habituation and measurements, while the second included the test protocol. These sessions took place within the University of Pretoria High Performance Centre Biokinetics Laboratory, and within the Physiology laboratory in the Human Kinetics and Ergonomics Department at Rhodes University.

SESSION 1: HABITUATION, ANTHROPOMETRIC MEASUREMENTS AND MAXIMAL AEROBIC POWER TEST

During the first session the experimental procedure was explained both verbally as well as in writing to the subject, and any queries were addressed. Following this, the subject was provided with a letter of informed consent which was to be completed before experimentation could begin. The subjects were also required to complete a brief questionnaire pertaining to their training history. Following this, basic demographic and anthropometric data were collected, including age (years), stature (mm) and body mass (kg).

Following the collection of demographic and anthropometric data, subjects were required to warm up utilising the Lamberts and Lambert Submaximal Cycle Test (LSCT) (Lamberts *et al.,* 2009). In order to facilitate this warm-up, subjects were fitted with a Polar heart rate monitor. This 17-minute protocol was performed at three different exercise intensities defined by different target heart rates. During the warm up, subjects cycled for 6 minutes at 60% of HR_{MAX}, 6 minutes at 80% of HR_{MAX} and finally 3 minutes at 90% of HR_{MAX}. Target heart rates were based on age predicted maximum heart rate using the formula: MHR = 220-age(years). Upon completion of the LSCT test, subjects were required to stop cycling and sit upright for two minutes to aid recovery. A further one minute easy cycling was allowed before commencement of the Maximal Aerobic Power (MAP) test.

The MAP test was performed at a starting work rate of 2.50W.kg^{-1} body mass, after which the load increased by 20W each minute until the subject could not sustain a cadence greater than 70rpm, or was volitionally exhausted. MAP was determined as the mean power output during the last completed minute of the MAP test.

SESSION 2: EXPERIMENTAL CONDITIONS

Session 2 consisted of both experimental protocols, i.e. the ‘control’ run and the ‘transition’ run. Subjects were first familiarised with the equipment and protocols as explained to them in the first session, and any queries were dealt with before testing commenced. Prior to the warm up, the subjects upper thigh was strapped with Fixomull tape in order to prevent sweat running down the legs. Subjects were then fitted with a Polar heart rate monitor and were requested to remain still so that a reference heart rate could be recorded. The warm up, which consisted of a seven-minute run at 60% of age predicted maximum heart rate, was then completed.

Immediately following the warm up, subjects were fitted with all experimental equipment. EMG electrodes were attached to the tibialis anterior, gastrocnemius, vastus lateralis, rectus femoris and biceps femoris muscles located by palpating the muscle belly. Once all EMG electrodes were attached, the K4b^2 Ergospirometer receiving unit and battery were then strapped to the subject’s back, while the mask was fitted over the subject’s nose and mouth as described above. Finally, the Crossbow™ 3-Axis GP series accelerometer was connected to the right hand side of the subjects lower back, proximal to the sacroiliac joint.

The ‘control’ run was completed first to ensure that no negative effects of the cycle protocol could affect the results of the control protocol. Subjects were required to run at a speed of 15km.h^{-1} for seven minutes, with approximately 30 seconds of treadmill acceleration preceding the start of the test. Once the subject had reached the target speed, measurement of both physiological and biomechanical parameters commenced. Stride was calculated in strides.min^{-1} from 1:30 to 2:30 and again from 4:30 to 5:30 by counting the number of strides taken during that minute, this value was then used to calculate average stride length over that time. One stride was considered to be from heel strike of the right foot, to heel strike of the same foot. In order to determine if any changes occurred during the run, physiological data were collected from 3:00 to 4:00 and again from 6:00 to 7:00. Similarly, both ‘central’ and ‘local’ Ratings of Perceived Exertion (RPE) were recorded at minute 4, and again at minute seven, after which the test was terminated. Once off the treadmill, subjects were required to sit still until heart rate had returned to within 10% of pre-test reference values.

Once subjects’ physiological responses had returned to reference values and the subject could be deemed rested, the second experimental condition could commence. This required subjects to cycle on a stationary bicycle for 20 minutes at 70% of their Maximal Aerobic Power (MAP) determined in session 1. This cycle protocol was then immediately followed by an identical run protocol as outlined for the ‘control’ run during which further biomechanical, physiological and perceptual data were collected.

3.10 STATISTICAL PROCEDURES

The data collected were statistically analysed using the STATISTICA program. STATISTICA, version 9.0, is a statistical and graphical software package used in the analysis of data. All data was reduced into a summary of descriptive statistics to obtain calculate mean, standard deviation and coefficient of variance for each condition. Independent T-tests (confidence level = 95%) were conducted between minute 3 and minute 6 of either protocol, as well between protocols at either interval. These determined if any significant differences existed either within or between protocols. Finally, a 1-way analysis of variance (ANOVA) was performed at each interval of each variable to determine if any significant differences existed between groups, with Tukey Post-Hoc analyses being used to establish where any differences identified by the ANOVA were located.

CHAPTER IV

RESULTS

Due to the growing popularity of multisport events, and triathlon in particular, there is an ever increasing need for research into such sports, with a view to improving both training regimes and race strategies in order to optimise performance. The current research sought to determine the influence of cycling on subsequent run performance during multisport events such as triathlon. Furthermore, the present study aimed to determine the effects of training background on the above cycle-run transition, focusing on the ability of trained triathletes, single sport runners and single sport cyclists to cope with the physical demands placed upon them by this transition. In order to account for all potential influential factors, biomechanical, physiological and psychophysical data were collected and analysed. In each case, the data were analysed with the aim of determining if any inter- or intra-group significant differences were present, thereby providing an indication of the effects of the cycle protocol on the responses within each group, as well as on the differences between each group. These data are displayed in a reduced format below.

Throughout the next chapter of the current study, the format depicted in Table III will be adhered to with regards to the display of relevant descriptive data (means, standard deviations and coefficient of variations) as well as significant differences where applicable. SD refers to the standard deviation within each group, while CV represents the coefficient of variation.

Table III: Example of table format for chapter IV

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	Mean ±SD* (CV)	Mean ±SD (CV)	Mean ±SD (CV)	Mean ±SD (CV)
Runners	Mean ±SD (CV)	Mean ±SD (CV)	Mean ±SD (CV)	Mean ±SD (CV)
Cyclists	Mean ±SD (CV)	Mean ±SD (CV)	Mean ±SD (CV)	Mean ±SD (CV)

Legend: * denotes significant difference between intervals; └─┘ denotes significant difference between groups (p < 0.05).

4.1 BIOMECHANICAL RESULTS

The biomechanical data collected during the current study can be sub-divided into two categories – those relating to muscle activity and those pertaining to the individuals running kinematics (stride rate, stride length and vertical acceleration).

ELECTROMYOGRAPHY

Mean muscle activity (EMG) data were recorded from minute 3 to minute 4, and minute 6 to minute 7 of each protocol. The activity in each measured muscle have been processed and evaluated, with the results displayed below,, as opposed to runners at minute 3.

Table IV details the EMG activity of the tibialis anterior muscle during both the control and transition protocols. During the control run, cyclists had the highest activity levels (0.468±0.63mV), while triathletes recorded the lowest (0.129±0.04mV), a difference of 72.4% between the two groups. There were no significant differences between the groups at minute 3 or minute 6 of the control run. However, it is apparent that there is significantly greater intra group variability for the cyclists and runners than for the triathletes. In terms of differences between the 3rd and 6th minute of the control run, both the runners and cyclists demonstrated no difference, while the triathletes showed a significant decrease

As with the control run, the triathletes recorded the lowest tibialis anterior muscle activity during the transition run, regardless of time interval. None of the groups recorded a change in activity over time despite the cyclists mean tibialis anterior muscle activity increasing by 27.3% from minute 3 to minute 6 in the transition protocol. Although not statistically significant, this increase meant cyclists recorded the highest EMG activity (0.261±0.32mV) for this muscle at minute 6 of the transition run, as opposed to runners at minute 3.

Table IV: Tibialis anterior muscle activity (mV) measured at minute 3 and minute 6 during each protocol.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	0.129 (±0.04)* 30.45%	0.111 (±0.03) 28.94%	0.121 (±0.06) 48.85%	0.112 (±0.06) 54.98%
Runners	0.308 (±0.38) 123.72%	0.309 (±0.42) 135.96%	0.251 (±0.325) 129.5%	0.250 (±0.33) 133.08%
Cyclists	0.468 (±0.63) 135.05%	0.395 (±0.49) 123.87%	0.205 (±0.25) 121.63%	0.261 (±0.32) 120.92%

Legend: * denotes significant difference between intervals ($p < 0.05$).

Figure 4 is a graphical representation of the changes which occur between the control and transition protocols at each interval (minute 3 and minute 6). Triathletes were the least affected by the cycle protocol, recording 6.2% and 0.9% differences between protocols at minute 3 and minute 6 respectively. Both cyclists and runners showed decreases in tibialis anterior muscle activity after cycling, with the cyclists recording the largest decrease (56% at minute 3 and 33.9% at minute 6), followed by the runners (18% at minute 3 and 19% at minute 6). These differences, however, were not statistically significant due to the high group variation in the results. Interestingly, the triathlete group were far more homogenous in their responses during both the control and transition protocols. This may be indicative of a standardised, or optimal, muscle recruitment pattern that is adopted by more highly trained athletes. This view is supported by research by Chapman *et al,* (2007) who found that novice athletes have a greater variability in muscle recruitment as opposed to their well trained counterparts.

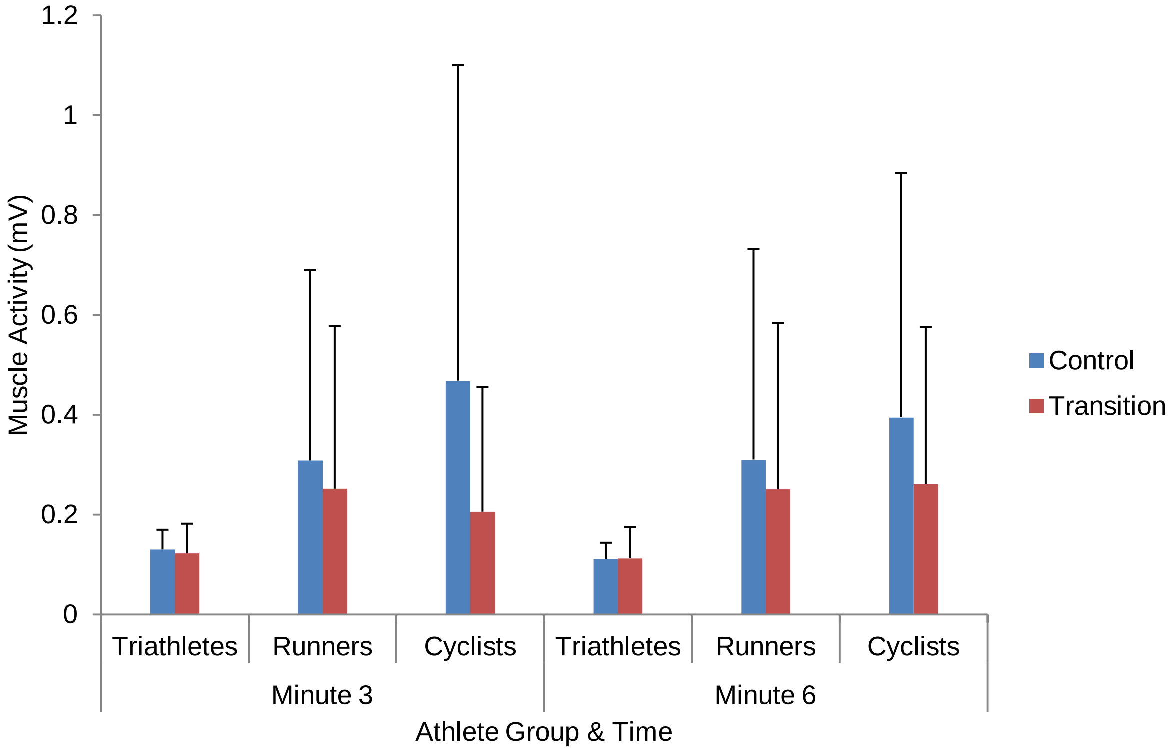

Figure 4: Tibialis anterior muscle activity changes between protocols, measured at minute 3 and minute 6.

Gastrocnemius

All three subject groups elicited similar gastrocnemius activity during the control run at minute 3 and minute 6, with no differences found between time frames. No differences were recorded between subject groups for the control run, with responses ranging between 0.119±0.09mV and 0.118±0.09mV for the runners, and 0.149±0.09mV 0.133±0.06mV for the triathletes at minute 3 and minute 6 respectively.

Similar findings were evident for the transition protocol, where no significant differences were apparent between groups at either interval. Furthermore, no differences were evident for any of the groups between minute 3 and minute 6 of the transition protocol.

Table V: Gastrocnemius muscle activity (mV) measured at minute 3 and minute 6 during each protocol.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	0.149 (±0.09) 60.03%	0.133 (±0.06) 45.41%	0.105 (±0.04) 38.1%	0.093 (±0.02) 21.5%
Runners	0.119 (±0.09) 75.6%	0.118 (±0.09) 76.3%	0.094 (±0.02) 21.2%	0.092 (±0.02) 21.7%
Cyclists	0.12 (±0.07) 58.3%	0.141 (±0.13) 92.1%	0.102 (±0.08) 78.43%	0.119 (±0.15) 126.1%

Table V shows how both the triathlete and cyclist groups demonstrated a reduction in intra group variability during the transition run, when compared to the control run indicating that athletes who are more trained for running have a common response to the cycle protocol. Figure 5 demonstrates that there were no significant differences evident between the control and transition protocols at minute 3 for any of the three athlete groups. Furthermore, during the final minute of experimentation, the cyclists and runners still did not exhibit significant differences between the control and transition; however the triathlete group did show a statistically significant decrease in gastrocnemius activity (30%). Stars in all figures denote significant changes which occur between protocols.

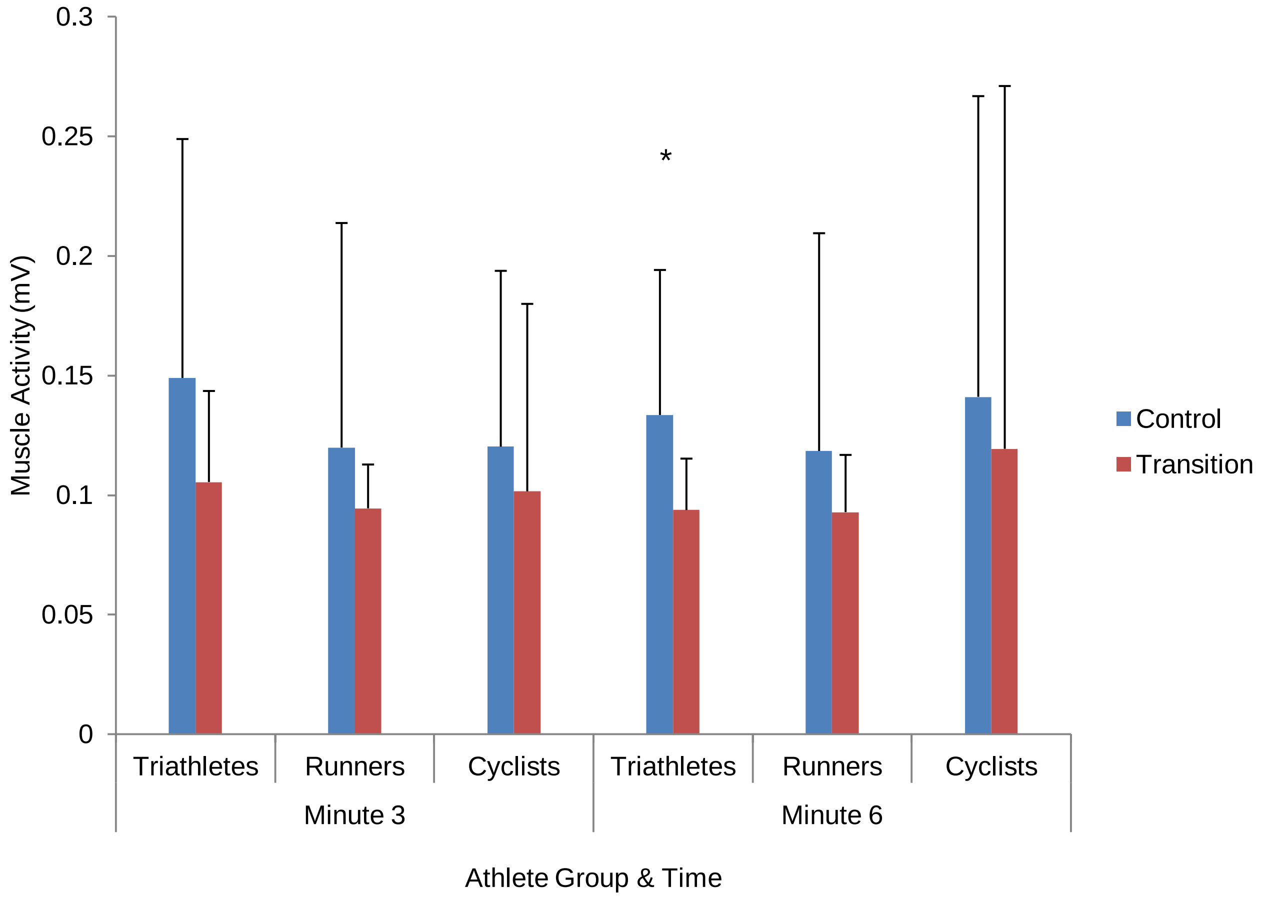

Figure 5: Gastrocnemius muscle activity changes between protocols, measured at minute 3 and minute 6.

Biceps femoris

There were no differences between minute 3 and minute 6 for the control run for any of the athlete groups. Furthermore the control run resulted in no differences in biceps femoris activity between athlete groups, with activity levels at minute 3 ranging from

0.129±0.13mV for runners to 0.16±0.16mV for cyclists. At minute 6, these responses ranged from 0.086±0.03mV for triathletes to 0.202±0.33mV for the cyclists.

Table VI: Biceps femoris muscle activity (mV) measured at minute 3 and minute 6 during each protocol.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	0.152 (±0.13) 88.19%	0.086 (±0.03) 40.04%	0.077 (±0.04) 54.62%	0.062 (±0.02) 36.22%
Runners	0.129 (±0.13) 101.02%	0.109 (±0.1) 89.54%	0.072 (±0.02) 31.74%	0.069 (±0.02) 30.55%
Cyclists	0.16 (±0.16) 98.08%	0.202 (±0.33) 165.6%	0.07 (±0.02) 24.58%	0.071 (±0.2) 30.88%

Similar results were evident for the transition run, with no differences being evident either within groups over time, or between groups at either interval. The transition protocol saw the triathlete group record the highest activity level at minute 3 (0.077±0.04mV), followed by the runner (0.072±0.02mV) and cyclist (0.07±0.02mV) groups respectively.

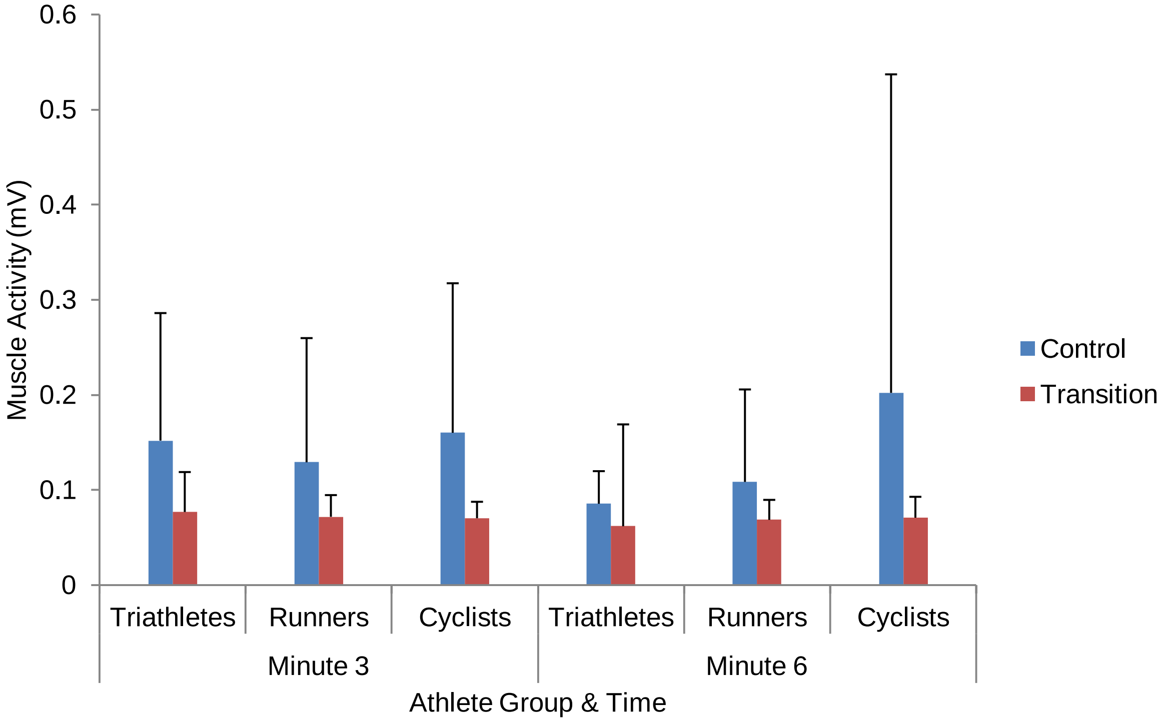

Figure 6: Biceps femoris muscle activity changes for each group during each protocol, measured at minute 3 and minute 6.

Despite muscle activity decreasing between protocols at all intervals, no significant changes were recorded, primarily due to the large intra group variation evident during the control run. It is evident, however, that there was significantly less variation within each group during the transition run, suggesting a more uniform response from subjects after the cycle protocol.

Vastus lateralis

Despite the cyclists and runners showing 45% and 10.6% decreases in vastus lateralis activity between minute 3 and minute 6, these changes were shown not to be statistically significant. Although responses ranged from 0.122±0.12mV for runners at minute 3 to 0.248±0.42mV for cyclists at the same interval, no significant differences were recorded between groups for the control run. At minute 6 the runners still had the lowest responses (0.109±0.1mV) while the triathlete group now recorded the highest with 0.138±0.1mV.

Table VII: Vastus lateralis muscle activity (mV) measured at minute 3 and minute 6 during each protocol.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	0.223 (±0.22) 96.75%	0.138 (±0.1) 74.25%	0.111 (±0.07) 65.64%	0.164 (±0.07) 92.95%
Runners	0.122 (±0.12) 89.54%	0.109 (±0.1) 76.64%	0.071 (±0.01) 20.3%	0.073 (±0.02) 21.69%
Cyclists	0.248 (±0.42) 169.18%	0.135 (±0.15) 111.4%	0.081 (±0.05) 66.9%	0.079 (±0.5) 63.6%

Similar findings were evident in the transition protocol, with no differences being evident between subject groups at either interval. Responses ranged from 0.071±0.01mV (runners) to 0.111±0.07mV (triathletes) at minute 3, and 0.073±0.02mV and 0.164±0.07mV for the same groups at minute 6. Furthermore, no differences occurred over time in any of the three groups.

As with the Biceps Femoris muscle activity, the transition had a similar effect on all three subject groups, apart from the triathlete group at minute 6. All three subject groups recorded a decrease in activity from the control to transition protocols at minute 3, with the greatest decrease occurring within the cyclist group (67.3%) followed by the triathlete group (50.2%). It is interesting to note that the triathlete groups responses increase from minute 3 to minute 6 of the transition run. There is also a concomitant increase in the amount of intra-group variability for the triathletes at this interval.

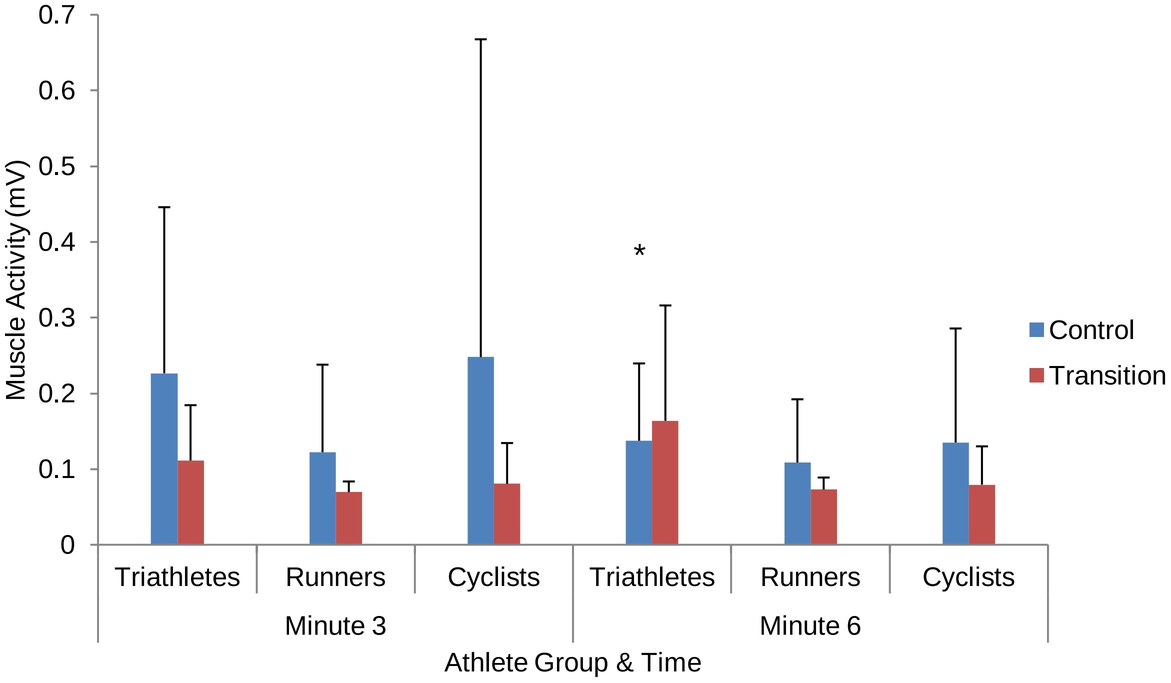

Figure 7: Vastus lateralis muscle activity changes between protocols, measured at minute 3 and minute 6.

Rectus femoris

The control run resulted in no significant differences in rectus femoris muscle activity being evident between groups, despite responses ranging from 0.139±0.11mV for triathlete to 0.548±0.87mV for cyclists at minute 3, with similar differences being evident at minute 6. The lack of significance in this regard can be accounted for by the high variation within groups (77% for triathletes, 113% for runners and 159% for cyclists). The large variation within each group would have the effect of masking any significant differences, as the range of responses was too great to allow for differences to stand out. Furthermore, no significant changes occurred between minute 3 and minute 6 for any of the three groups.

Similar findings are evident within the transition protocol results. The range of responses decreased across intervals (0.072±0.03mV for triathletes at minute 3 to 0.223±0.33mV for cyclists at the same interval), resulting in no significant differences being evident between groups at either interval. Furthermore, no differences exist within groups with respect to time, as a result of the cycle protocol.

Table VIII: Rectus femoris muscle activity (mV) measured at minute 3 and minute 6 during each protocol.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	0.139 (±0.11) 76.96%	0.113 (±0.1) 63.71%	0.072 (±0.03) 39.94%	0.066 (±0.03) 45.8%
Runners	0.349 (±0.39) 112.5%	0.31 (±0.4) 128.8%	0.159 (±0.22) 138.94%	0.173 (±0.23) 132.58%
Cyclists	0.548 (±0.87) 159.2%	0.455 (±0.75) 165.6%	0.223 (±0.33) 148.48%	0.208 (±0.3) 144.9%

The impact of the cycle protocol on the rectus femoris EMG responses at each interval are depicted in Figure 8. A decrease in mean muscle activity, although insignificant, between protocols was recorded in all three subject groups at both time intervals. The cyclist group were the most affected by the transition, with a 59.3% decrease at minute 3 and a 54.3% decrease at minute 6. Although the triathlete group was the least affected by the cycle protocol, they still recorded a 48.2% decrease in activity from minute 3 of the control protocol, to minute 3 of the transition protocol and 41.6% decrease between minute 6 of either protocol.

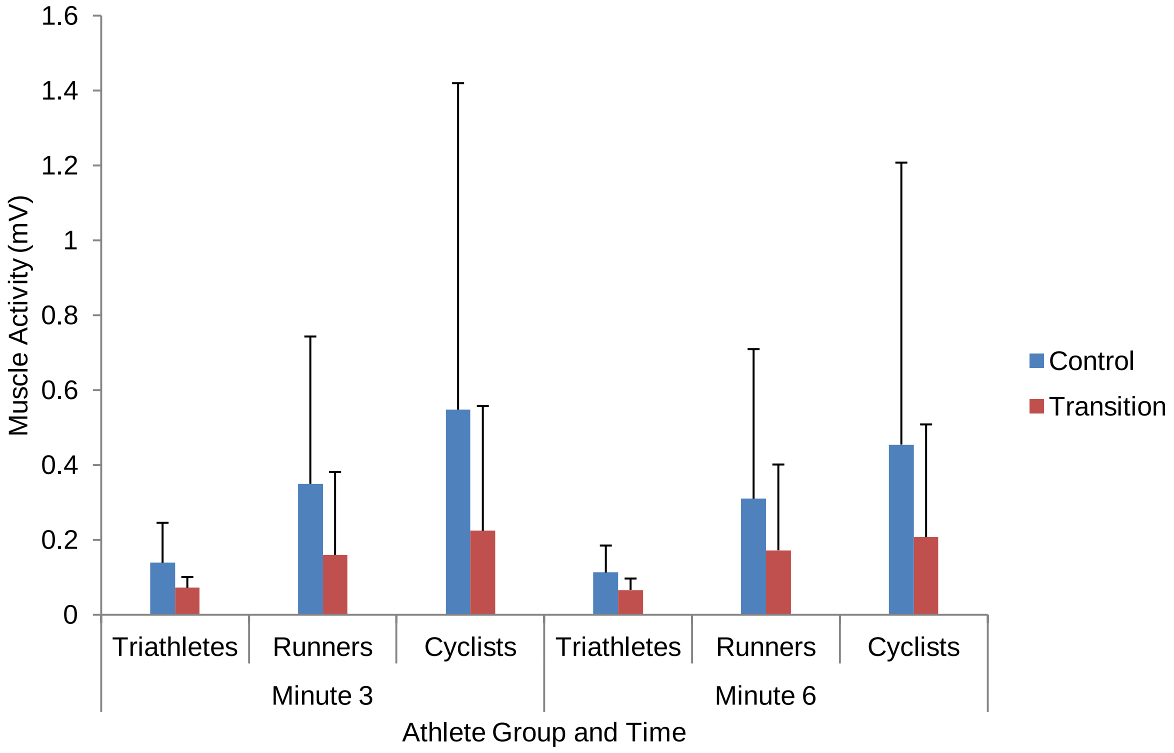

Figure 8: Rectus femoris muscle activity changes between protocols, measured at minute 3 and minute 6.

RUNNING KINEMATICS

Kinematic data (stride rate, stride length and vertical acceleration) were recorded at the same time (minute 3 – 4 and 6 – 7) as other biomechanical and physiological data in order to allow for cross comparison of results.

Stride rate

Table IX shows a breakdown of each subject groups mean stride rate at both intervals, for both the control and transition runs. During the control run, triathletes recorded a significantly higher stride rate at both minute 3 (87.72±4.24strides.min^{-1}) and minute 6 (86.8±3.99strides.min^{-1}), than the runners and cyclists at both intervals, while there were no differences between the runners and cyclists responses. No significant differences were found between time intervals for any of the athlete groups tested. During the transition protocol, although the triathletes still had the highest stride rate, there was no longer any statistical difference between the groups of athletes. Once again, time interval did not affect the stride rate responses elicited.

Table IX: Stride rate (strides.min^{-1}) measured at minute 3 and minute 6 for both protocols.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	87.72 (±4.24) 4.8%	86.8 (±3.99) 4.6%	85.54 (±5.03) 5.87%	85.82 (±4.53) 5.28%
Runners	82.5 (±4.98) 6.04%	82.0 (±4.75) 5.79%	82.5 (±4.6) 5.57%	82.0 (±5.67) 5.69%
Cyclists	83.33 (±3.34) 4.01%	82.5 (±3.21) 3.88%	82.5 (±1.93) 2.34%	81.83 (±2.62) 3.2%

Legend: ⌊____⌋ denotes significant difference between groups.

The triathletes were the only group to report a significant effect of the cycle protocol on running stride rate, recording significant decreases in stride rate at both intervals of the transition run as depicted in Figure 9. The running and cyclist groups were unaffected by the transition between running and cycling, with no changes in stride rate between the control and transition protocols.

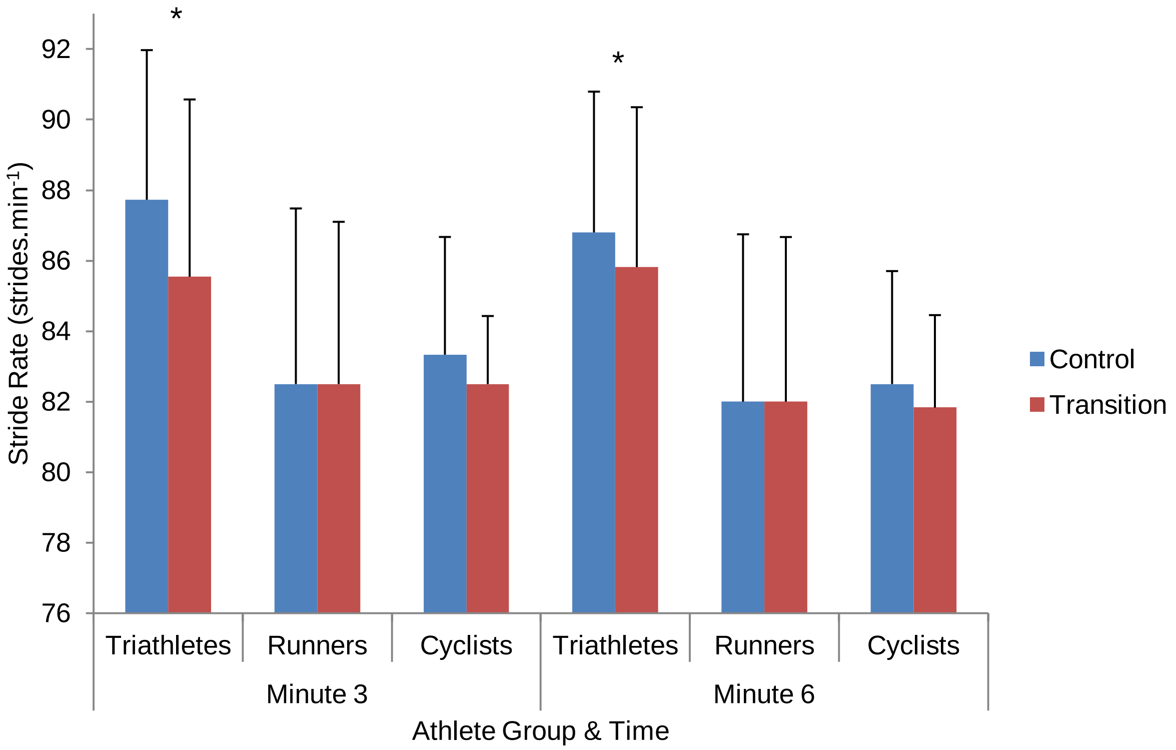

Figure 9: Changes in stride rate (strides.min^{-1}) between protocols, measured at minute 3 and minute 6.

Stride length

Table X lists the mean stride length of each subject group at minute 3 and minute 6 of both the control and transition protocols. As can be expected given the stride rate results in Table IX, triathletes recorded the lowest stride length during the control run (2.85±0.13m), followed by cyclists (3.00±0.12m), with runners recording the highest (3.04±0.18steps.min^{-1}). A statistically significant difference exists between the triathlete and runner groups at both intervals during this protocol. A similar trend is followed during the transition run, with triathletes once again recording the lowest stride rate at minute 3 (2.93±0.17m) and minute 6 (2.92±0.14m). The cycle protocol had the effect of reducing the difference between groups such that the significant difference between groups no longer exists.

Table X: Stride length (m.stride^{-1}) measured at minute 3 and minute 6 for each protocol.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	2.85 (±0.13) 4.7%	2.88 (±0.12) 4.43%	2.93 (±0.17) 5.9%	2.92 (±0.14) 5.12%
Runners	3.04 (±0.18) 5.87%	3.05 (±0.18) 5.82%	3.03 (±0.17) 5.68%	3.06 (±0.17) 5.68%
Cyclists	3.00 (±0.12) 4.18%	3.03 (±0.12) 3.98%	3.03 (±0.07) 2.33%	3.05 (±0.09) 3.2%

Legend: └───┘denotes Significant Difference between groups.

The changes in stride length between the control and the transition run are shown in Figure 10. As stride rate decreases from control to transition, so stride length increases across the change in protocol. Triathletes again recorded the only statistically significant increases (2.4% between control and transition at minute 3, and 1.3% at minute 6).

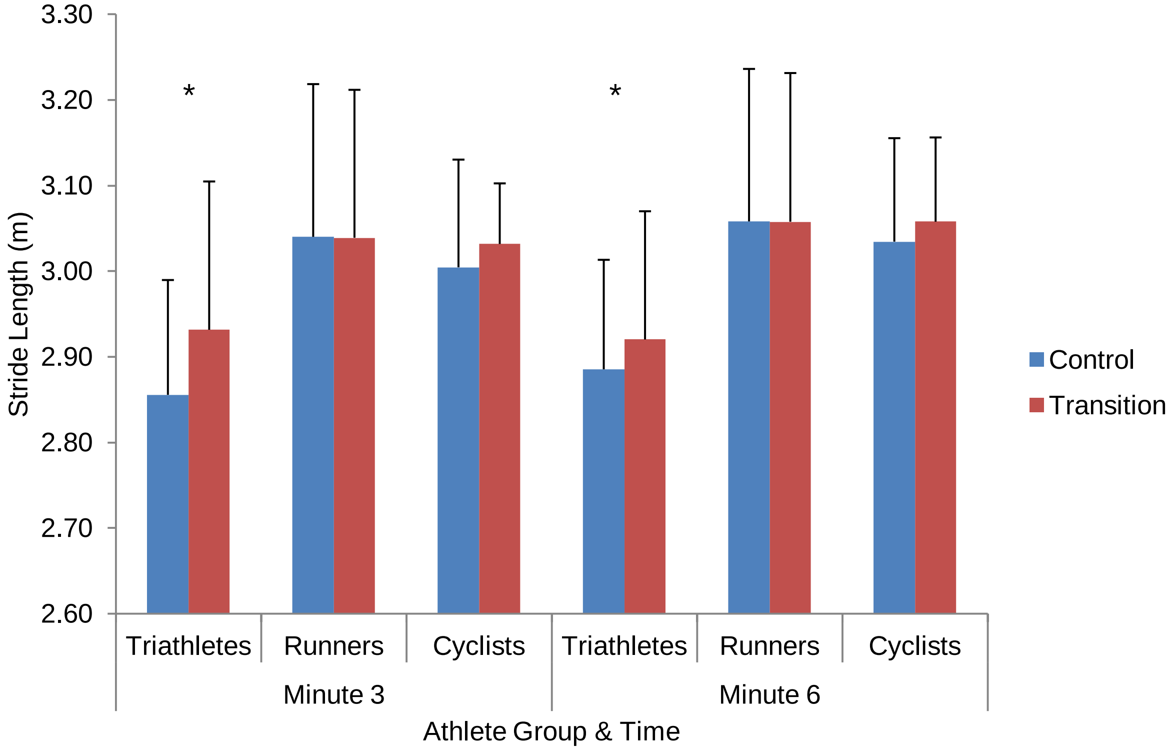

Figure 10: Changes in stride length (m) between protocols, measured at minute 3 and minute 6.

Vertical acceleration

Changes in vertical acceleration between minute 3 and minute 6 of each protocol are shown in Table XI below. At minute 3 of the control run, the trained cyclists recorded the highest vertical acceleration, with runners recording the lowest. There is a high degree of inter- and intra-group variability for the runner and cyclist groups with responses ranging from 11.15 (±8.91)m.s^{-2} for the cyclists and 6.69(±6.36)m.s^{-2} for the runners, resulting in a 40% difference between these groups at this interval. Although the runners recorded the only statistically significant increase between minute 3 and minute 6, they still recorded the lowest mean vertical acceleration at minute 6 of the control protocol.

Table XI: Vertical acceleration (m.s^{-2}) measured at minute 3 and minute 6 during each protocol.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	11.09 (±4.11) 37.02%	10.47 (±4.15) 39.66%	10.82 (±3.82) 35.28%	10.70 (±4.61) 43.09%
Runners	6.69 (±6.36)* 94.98%	7.05 (±6.32) 89.64%	6.87 (±5.16) 75.08%	6.92 (±5.24) 75.75%
Cyclists	11.15 (±8.91) 79.92%	11.30 (±9.00) 79.68%	12.30 (±9.22) 74.99%	12.41 (±9.11) 73.45%

Legend: * denotes Significant Difference between intervals;

The transition protocol produced very similar trends in vertical acceleration responses as the control protocol, with the cyclists again recording the greatest vertical acceleration, and runners the lowest. Figure 11 provides a graphical representation of the effect of the transition between the control and transition protocols on the mean running vertical acceleration of each of the subject groups. At both intervals, the triathlete vertical acceleration responses have decreased compared to the control run, while the cyclist groups responses have increased, however the running group records the only significant change between protocols. Despite this, the running group displayed the greatest ability to control their vertical acceleration at the start of the transition run, and quickly rehabituated to their natural running pattern, thereby correcting the imbalances caused by the cycle protocol.

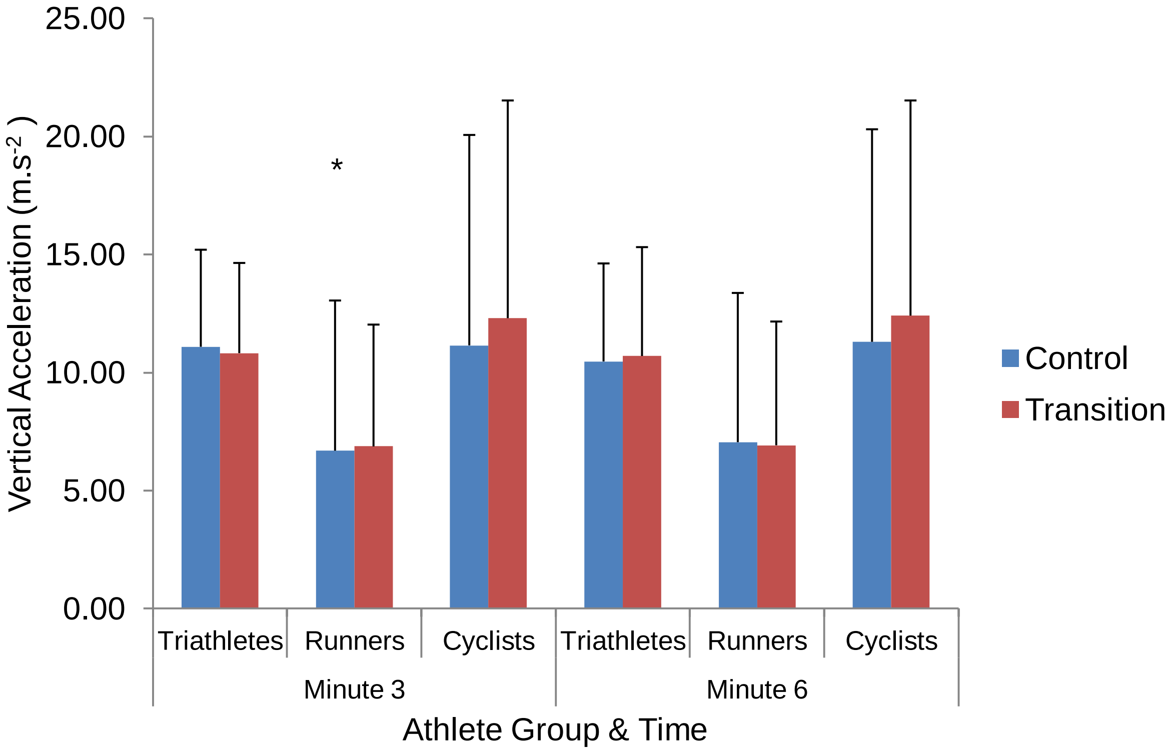

Figure 11: Changes in vertical acceleration ($m.s^{-2}$) between protocols, measured at minute 3 and minute 6.

4.2 PHYSIOLOGICAL RESULTS

Physiological data were recorded at minute 3 and minute 6 for each protocol. Although several measures were recorded, the current research focused on three key physiological variables: heart rate ($bt.min^{-1}$), oxygen consumption ($ml.kg^{-1}.min^{-1}$) and energy expenditure ($kcal.min^{-1}$). Each of these variables are displayed and discussed separately below.

HEART RATE

The mean heart rate responses of each athlete type at minute 3 and minute 6 for both protocols are recorded in Table XII. Both the triathletes and runners showed no significant differences between minute 3 and minute 6 of the control run, indicating that they had reached a steady state in heart rate responses. However the cyclist group, who were the least experienced with running protocols, showed a significant increase from 159 to 165 beats per minute, a response that was shown to be statistically similar to the other two groups.

Table XII: Heart rate responses (bt.min^{-1}) recorded at minute 3 and minute 6 for both protocols.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	163 (±13) 8.12%	165 (±15) 9.33%	168 (±9) 5.61%	171 (±10) 6.08%
Runners	161 (±10) 6.71%	167 (±12) 7.29%	174 (±10) 6.06%	174 (±11) 6.73%
Cyclists	159 (±13)* 8.5%	165 (±13) 8.26%	171 (±11)* 6.69%	174 (±12) 7.15%

Legend: * denotes Significant Difference between intervals

In terms of the transition protocol, the cyclists (as in the control run) demonstrated a significant increase in heart rate from minute 3 to minute 6, albeit a small increase of only 3bt.min^{-1}. All three groups had similar heart rate responses during the transition ranging between 168 and 174, and 171 and 174 for minute 3 and minute 6 respectively, indicating similar levels of physical strain.

Figure 12 graphically displays the effect of the transition on the mean heart rate responses at each interval for each subject group. All three subject groups recorded a significant increase in heart rate from the control run to the transition run at each interval, apart from the triathlete group at minute 3. This suggests that the triathlete group were the least affected by the transition from cycling to running. The greatest increase in heart rate at minute 3 was recorded by the runners, who showed an 8.6% increase from the control run to the transition run, followed by a 4.5% increase at minute 6. The cyclists, however, recorded the greatest increase at minute 6, with

6% increase between protocols. Triathletes recorded the lowest increase between protocols at minute 3 and minute 6, with a 3.3%and 3.1% increase respectively.

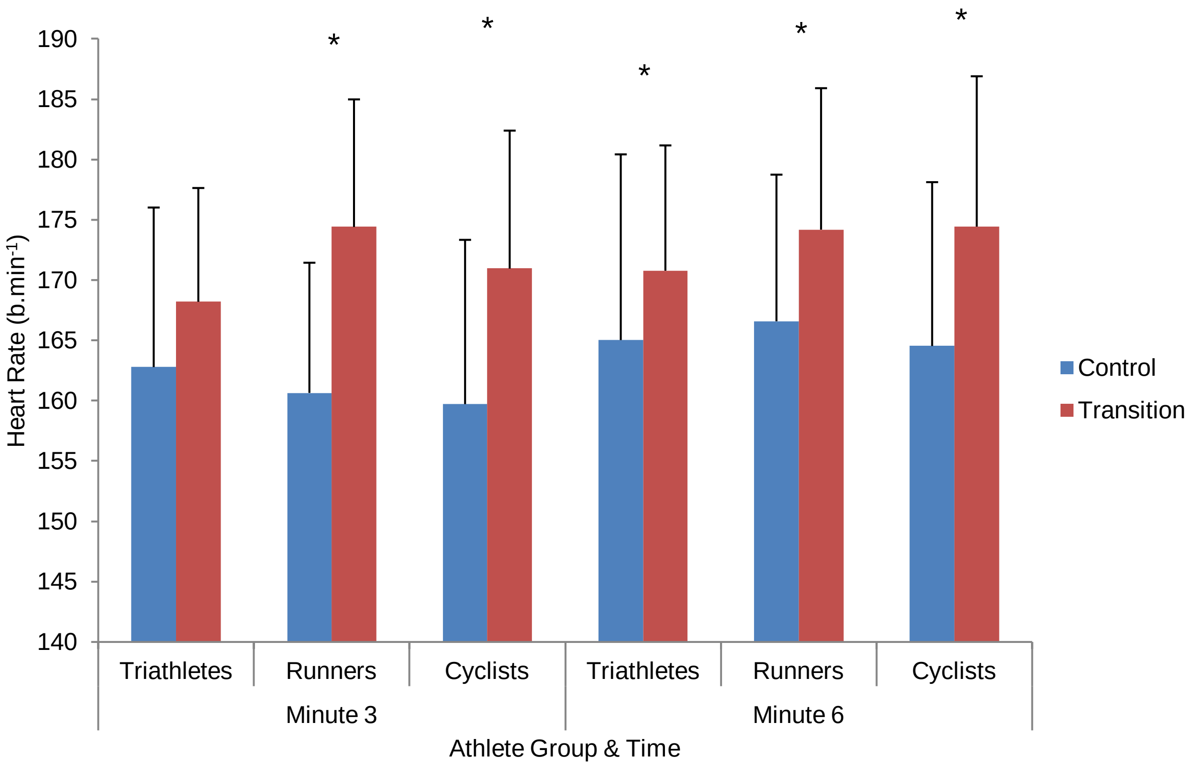

Figure 12: Mean heart rate responses (b.min^{-1}) measured at minute 3 and minute 6 for both protocols.

OXYGEN CONSUMPTION (VO$_2$)

The mean oxygen consumption data are presented in Table XIII. Triathletes recorded the highest oxygen consumption at minute 3 (37.99±4.71ml.kg^{-1}.min^{-1}) of the control run, with runners recording the lowest (34.36±3.63ml.kg^{-1}.min^{-1}). There were significant differences between triathletes and runners at minute 3, as well as between runners and cyclists at the same interval. The single sport runners recorded the only statistically significant increase (3.6%) from minute 3 to minute 6 of the control run. That said, despite the significance of the increase in oxygen consumption for the runners, the triathlete group still recorded the highest values at minute 6, with a mean oxygen consumption of 38.58ml.kg^{-1}.min^{-1}, as opposed to the runners who with 35.62ml.kg^{-1}.min^{-1}, recorded the lowest, a difference of 7.6% between the two groups, all statistical differences present at minute 3 had, however, been removed.

Table XIII: Oxygen consumption (ml.kg^{-1}.min^{-1}) recorded at minute 3 and minute 6 for both protocols.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	37.99 (±4.71) 12.41%	38.58 (±5.66) 14.68%	39.86 (±4.13) 10.36%	40.40 (±4.33) 10.77%
Runners	34.36 (±3.63)* 10.56%	35.62 (±5.06) 14.22%	40.35 (±3.41) 8.46%	40.82 (±4.87) 11.93%
Cyclists	36.93 (±3.87) 10.48%	37.55 (±3.56) 9.47%	39.98 (±4.89) 12.22%	40.36 (±5.73) 14.2%

Legend: * denotes Significant Difference between intervals; └─┘ denotes Significant Difference between groups.

The transition run resulted in trends being reversed as a result of the cycle protocol, with the triathletes (39.86±4.13ml.kg^{-1}.min^{-1}) recording the lowest oxygen consumption values at minute 3, while the runners (40.35±3.41ml.kg^{-1}.min^{-1}) recorded the highest responses. Figure 13 graphically represents the impact of the transition protocol on the mean oxygen consumption of each of the subject groups. The lower responses of the running group at minute 3 of the control protocol are clearly represented, while the reduced variability between subject groups at minute 6 of the control and at either minute in the transition run is also clearly depicted. This is a result of the transition having a significant impact on both the runners and cyclists, such that all three groups' responses during the transition protocol were similar. The greatest impact, however, was on the runners, while the triathletes were unaffected.

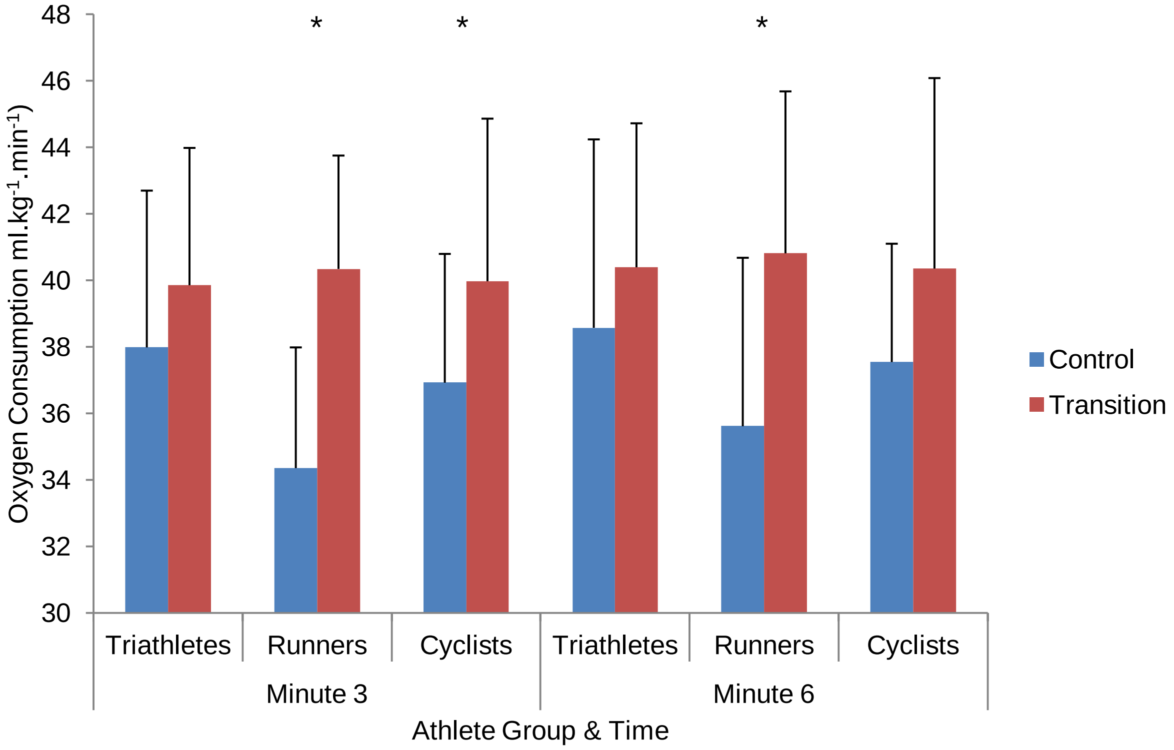

Figure 13: Mean oxygen consumption (ml.kg^{-1}.min^{-1}) data recorded at minute 3 and minute 6 for both protocols.

ENERGY EXPENDITURE

Table XIV shows each subject groups mean absolute energy expenditure for both minute 3 and minute 6 of the two protocols. The data presented shows a consistent trend with all values increasing from minute 3 to minute 6 during either protocol, with only the runners showing a significant increase. During the control run there were no significant differences in absolute energy expenditure between groups at either interval, with responses ranging from 13.74±2.21kcal.min^{-1} (runners) and 13.9±2.11kcal.min^{-1} (cyclists) at minute 3, and 13.96±2.65kcal.min^{-1} (triathletes) and 14.31±2.65kcal.min^{-1} (runners) at minute 6.

Table XIV: Absolute energy expenditure (kcal.min^{-1}) recorded at minute 3 and minute 6 during both protocols.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	13.83 (±1.56) 11.24%	13.96 (±1.76) 12.63%	13.92 (±1.2) 8.6%	14.10 (±1.34) 9.48%
Runners	13.74 (±2.21)* 16.1%	14.31 (±2.65) 18.54%	15.24 (±2.52) 16.53%	15.34 (±2.99) 19.52%
Cyclists	13.90 (±2.11) 15.19%	14.02 (±1.99) 14.23%	14.22 (±2.42) 16.99%	14.34 (±2.45) 17.08%

Legend: * denotes Significant Difference between intervals;

During the transition protocol, none of the subject groups recorded any statistically significant changes in absolute energy expenditure between intervals of the transition procedure. Furthermore, no differences existed between groups as athletes responses ranged from 13.92±1.2kcal.min^{-1} (triathletes) to 15.24±2.52kcal.min^{-1} (runners) at minute 3 of the transition run.

Due to the variations in body mass between subject groups, energy expenditure was also measured relative to each individuals body mass. Interestingly, when considering relative energy expenditure (kcal.kg^{-1}.min^{-1}) as displayed in Table XV, the triathlete group now records the highest energy expenditure at minute 3 (0.19±0.019kcal.kg^{-1}.min^{-1}) and minute 6 (0.193±0.02kcal.kg^{-1}.min^{-1}) of the control run, while the runner group records the lowest energy expenditure at both of these intervals (0.177±0.037kcal.kg^{-1}.min^{-1} and 0.184±0.043kcal.kg^{-1}.min^{-1} respectively). Contrastingly, during the transition protocol, the running group records the highest relative energy expenditure at both intervals (0.197±0.043kcal.kg^{-1}.min^{-1} and 0.198±0.048kcal.kg^{-1}.min^{-1} respectively), while the triathletes recorded the lowest (0.192±0.015kcal.kg^{-1}.min^{-1} and 0.195±0.018kcal.kg^{-1}.min^{-1}).

Table XV: Relative energy expenditure (kcal.kg^{-1}·min^{-1}) recorded at minute 3 and minute 6 of each protocol.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	0.19 (0.019) 9.68%	0.193 (±0.02) 11.21%	0.192 (±0.015) 8.08%	0.195 (±0.018) 8.47%
Runners	0.177 (±0.037)* 21.37%	0.184 (±0.043) 23.10%	0.197 (±0.043) 21.94%	0.198 (±0.048) 19.52%
Cyclists	0.188(±0.02) 10.61%	0.19 (±0.017) 9.24%	0.192 (±0.023) 12.1%	0.194 (±0.026) 13.57%

Legend: * denotes Significant Difference between intervals;

An increase in both absolute and relative energy expenditure is also present between the control and transition protocols for all three subject groups.. Figure 14 shows the increase in mean absolute energy expenditure for all three groups at both intervals for either protocol. Although there were increases in energy cost for all three subject groups during the transition run, only the runners recorded a statistically significant increase at both time intervals.

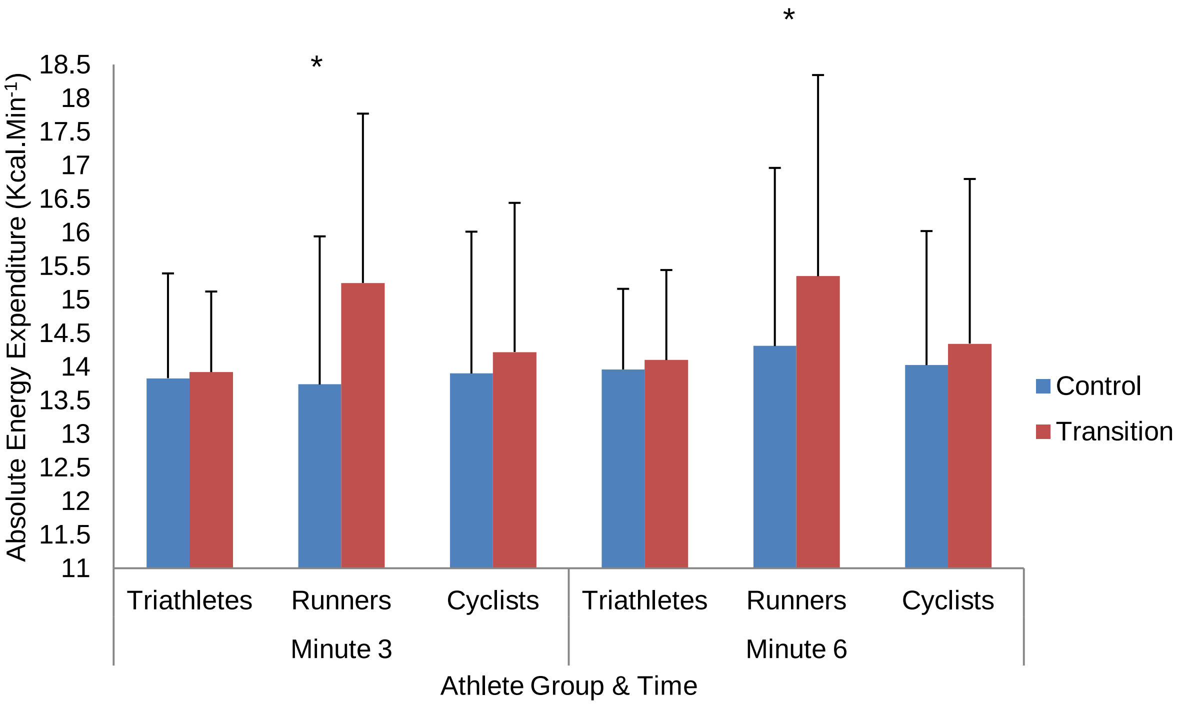

Figure 14: Mean absolute energy expenditure responses (kcal.min^{-1}) at minute 3 and minute 6 for both protocols.

The transition from cycling to running has a greater effect on runners than either of the other subject groups when considering both absolute and relative energy expenditure, recording the highest energy expenditure during the transition run in both cases, hence also recording the greatest increase in energy expenditure between protocols. The triathlete group was the least affected in both absolute and relative terms, recording a slight decrease in energy expenditure between the control protocol and minute 3 of the transition protocols, while still recording the lowest energy cost at minute 6 of the transition protocol.

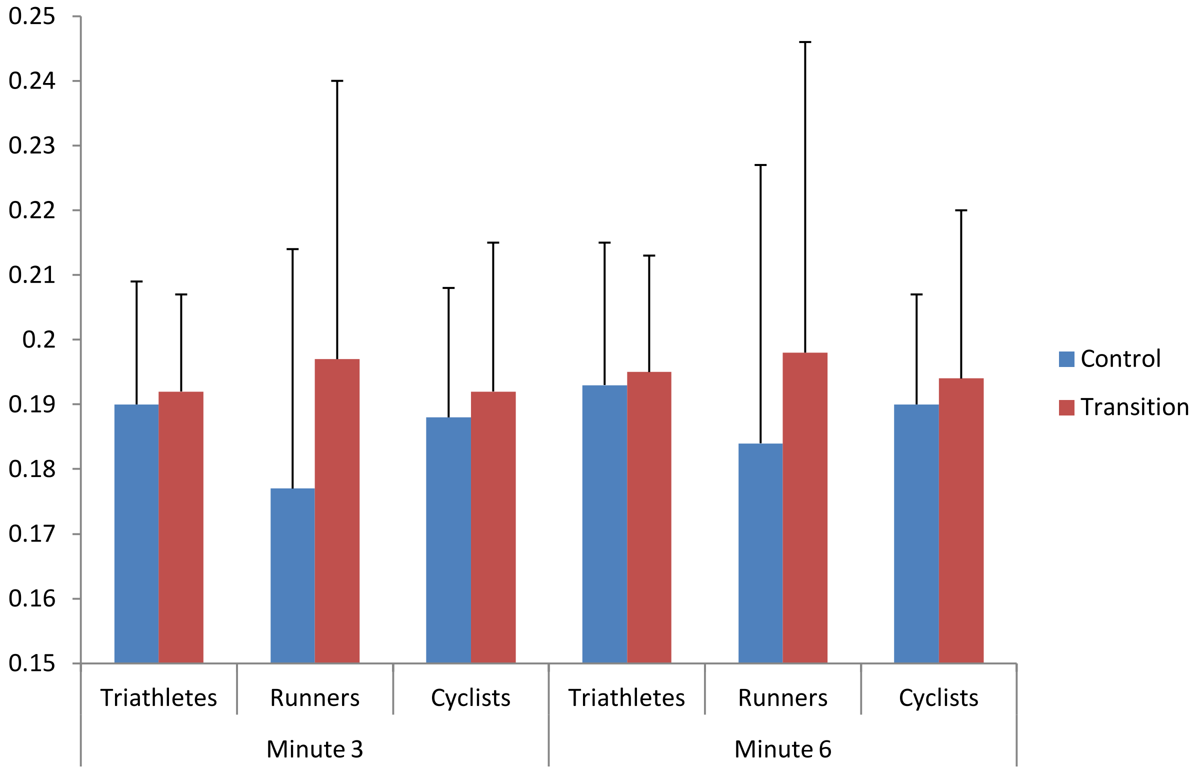

Figure 15: Relative energy expenditure ($kcal.kg^{-1.}min^{-1}$) measured at minute 3 and minute 6 for both protocols.

4.3 PSYCHOPHYSICAL RESULTS

Each athlete groups mean subjective ratings of perceived exertion (RPE) are recorded in Table XVI and Table XVII. This variable is purely subjective in nature, and is simply an indication of the intensity at which subjects perceive themselves to be working in each protocol.

CENTRAL RATING OF PERCEIVED EXERTION

Central RPE refers to the subjects' indication of how hard they perceived their cardiorespiratory systems to be working. Table XVI shows the mean central RPE for all subject groups at both minute 3 and minute 6 for each test protocol. Runners and cyclists recorded an equal central RPE at minute 3, while runners recorded the smallest increase between intervals (7.6%), and thus also had the lowest central RPE at minute 6. All subject groups recorded a significant increase in central RPE from minute 3 to minute 6 of the control run.

Between minute 3 and minute 6 of the transition run, only runners and cyclists recorded a statistically significant increase. The triathletes recorded the smallest increase (4.8%) and hence had the lowest central RPE at minute 6. The running group showed the greatest increase (9%) from minute 3 to minute 6, and also recorded the highest central RPE at minute 6 of the transition run.

Table XVI: Central rating of perceived exertion recorded at minute 3 and minute 6 during each protocol.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	11.45 (±1.86)* 16.27%	12.80 (±1.99) 15.54%	13.27 (±2.37) 17.86%	13.91 (±2.98) 21.44%
Runners	10.92 (±2.02)* 18.51%	11.75 (±2.14) 18.19%	13.00 (±1.91)* 14.67%	14.17 (±2.41) 16.98%
Cyclists	10.92 (±1.88)* 17.23%	11.92 (±2.5) 21%	12.92 (±2.71)* 21%	14.00 (±3.19) 22.79%

Legend: * denotes Significant Difference between intervals;

It is possible to see from Figure 16that the cycle protocol had a significant effect on all three subject groups at minute 3 of the transition run, with all three subject groups finding the transition run to be significantly harder at this point than at the same interval in the transition run. All three groups increased by a significantly, with triathletes recording the smallest increase (15.8%) and runners recording the largest (19.04%).

At minute 6, all three subject groups again recorded an increase in perceived exertion. As displayed in Figure 16, however, the triathlete group recorded the smallest increase from the control protocol to the transition protocol at minute 6, with an increase of just 8.7%. The triathletes were also the only subject group to not record a statistically significant increase between protocols, with cyclists recording the next largest increase (17.44%) and runners showing the greatest influence of the transition, recording both the greatest increase between protocols (18.6%) and returning the highest central RPE rating at minute 6 of the transition run.

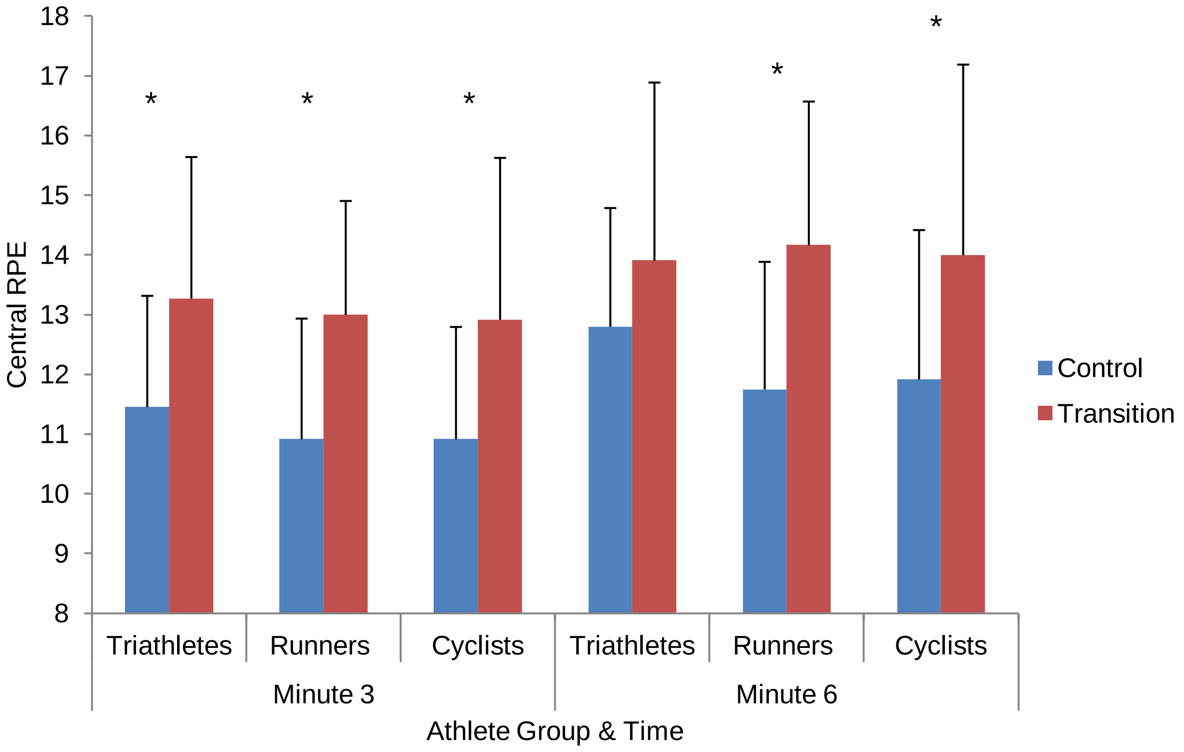

Figure 16: Central ratings of perceived exertion recorded at minute 3 and minute 6 for each protocol.

LOCAL RATING OF PERCEIVED EXERTION

Local Rating of Perceived Exertion (RPE) refers to the subject's perception of how hard their musculoskeletal system is working during the current task. For the purposes of the current investigation, subjects were required to rank the local RPE with specific reference to their leg muscles.

Table XVII provides a summary of each subject groups mean local RPE at both minute 3 and minute 6 of each protocol. At minute 3 of the control protocol, there was very little variation (0.7%) between subject groups. All three groups increased their RPE ratings at minute 6 of the control run. With both the runners and the cyclists recorded statistically significant increases between minute 3 and minute 6.

Table XVII: Local rating of perceived exertion recorded at minute 3 and minute 6 during each protocol.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	11.18 (±2.04) 18.25%	11.7 (±1.83) 15.63%	12.73 (±2.61) 20.52%	13.09 (±2.55) 19.46%
Runners	11.17 (±2.17)* 19.41%	12.25 (±1.86) 15.22%	13.58 (±1.83)* 13.49%	14.50 (±2.24) 15.42%
Cyclists	11.25 (±1.29)* 11.45%	11.83 (±1.59) 13.40%	13.42 (±1.88)* 14.02%	14.25 (±2.45) 17.22%

Legend: * denotes Significant Difference between intervals; ⎵ denotes Significant Difference between groups.

Minute 3 of the transition run resulted in a far greater variation between subject groups (6.7%) than the same interval of the control protocol. As with the control run, only the runners and cyclists increased significantly from minute 3 to minute 6, with runners once again recording the greatest increase (6.7%) and also the highest RPE rating (14.5±2.24) at minute 6. The triathletes again recorded the smallest increase between intervals (2.8%), and also recorded the lowest RPE rating (13.09±2.55) at minute 6 of the transition run. Interestingly, the triathletes perceived the transition task to be easier at minute 6 than either of the other two subject groups did at minute 3 of the same task.

Table XVII provides a graphical indication of the effects of the cycle protocol on each subject groups mean local RPE. All three subject groups recorded significant increases in RPE ratings from the control to transition protocol, at either interval. At minute 3, the runners were the most affected, recording a 21.6% increase, while the cyclists recorded the greatest increase (20.5%) between control and transition running at minute 6.

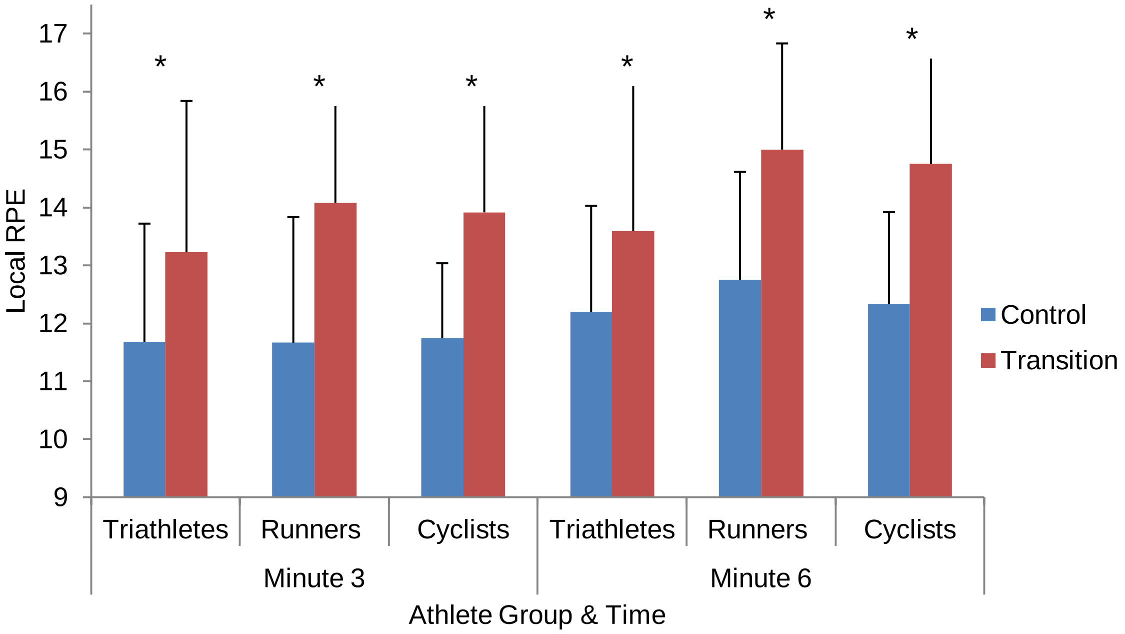

Figure 17: Mean Local Ratings of Perceived Exertion recorded at minute 3 and minute 6 for each protocol.

4.4 HYPOTHESES

It was expected that the results of the current study would be affected by factors associated with the transition from cycling to running, as well as by each athletes sporting background, and subsequent subject group. It was therefore hypothesised that the transition run would reflect greater biomechanical, physiological and perceptual strain on the athletes when compared to a control run. Furthermore, it was expected that the triathlete group would be less affected than the single sport runners and cyclists. Due to a lack of research into the abilities of single sport runners and cyclists to transition effectively, any hypotheses regarding the differences between these two groups was purely non-directional.

IMPACT OF THE TRANSITION

1. The hypothesis under test was that there would be no differences in biomechanical responses (muscle activity and running kinematics) between the control and transition protocols for any of the three athlete groups.
    a) The triathlete group recorded a significant difference in muscle activity between a control and transition protocol for the gastrocnemius muscle at minute 3. Furthermore, the transition from cycling to running had a significant effect on triathletes gait responses, as changes were evident for both stride rate and stride length at either interval. Thus, in terms of muscle activity this hypothesis is accepted as there is only 1 difference of a possible 20 (5%). However, in terms of running kinematics this hypothesis is rejected, as there are 8 differences from a possible 12 (66%).
    b) The runners recorded no significant changes in muscle activity between control and transition running for any of the tested muscles. There was, however, a significant change in vertical acceleration between conditions at minute 3. However, this hypothesis is accepted in terms of both muscle activity and running kinematics, as there is only one difference reported out of a possible 32 (3.1%).
    c) The cyclist group did not record any significant changes in either muscle activity or running kinematic responses between protocols at either interval. Hence, this hypothesis is accepted in both cases.

2. The hypothesis under test was that there would be no differences in physiological responses (Heart rate, VO_2 and Energy Expenditure) between the control and transition protocols for any of the three athlete groups.
    a) The triathlete group recorded no significant changes between conditions for either oxygen consumption or energy expenditure. There was, however, a significant increase in heart rate at minute 6. This hypothesis, however, is accepted as there is only 1 difference from a possible 12 (8.3%).
    b) The running group recorded significant changes in all three physiological variables, at both time intervals, as a result of the transition from cycling to running. This hypothesis is therefore rejected as significant differences are reported in all possible cases.
    c) The cyclist group reported no significant changes in oxygen consumption or energy expenditure as a result of the transition. However, an increase in heart rate was recorded at both minute 3 and minute 6. Hence, on balance this hypothesis is accepted, as there are only 4 differences from a possible 12 (33%).

3. The hypothesis under test was that there would be no differences in Perceptual responses (RPE) between the control and transition protocols for any of the three athlete groups.
    a) The triathlete group reported a perceived increase in both central and local RPE between the control and transition run, at either interval. This hypothesis is thus rejected.
    b) There was a significant increase in both central and local RPE between conditions for the running group. This difference was evident at both intervals. This hypothesis is therefore rejected.
    c) The cyclist group reported a significant increase in both central and local RPE as a result of the transition from cycling to running. It is possible, therefore, to reject this null hypothesis.

IMPACT OF ATHLETE GROUP

1. The hypothesis under test was that there would be no differences in biomechanical responses (muscle activity and running kinematics) between any of the three athlete groups for either the control or the transition protocols.

   a) There were no significant differences in muscle activity for the control run between any of the tested athlete groups. There were, however, differences in running kinematics as the triathlete stride rate was significantly lower than either of the other two groups. Furthermore, the triathlete groups stride length was different to the running group. No differences in vertical acceleration were evident. This hypothesis however, is accepted in both regards, as there are no differences in muscle activity, and only 4 of a possible 18 for running kinematics.

   b) During the transition run there were no significant differences between groups for any of the biomechanical variables. This hypothesis can therefore be accepted.

2. The hypothesis under test was that there would be no differences in physiological responses (Heart rate, VO_2 and Energy Expenditure) between any of the three athlete groups for either he control or the transition protocols.
   a) During the control run, no significant differences in heart rate or energy expenditure were evident between groups at either interval. There was however, a difference in oxygen consumption evident at minute 3 between triathletes and runners, as well as between runners and cyclists. On balance, however, this hypothesis can be accepted.

   b) No differences between groups were evident for any physiological variables at either interval of the transition run. This hypothesis can therefore be accepted.

2. The hypothesis under test was that there would be no differences in Perceptual responses (RPE) between any of the three athlete groups for either the control or the transition protocols.

    a) No differences between groups were evident for any physiological variables at either interval of the control run. This hypothesis can therefore be accepted.

    b) No differences between groups were evident for any physiological variables at either interval of the transition run. This hypothesis can therefore be accepted.

CHAPTER V

DISCUSSION

Research into the effects of a prior cycle protocol on running efficiency and performance has become an important topic in recent years, largely due to the growing popularity of multisport competition, which has seen a boom since the inception of triathlon on the Olympic roster at the 2000 Sydney summer Olympics. While previous research has focused on aspects such as the effects of cycling on motor coordination (Chapman *et al.,* 2008), on endurance performance (De Vito *et al.,* 1995) and on different cycle pacing strategies and their influence on transition running (Hausswirth *et al.,* 1999), the current study focused on the influence that an athlete's training and competition history may have on their triathlon performance ability. By focussing on the cycle-run transition, identified as the key transition during triathlon, the current study aimed to determine if any difference in transition ability existed between trained triathletes, runners and cyclists, and which of the latter two groups of single sport athletes may be more suited to triathlon competition. The results of the current study are discussed in detail below, with a view to comparing the current results with those of relevant previous research in order to draw valid conclusions regarding the effects of a prior cycle protocol on subsequent running performance.

5.1 BIOMECHANICAL RESULTS

ELECTROMYOGRAPHY (EMG)

Due to the large inter-individual variations inherent to muscle activity while running, as identified by Guidetti *et al.,* (1996), the current study chose to focus primarily on the trends present in the results between groups, as well as the percentage contribution of each muscle, rather than on individual data sets. Muscle activity data is representative of the amount of musculoskeletal strain placed on an individual during a given task, and may therefore be used as a tool for comparison between both individuals and groups (Arsenault *et al.,* 1986). Furthermore, muscle activity could provide an indication of the skill level of an individual in completing a task, as a lesser-skilled individual may require greater muscle activity to complete a task (Chapman *et al.,* 2007).

Impact of specific muscles

The impact of the cycle protocol on the measured muscle activity can also be considered in terms of each muscle's percentage contribution to the overall muscle activity (see Figure 18). Although the graphic below provides an insight into the contributions of each muscle to the total measured muscle activity, it must be noted that this is merely an indication and cannot be considered as standard due to the various factors, outlined previously, which may affect the validity of EMG analysis. During both the control and transition protocols the triathlete group showed an evenly balanced distribution of muscle contribution, while the runner and cyclist groups show a predominance of tibialis anterior and rectus femoris contribution during both protocols.

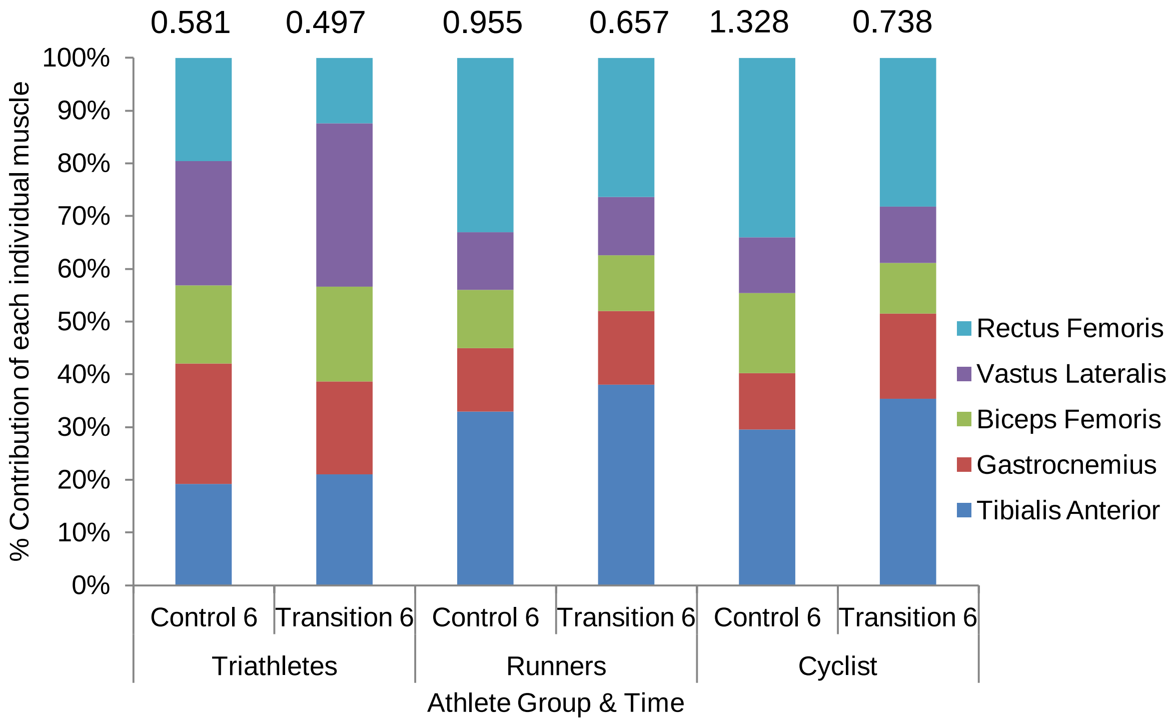

Figure 18: Percentage contribution of each measured muscle to overall muscle activity (Sum of muscle activity represented above each bar).

During the transition run, the triathlete groups' tibialis anterior and vastus lateralis muscle activity increased slightly, with a concomitant decrease in rectus femoris and gastrocnemius activity. A similar trend is followed in the cyclist and runner groups, although with even smaller variations in terms of the cyclists, and much larger variations recorded for the runners. The effect of the cycle protocol and transition run on tibialis anterior in particular can be expected due to the crucial role that this muscle plays in both cycling and running performance (Chapman *et al.,* 2008). Tibialis anterior is therefore negatively affected by the cycle protocol, such that there was a fatigue response causing a slight increase in muscle activity.

Primary versus Secondary muscle recruitment

The small fluctuations in percentage contribution of the muscles measured in the current research do not adequately account for the large decreases shown in mean muscle activity measured for the five muscles between the control and transition phase. A plausible explanation for this is that, due to the demands being placed on the primary lower limb muscles by both the control run and cycle protocols, there may be an increase in the activation levels, during the transition run, of more minor muscles not tested during the current study. Thus, particularly during the early stages of the transition run, when the primary muscle groups are in a recovery stage post-cycle, it is likely that secondary muscles may play an important role in maintaining running performance. This theory is supported, in part, by previous research by Chapman *et al.,*(2008), who found that the mean amplitude of peak EMG activity in the tibialis anterior muscle was reduced during a post-cycle transition run in at least some elite triathletes, a pattern that was present in the current research where only six of the 11 triathletes showed a reduced mean tibialis anterior activity after cycling. The above authors go on to state that it is possible that, during transition running, the patterns of muscle recruitment may be more similar to cycling than running. Hence, in the first part of the transition run protocol, athletes may rely more heavily on the gluteus muscles, soleus and semimembranosus (Chapman *et al.,* 2008). It is apparent from both the current study, and that of Chapman *et al.* (2008), that further research into the influence of these secondary muscle groups is necessary.

The combination of these theories may explain some of the fluctuations in muscle activity levels seen in Figure 19. As discussed previously, the cyclist group recorded the greatest decrease in mean muscle activity post-cycle. This suggests that although the cyclists are more predisposed to cycling, they also require greater secondary muscle recruitment post-cycle in order to maintain running performance. It follows thus, that the running group, being the next least experienced at the crossover from cycling to running, recorded the second greatest decrease in mean muscle activity, thereby inferring that this group had the second highest demand placed on secondary muscle groups. it is also possible, as highlighted by Chapman *et al.,* (2008), that the running muscle recruitment of the cycling group may have been more representative of cycling recruitment patterns than of running, which may account for the variability in muscle responses.

Impact of athlete group

Table XVIII: Mean muscle activity (mV) in all measured muscles.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	0.159 (±0.133)* 83.6%	0.116 (±0.06) 45.1%	0.097 (±0.052) 53.6%	0.106 (±0.091) 85.8%
Runners	0.205 (±0.27) 131.7%	0.191 (±0.277) 145%	0.131 (±0.18) 137.4%	0.133 (±0.19) 142.8%
Cyclists	0.309 (±0.53) 171.2%	0.26 (±0.44) 169.2%	0.136 (±0.194) 142.6%	0.148 (±0.211) 142.6%

Legend: * denotes Significant Difference between intervals; └──┘ denotes Significant Difference between groups.

Table XVIII provides the mean muscle activity for all five muscles measured in the current study. The amalgamation of the data recorded for the tibialis anterior, gastrocnemius, biceps femoris, vastus lateralis and rectus femoris muscles may provide insight into the musculoskeletal demands placed on the combined tested muscle groups by both the control and transition (post cycle) protocols. It is possible to determine from the above table that the triathletes had the lowest muscle activity at all intervals in both protocols, followed by the runners, and finally the cyclists.

The aim of the current study was to determine the effects of a cycle protocol on athlete responses to a subsequent run protocol. In order to isolate the effects of the cycle, it was necessary to incorporate a control (run only) protocol as a comparative variable. As stated above, triathletes had a lower mean lower limb muscle activity than either of the other two subject groups at minute 3 and minute 6 of the control run. This is likely a result of the performance classification of each of the tested groups. As the triathletes could be considered elite, while the runners and cyclists only sub-elite, it is to be expected that in certain cases the higher performance level of the triathlete group would influence the results. Thus, in terms of muscle activity, the triathlete, being potentially more trained in both running and cycling than either of the control groups in the current context, can be expected to have a greater level of muscle adaptability than single sport cyclists or runners who train specifically for their sport. Hence, while elite runners may have been expected to have the lowest muscle activity in running specific muscles during a running task, when considering both the performance level of the runners tested, and a combination of both cycling and running related muscle groups, it is plausible that triathletes, being more trained, would elicit superior (i.e. lower) levels of muscle recruitment. That said, cyclists record the highest muscle activity across both protocols, which can again be a result of the fact that this subject group was being required to complete a task which may seem foreign to them in terms of muscle recruitment. This finding is in agreement with a previous study by Chapman *et al.,* (2008), who found that leg muscle activity during running is less skilled in less trained runners (in the case of the current research, cyclists) than in highly trained runners, suggesting that adaptations to running muscle activity continue with long term training in single-discipline running athletes. The same authors further stated that less trained runners (i.e. relative to cyclists in the current context), when tested at a running speed equal to that of trained runners and triathletes, would be running at a speed closer to their maximum than either of the other two groups, and would therefore require greater levels of muscle activity (Chapman *et al.,* 2008).

As seen in Table XVIII, all three subject groups mean muscle activity decreased from minute 3 to minute 6 of the control protocol, with the greatest decreases occurring within the triathlete and cyclist subject groups. This was largely expected due to the specificity of the responses associated with a running task. The running group, being the most experienced in the given task, can be expected to record the most consistent responses, while a familiarisation period would be necessary within the cyclist and triathlete groups, allowing their muscle recruitment patterns to adapt to that which is most suitable for the given task. Lavcanska *et al.,* (2005) found that it took subjects with no treadmill experience just 6 minutes to become familiarised to treadmill running. It can therefore be assumed, due to the brief familiarisation process utilised during the current study, that the subjects in the current study would have become familiarised more quickly than those in the study by Lavcanska *et al.,* (2005). Similarly, White *et al.,* (2002) found that subjects who were experienced in treadmill running prior to experimentation took just 30 seconds to become familiarised to treadmill running during testing. Thus, it can be assumed that, during the current study, subjects would have taken between 30 seconds and 6 minutes to become familiarised to treadmill running. Furthermore, it is highly likely, given their sport specific training, that the runners would familiarise the fastest, followed by the triathletes and finally the cyclists, given the fact that, during the current research, these athlete groups could be categorised as elite, trained and untrained respectively when considering running ability.

Impact of cycle-run transition

The transition from the cycle to run (transition protocol) further reduces the muscle activity levels of each of the subject groups. Due to the familiarisation phase present during either protocol for the triathlete and cyclist groups, the current study chose to compare the end (minute 6) of the control protocol to the end (minute 6) of the transition protocol. Although the muscle activity levels of all three groups approximate to each other as a result of the transition, each group requires a different decrease in mean activity before reaching the common recruitment level. The cyclist group is the most affected by the change in protocols, which could be as a result of their muscle recruitment being more suited to an ideal cycling pattern compared to either of the other two groups, hence the cyclists may have been more predisposed towards recruitment of the primary muscles for cycling, thus once again requiring greater muscle adaptation when returning to the running protocol. The next greatest decrease occurs within the running group, where the cycle protocol would most likely have caused the greatest disruption to the muscle activity patterns. Muscle activity in the triathlete group was the least affected by the transition, which can be expected due to their experience with the transition itself, and the fact that their muscles are both trained and adapted to the demands of cycling and running.

Is there an ideal level of muscle recruitment?

A consistent trend throughout the EMG data collected is the high intra-group variability which is present, as a result of highly variable levels of muscle recruitment between athletes in each group. That said, the triathlete group showed an intra-group variability that was a lot smaller than either of the other two groups. However, it must be noted that in many cases the levels of variability within each group was decreased by the transition from running to cycling. In the case of the biceps femoris, vastus lateralis and rectus femoris results, a high measure of intra-group variability either remained unchanged by the transition, or decreased during the transition run for all three. These decreases may be indicative of either a fatigue effect, or of the cycle protocol causing a more uniform pattern of muscle recruitment during the subsequent running protocol. Interestingly, the triathlete group has lower intra-group variability for the tibialis anterior and gastrocnemius muscles during both protocols, while the runners and cyclists are high, which suggests that there is an optimal level of muscle recruitment for these muscles which the triathletes equate to, either as a result of transition experience or athlete performance level.

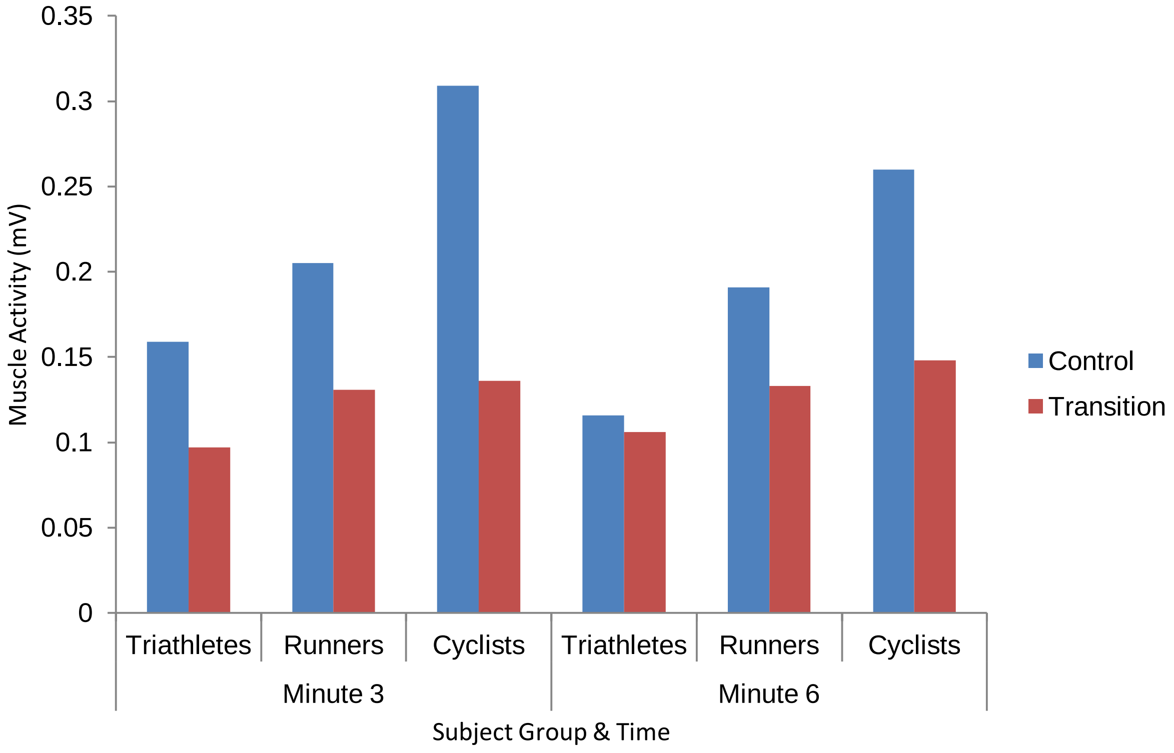

Figure 19: Mean muscle activity changes (mV) for all measured muscles from control to transition protocol.

It is apparent, given the data in Figure 19 that during the control protocol there were large differences in muscle activity between each of the groups, with a significant difference ($p < 0.05$) between the triathlete and cyclist groups. Although the triathlete groups mean muscle activity remains similar between control and transition, particularly at minute 6, the transition from running to cycling has the effect of reducing the cyclist and runner groups mean activity levels. The net result of these reductions is that these groups responses approximate to those of the triathlete group, thereby reducing the intergroup variability. This may suggest that there is an ideal muscle activity level for triathlon performance, which the triathletes are able to achieve sooner than either the runners or cyclists due to their superior experience with the transition from cycling to running.

STRIDE RATE AND STRIDE LENGTH

Stride rate and stride length are directly dependent on each other, and are linked by an inverse relationship such that as stride rate decreases so stride length should increase by the same margin It has also been established that stride rate and stride length do contribute to running efficiency and thus performance (Gottschall and Palmer, 2000). Previous research into the effects of cycling on stride length and stride frequency while running has shown that fatigue causes runners to systematically alter their running technique by decreasing both their stride length and stride frequency, thereby manipulating mechanical efficiency through running stride alterations (Cavanagh and Kram, 1985;Gottschall and Palmer, 2000), but little research has been conducted on the effects of cycling, and hence cycling-related fatigue, on stride rate and stride length.

The results of the current study confirm the inverse relationship between stride rate and stride length, as well as the effects of fatigue on stride rate, as all three subject groups stride rates decreased over time. That said, the triathlete group was the only group to record a significant decrease in stride rate, and associated increase in stride length, as a result of the cycle protocol. This finding is in contrast to a previous study by Gottschall and Palmer (2000) which found, in a sample group of experienced triathletes, that running kinematics immediately following a cycle protocol are significantly altered to those during a control run, however in this case stride rate increased and stride length decreased. However, over the course of the subsequent run, these authors found that stride rate decreased below that of the control run, while stride length increase higher than that recorded during the control run, findings that support the results of the current research.

The triathlete groups mean stride rate during the control condition was significantly higher than both the single sport runners and single sport cyclists, implying that this athlete groups freely chosen stride rate was inherently higher than either of the other two groups. During the transition protocol, however, there was no longer any significant difference in stride rate between the three subject groups. Interestingly, it is apparent thus that while the gait responses of the runner and cyclist groups were relatively unaffected by the transition from running to cycling, the triathlete group recorded a significant decrease in stride rate after the transition. Although this significant change is supported by literature (Gottschall and Palmer, 2000), the interaction between groups is particularly interesting when considering the effects of the transition on running economy. Although the triathlete group recorded the only significant change in gait responses after the transition, they did not record any significant decrease in running economy as a result. The runner and cyclist groups, however, did not alter their gait responses, but recorded significant decreases in running economy post-cycle. Thus, it is possible that the triathlete group actively reduced their gait responses in attempt to preserve their running economy post-cycle, allowing for improved performance after the transition.

VERTICAL ACCELERATION

Although vertical acceleration was chosen as a kinematic variable during the current study, it was used as an indication of the vertical displacement of the athletes centre of mass while running, thus providing insight into the effects of the cycle protocol on the different athlete groups. During normal running there is a reduction in vertical displacement as forward (horizontal) propulsion of the body becomes more pertinent. However, as it is impossible to completely negate the vertical aspect of locomotion, the minimisation of this component is an important factor in improving running economy (Noakes., 2001). Although there is a paucity of research available regarding the effects of cycling on the vertical displacement of athletes in a subsequent running protocol, it is possible to compare the results of the current study to those which have focused purely on kinematics of single sport running.

Previous research by Cavanagh (1982) found that elite runners have a lower vertical displacement when compared to their sub-elite counterparts. These results are comparable to those recorded during the current study, wherein the running group (most experienced) had a lower vertical displacement than the triathletes (intermediate) while the cyclists, considered to be the least experienced, recorded the highest vertical displacement. These conclusions are applicable to both intervals in either protocol. Further research by Dutton and Smith (2002) reported an increase in vertical displacement as a result of fatigue, which is contrary to the current research. Although an increase in vertical displacement was recorded in the cyclist group over time and after the cycle protocol, the triathlete and running groups actually lowered their vertical displacement responses during the transition protocol. This is an important consideration when considering the effects of vertical displacement on running economy. The triathlete and runner groups, being trained at running, may have subconsciously reduced their vertical displacement in order to preserve their running economy. This was successful in the triathletes’ case, where no significant changes in stride rate were recorded post cycle. The runners, however, did record significant decreases in running economy post cycle. This may lead to the conclusion that experienced runners may have an increased ability to control their vertical displacement in a fatigued state, for the running group, however, who were more negatively affected by the prior cycle protocol, the reduction in vertical displacement of the centre of mass was not sufficient to preserve running economy.

5.2 PHYSIOLOGICAL RESULTS

HEART RATE

Effect of athlete group

Table XII provides a summary of each subject groups mean heart rate responses during each protocol, showing that in this case, both the triathlete and runner groups reached a plateau in their physiological responses, while the cyclist group did not. The failure of the cyclist group to reach a plateau during the control protocol could be due to their training history and specificity, as these athletes would have been most unaccustomed to running exercise. This theory is supported by research by Fernhall and Kort (1990), who found that, during submaximal exercise, training specificity appears to have a significant effect on the physiological responses to treadmill running. This lack of running specificity within the cycling group may have thus been responsible for the greater increase from minute 3 to minute 6. A similar explanation can be used to explain the lack of a physiological plateau in the cyclist groups' responses during the transition protocol. This was followed by the largest increase from minute 3 to minute 6, which can again be attributed to a lack of specificity to running, as well as the onset of fatigue.

The ability of the triathlete and runner groups to attain a plateau in their heart rate responses can be attributed to their greater level of training specificity in comparison to the cyclist group. Both of these groups would have been more accustomed to running, due to habitual nature of their training in this discipline, and can therefore be expected to have reach a plateau sooner than the cyclist group.

Effect of cycle-run transition

All three groups mean heart rate increased from the control to transition protocols, showing an increase in the aerobic demand of running after cycling. With all three groups recording a significant increase from the end of the control run to the end of the transition run. This finding is supported by the findings of and Hausswirth *et al.,* (1996) and Hue *et al.,* (1998), who found that heart rate responses were significantly higher following a cycle-run protocol than after a lone run protocol. These findings back up previous research by Kreider *et al.,* (1988), which found a significant difference between the heart rate measured after a 10km control run, and a laboratory based triathlon protocol. Once again, the direct effect of the cycle protocol on heart rate responses can be determined by comparing minute 6 of the control run to minute 3 of the transition run. The running group were the only group who recorded a significant increase in heart rate as a direct result of the cycle protocol, which can be explained by their lack of experience in the cycle protocol. As mentioned previously, however, the cyclist group then recorded a significant increase at minute 6 of the transition run, the likely cause again being the transition from a habituated task to an unfamiliar one. The triathlete group were least affected by the cycle protocol, recording just 1.9% increase in heart rate.

OXYGEN CONSUMPTION

Effect of athlete group

As can be seen in Table XIII, oxygen consumption data was relativised according to each individual’s body mass, allowing for a direct comparison between individuals of different sizes.

It follows thus, that the triathlete group recorded the greatest oxygen consumption at minute 3 and minute 6 of the control protocol, while the runners had the lowest oxygen consumption at the same intervals as these groups had the lowest and highest mean body mass respectively. As shown by the data in Table XIII, the running group once again failed to reach a physiological plateau in their responses by minute 6 of the control run. Although surprising, this group did reach plateau in terms of heart rate responses, it is thus plausible that although a plateau had been reached in this group's oxygen consumption, their responses were lagging slightly behind those recorded for heart rate.

The transition from cycling to running had the effect of minimising the variance between athlete groups, such that the responses of all three groups approximated to each other (1.2% difference between highest and lowest at minute 3, as opposed to 10% difference during the control protocol). There were no significant differences in oxygen consumption between athlete groups at either minute 3 or minute 6 of this protocol. This is surprising as it was expected that the triathlete group, being the most experienced with the cycle-run transition, would have a lower oxygen cost during transition running than either of the other two athlete groups. The results of the current study, in which no inter-group differences were evident, are in contrast to previous research by Millet *et al*., (2000), who found that triathlon ability level had a significant effect on oxygen consumption. This study, however, utilised a maximal cycle protocol, while the current study made use of a submaximal protocol, which may account for differences in the results between the two studies.

Effect of cycle-run transition

Prior studies by both Millet and Vleck (2000) and Pialoux *et al.,* (2008) have reported an increase in the oxygen cost of running after a prior high intensity cycling bout. These studies are both partially in agreement with the findings of the current research in which both the cyclist and runner groups mean oxygen consumption increased between a control run and a transition run. It must be noted, however, that these studies utilised triathletes, while the triathlete group in the current research did not record any significant increases as a result of the transition from running to cycling. As with the heart rate data discussed previously, the triathletes recorded the smallest increases in oxygen cost as a result of the transition from running to cycling, which may be a result of their experience with the transition itself. The runners, on the other hand, again recorded the greatest increase in responses as a result of the transition from cycling to running, which can again be attributed to their lack of specificity regarding the cycle protocol (Fernhall and Kort, 1990).

The limited effect of the transition from cycling to running on the triathlete group is in contrast to previous research by Millet and Vleck (2000) and Pialoux *et al.,* (2008), both of which reported significant effects of the transition on oxygen consumption and other ventilatory responses. The distinction between both of these previous studies and the current research comes when considering the ability level of the triathletes tested. While the current research made use of elite triathletes, both of these prior studies utilised sub-elite or mid-level triathletes. These athletes may have been more affected by the transition than the elite athletes utilised during the current research.

ENERGY EXPENDITURE

Data from Table XIV shows that a physiological plateau in absolute energy expenditure (kcal.min^{-1}) was reached for triathletes and cyclists in both protocols, but only for the transition protocol in the running group.

Absolute versus Relative energy expenditure

Due to the large variability in body mass present between subject groups, the current study deemed it necessary to consider both absolute energy expenditure (kcal.min^{-1}) and energy expenditure relativised to each individuals body mass (kcal.kg^{-1}.min^{-1}). The use of relative energy cost was particularly pertinent given the current study's focus on running performance during a transition, or post-cycle, run. The transition from cycling to running constitutes a change from a non-weight-bearing activity to one associated with impact forces of two to three times the body mass of the athlete (Quigley and Richards, 1996; Hausswirth *et al.*1996). Hence, with increasing body mass, it becomes more necessary to account for relative energy expenditure. In the current context, although no significant differences in body mass are present between subject groups, there is an 8% difference between the triathlete (lowest) and runner (highest) groups, which may prove influential when considering overall energy cost.

Effect of athlete group

It is interesting to note, that when considering relative energy cost (Table XV) for the control run, the runner group recorded the lowest energy cost at both intervals, while the triathlete group recorded the highest. The cyclist group recorded a similar energy cost to the triathlete group, as there is only a 1% difference in between the groups at either interval. This is surprising given the training status of each group, as it would be expected for the triathlete group to have a lower energy cost than the cyclists.

The transition from running to cycling had the effect of increasing the differences between subject groups when considering absolute energy expenditure, and these differences, although smaller, are emulated by the relative energy cost data. When considering either variable, the triathletes recorded the lowest energy expenditure at both minute 3 and minute 6 of the transition run, while the runners recorded the highest at both intervals. Although all three subject groups recorded a progressive rise from minute 3 to minute 6 of the transition protocol, the absence of any statistical significance is indicative of a physiological plateau being reached in all three groups.

Effect of cycle – run transition

The transition from cycling to running resulted in an increase in both absolute and relative energy expenditure in both the cyclist and runner groups, with a significant difference in the latter case, while the triathlete group recorded only minor fluctuations in mean energy cost. The 2% and 7.19% increases in absolute energy expenditure between minute 6 of either protocol, recorded by the cyclist and runner groups respectively, are in agreement with previous research by Hausswirth *et al.* (1996), who found that the energy cost of running was between 1.6% and 11.6% higher for a transition run than for a control run. This study, however, did not use trained triathletes as subjects, which may explain the similarity between their results and those of the current research. A subsequent study by Millet *et al.,* (2000), found that with increased triathlete experience and performance level, came a concomitant decrease in physiological alterations caused by the transition from running to cycling. A previous study by Marino and Goegan (1993) found no significant difference in energy cost between a control and transition run in an elite triathlete sample. Finally, Pialoux *et al.,* (2008) found that, within a group of middle level triathletes, no significant increases were recorded between a sub-maximal running test, and a sub-maximal transition running test. Each of these prior studies support the findings of the current research, which showed little effect of the cycle protocol on the energy cost responses within the elite triathlete group. It is thus possible to conclude that, in the current context, the cycle protocol has a limited effect on transition running in the triathlete group. Hence, it appears likely that being trained and experienced in the transition from running to cycling may be an important determinant of triathlon success. That said, future research should focus on more long term effects of the cycle protocol, as this lack of impact may be a transient effect.

Interestingly, when comparing the two single sport groups, it is the running group that is the most adversely affected by the cycle protocol, recording a 7.19% increase at minute 6 of the transition run, as opposed to just a 2% increase recorded by the cyclists, while both groups mean energy cost increased by less than 1% from minute 3 to minute 6 of the transition run. These results suggest that the cycle protocol has an important role to play in triathlon success, and it appears that habituated cyclists are the least affected by the cycle itself, thus suggesting that it may be easier for habituated cyclists to cross over into triathlon than for habituated runners.. The fact that the runner group recorded the greatest increase, and subsequently the highest energy cost during the transition, from cycling to running can be expected due to the fact that this group would have been most affected by the prior cycling bout. Although this group would be expected to be the most competent in terms of the running protocol, they would have been most displaced by the prior high intensity cycle protocol as a result of their lack of specificity with this discipline. The cyclist group, on the other hand, would have been disrupted by the control run, but would have found a comfortable level of intensity and habituation during the course of the cycle protocol, potentially resulting in a lower energy cost during the subsequent run. It is likely, however, that over a longer time frame the cyclist group may have once again been more affected than the running group, as the cyclists would have transitioned from a habituated task to an unfamiliar one. The runners, on the other hand, may improve in their responses over time, as they transition from an unfamiliar task to one in which they are both trained and habituated.

5.3 PSYCHOPHYSICAL RESULTS

Subjects were required to give a subjective rating of their perceived exertion (RPE) at minute 3 and minute 6 for each of the two protocols. These perceptual ratings were split into either Central or Local RPE, with central RPE referring to how hard subjects perceived their physiological systems to be working, while local RPE related to the extent to which subjects perceived their musculoskeletal system (specifically legs) were taxed. Both central and local RPE are measured on the same 14-point scale (Figure 3 in chapter 3).It must be noted that RPE ratings are purely subjective in nature, and are therefore heavily influenced by the subjects experience with using such a scale. Thus it is well known that an individual's subjective responses to a task differ to that which is physically evident (Straker *et al.,* 1997). This may lead to reduced validity of perceptual results. Furthermore, the competitive nature of top level athletes may lead to a distorted perception of task difficulty.

CENTRAL RATING OF PERCEIVED EXERTION

As seen in Table XVI, all three subject groups perceived a significant increase in the intensity of the control running task from minute 3 to minute 6. Interestingly, both runners and cyclists recorded lower central RPE ratings than the triathlete group at both intervals of the control run. While during the transition run, these two groups recorded higher central RPE ratings than the triathlon group. Although the validity of the results are compromised by poor correlations with measured heart rate, it is apparent from the data collected that the triathlete group found the transition run to be more manageable than either the runner or cyclist group, which is expected given their greater experience with the transition from cycling to running.

The use of central RPE responses has often been advocated as an attempt to gain an accurate reflection on the tasks difficulty, and as such has often been correlated with heart rate responses. Robertson *et al.,* (2000) argues that opinions differ as to the suitability of RPE recordings as opposed to direct physiological assessment through heart rate. In order to determine the validity of each individuals central RPE rating during the current study, Pearson Product Moment correlations were conducted on all heart rate and central RPE data. All three subject groups recorded poor correlations between heart rate and central RPE at both intervals in each protocol, which negatively impacts the validity of the perceptual results collected during the current study. It is possible, however, to compare each group's perceptual results in order to provide an indication of how difficult each group found each of the protocols. Despite the poor correlations to heart rate, the significant increase in central RPE responses is similar to a prior study by Hue *et al.,* (1998), who found that within a sample group of 7 male triathletes, all 7 recorded an increase in their perception of run difficulty after cycling.

LOCAL RATING OF PERCEIVED EXERTION

Local RPE data were collected from each athlete in order to gain an indication of how hard each athlete perceived their musculoskeletal system to be working, with specific reference to their lower limbs. Although local RPE ratings are subject to the same validity problems as central RPE, it is possible to use the data collected to provide some indication of each athlete group's perception of the lower extremity musculoskeletal effort that was required in each protocol.

As with previous research by Hue *et al.,* (1998), all groups recorded an increase in local RPE between minute 3 and minute 6 of each protocol, as well as a significant increase between conditions. The triathlete group, due to their experience with the cycle-run transition, recorded the lowest local RPE ratings at each interval during the transition run. Both the runner and cyclist groups recorded significant increases in local RPE from minute 3 to minute 6 of the transition run (6.7% and 6.18% respectively), while the triathlete group increased by just 2.8%. Not only does this indicate that the triathlete group found the transition run less demanding than either the runner or cyclist groups, but that they were also able to maintain an intensity throughout the transition run. The runner and cyclist groups, contrastingly, required a consistent increase in lower extremity work in order to maintain the running speed required during the transition run.

5.4 DOES THE CENTRAL GOVERNOR PLAY A ROLE?

When considering the interaction between the physiological and biomechanical data collected during the current study, it can be considered anomalous that as mean physiological responses rise with ongoing time and in response to the transition between cycling and running, it is apparent that the mean muscle activity responses (for all 5 measured muscles) decrease from minute 3 of the control until minute 3 of the transition, after which there is an increase in activity at minute 6 of the transition (Table XVIII and Figure 20). However, when considering previous research by Kay *et al.,* (2001), it may be possible that there is an element of central nervous system control over the level of skeletal muscle recruitment.

It has been suggested that the down-regulation of skeletal muscle activity through the use of efferent command signals may be an attempt by the central nervous system to control metabolic rate (Ulmer, 1996). Kay *et al.,*(2001) measured the efferent muscle activity in the rectus femoris muscle during a 60min self-paced cycle, with six 30s sprints interspersed throughout the protocol. This study found that the efferent drive in the rectus femoris muscle, indicated by both measured power output and muscle activity, initially decreased, only to increase to near starting values during the concluding stages of the protocol. These authors thus suggest the existence of a subconscious muscle power reserve during the initial 5 sprints, with a clear increase in intensity during the final sprint. This subconscious self-regulation of exercise intensity is also evident during the current research, where although athletes were making a conscious effort, as demonstrated by both increasing heart rate and central RPE (Table XII and Table XVI), there is a decrease in the mean muscle activity during the protocols, with the presence of an apparent 'end-spurt' at minute 6 of the transition run.

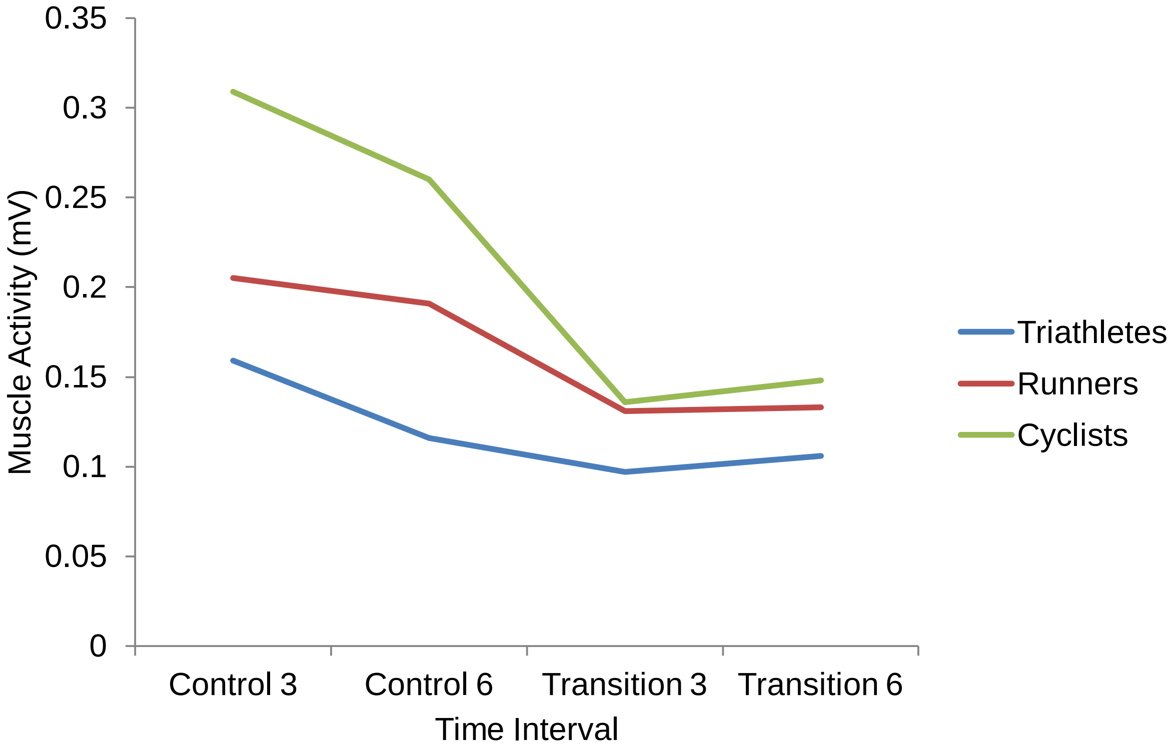

Figure 20: Changes in mean muscle (mV) activity over time

Although the current study made use of a close-looped protocol, in which both pace and time were controlled, which is in contrast to the study by Kay *et al.,* (2001), it is still evident that a mismatch between muscle activity and cardiovascular responses exists, which may be indicative of a de-recruitment of skeletal muscle, such that a muscle recruitment reserve exists, allowing for an 'end-spurt' of intensity in the concluding minutes of the transition protocol. This may be a control mechanism by which the central nervous system controls the athletes metabolic rate subconsciously, allowing for both an inherent resistance to fatigue, as well as for an ‘end-spurt’ during which the athlete is able to increase intensity without any detrimental effects on the body. Further research is required to quantify the effect that the central nervous system may have on overall performance, as this may have important implications for triathlon training and competition.

5.5 PRACTICAL SIGNIFICANCE AND IMPLICATIONS FOR PERFORMANCE

Despite the lack of statistically significant differences within much of the data obtained during the current study, there are still noteworthy differences which may influence performance. Athletic performance does not require the presence of statistical differences, as in many cases the smallest of margins can separate first and second place. It is therefore necessary, in the current context, to establish whether the results of the present study have any important implications when considering performance rather than statistical difference. This inference of practical significance can provide an insight into the potential role that the transition may play in terms of actual competition. It is, however, limited by the fact that differences may be circumstantial due to the athletes being tested, and may not be broadly applicable.

Running economy, described as the relationship between steady state oxygen consumption and running speed, has been shown to decrease both as a result of the effects of a prior cycling task and as a result of the onset of both biomechanical and physiological fatigue (Vercruyssen *et al.,* 2001;Pialoux *et al.,* 2008; Bonacci *et al.,* 2010). There is an inverse relationship between oxygen consumption and running economy, such that with increasing oxygen cost of a task, there is a concomitant decrease in the movement economy associated with that task.

Table XIX is a description of each subject groups mean oxygen cost per kilometre during both the control and transition protocols. As running speed was set at 15km.h^{-1}, it is possible to directly compare the responses of each subject group. As anticipated, there is a decrease in running economy both over time, and between conditions, as oxygen cost increases per kilometre. It is interesting to note that the triathlete groups running economy is lower than the runners or cyclists during the control run, but during the transition run the results of each group are similar, thus representing almost no change in the running economy of the triathletes as a result of the cycle protocol, while the runner and cyclist groups both recorded significant increases in oxygen cost per kilometre at minute 3 after the cycle protocol.

Within a homogenous group of subjects, as in the current study, running economy is an excellent indicator of endurance performance, as the runner with the best economy will consume less oxygen at a given workload, allowing them to run faster at the same intensity, or to run for longer at the same speed (Palmer and Sleivert, 2001). In the current study, at minute 3 of the transition protocol, the running groups mean running economy was 1.2% and 0.9% lower than the triathletes and cyclists respectively. Although this may seem small, when considering that during an Olympic distance triathlon athletes run 10km, a 1.2% difference at 15km.h^{-1} equates to 28.8 seconds, which may have significant triathlon performance implications. Similar margins are present at minute 6 of the control protocol, which would have similar implications for performance. For example, at the 2010 South African Triathlon Championships, just 30 seconds separated the top 4 finishers, while at the 2010 World Championships, held in Budapest, Hungary, just 4 seconds separated first and second, while 30 seconds separated the top 5 finishers in the men’s race. Finally, at the Beijing Olympics, there were only 20 seconds between the top 4 competitors.

When considering the effects of the cycle protocol on running performance, it is possible to determine from Table XIX that there is a 4.9%, 17.3% and 8.25% decrease in running economy between protocols at minute 3 for the triathlete, runner and cyclist groups respectively. These differences equate to a performance difference of 1min57.6s, 5min55.2s and 3min18s for a 10km run for each of these groups respectively. These results are important in that there is limited literature available regarding the abilities of different athlete groups to negotiate the transition between running and cycling. These equate to a performance difference for the triathlete group, and both statistical significance and performance implications for both the runners and cyclists. However, it is important to note that these effects may be transient, as the current research focused only on the first 7 minutes of running after the cycle protocol. It is plausible that these effects may wear off over time, which may lead to a change in the long term effects of running after cycling.

Table XIX: Oxygen cost per kilometre ($\mathrm{ml.O_2.kg^{-1}.km^{-1}}$) as an indication of running economy measured at minute 3 and minute 6 of each protocol.

	Control Run		Transition Run	
	Min 3	Min 6	Min 3	Min 6
Triathletes	151.97 (±18.86) 12.41%	154.33 (±22.66) 14.69%	159.46 (±16.51) 10.36%	161.60 (±17.31) 10.77%
Runners	🟩 137.48 (±14.52)* 10.56%	🟥 142.47 (±20.27) 14.22%	🟩 161.40 (±13.65) 8.46%	🟥 163.28 (±19.48) 11.93%
Cyclists	🟦 147.72 (±15.49) 10.48%	150.20 (±14.24) 9.47%	🟦 159.92 (±19.54) 12.22%	161.44 (±22.92) 14.20%

Legend: * denotes Significant Difference between intervals; Colours indicate significant differences between conditions.

It is apparent, therefore, from the above results, that improving running economy is an important aspect of training for triathlon performance, particularly when considering running economy following a prior cycling bout. It can also be concluded that as the cyclists appear less affected by the cycle protocol than the running group, it may be easier for single sport cyclists to cross into triathlon than for single sport runners.

5.6 TRIATHLETE SPECIFIC IMPLICATIONS

The focus of the current study was on the effects of a cycle protocol on subsequent running performance, as well as on the differences between trained triathletes and single sport runners and cyclists. However, it is also possible, based on the results obtained, to determine what makes one triathlete more successful than another. Of the elite triathletes tested during the current study, five took part in the 2010 South African Triathlon Championships with results ranging from 4th to 52nd. Based on the results of these championships, it is possible to determine the mean race running speed of each athlete for comparison with their measured running economy, which has been identified as a key determinant of triathlon performance (Bentley *et al.,* 2002). Given the fact that the running economy measured during the current research was obtained on a level treadmill at a constant running speed, the moderate correlations between race running speed (*in situ*) and running economy are of particular interest. This is especially the case when considering Figure 22, which provides an indication of the effect of average running speed of each top 10 athletes on their overall finishing position at the 2010 South African Triathlon Championships.

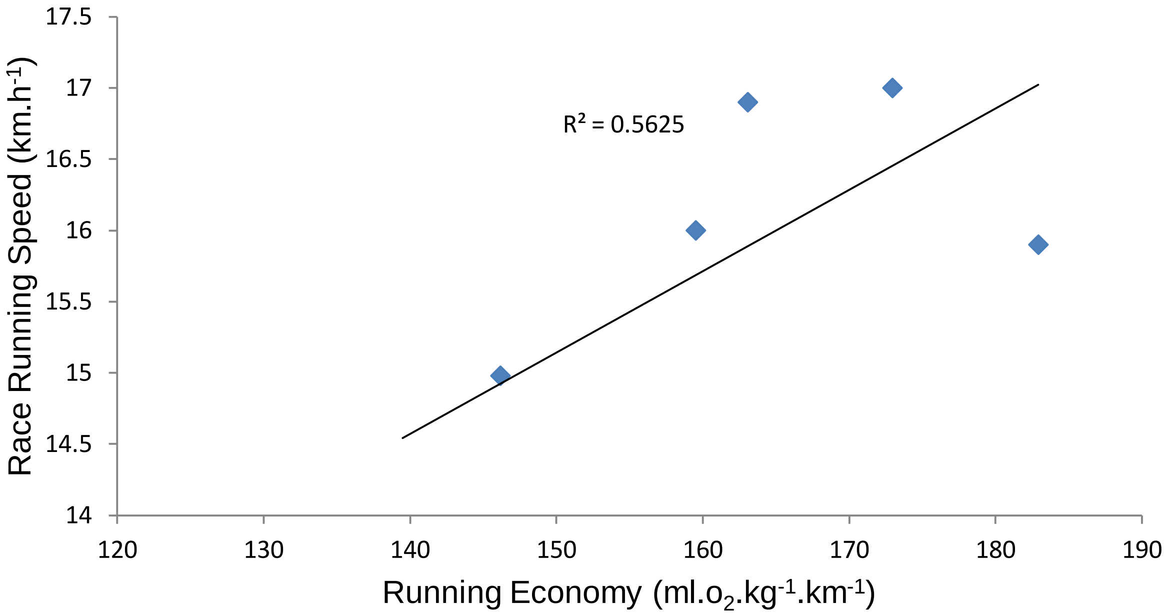

Figure 21: Correlation between measured running economy at minute 3 of the transition protocol and race running speed.

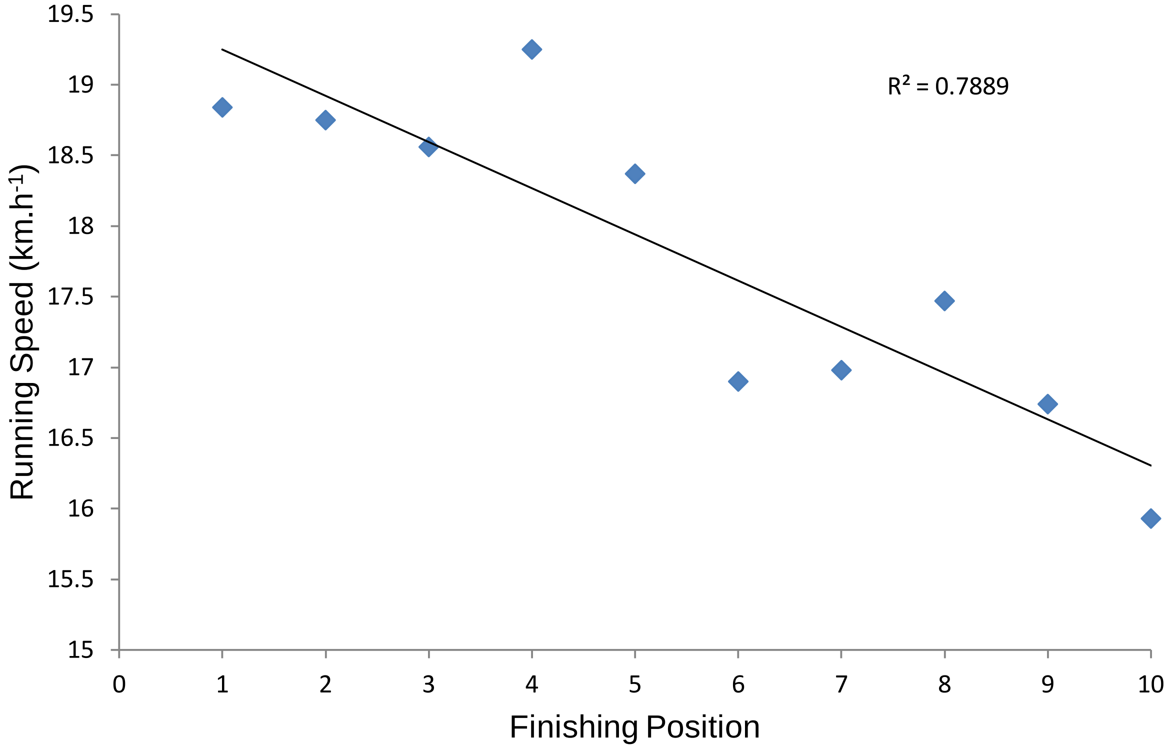

Figure 22: Correlation between run race speeds and finishing position for top ten finishers at 2010 South African Triathlon Championships

It is possible to determine from the above correlation that there is a strong influence of running speed and running ability on overall triathlon performance, which is in agreement with several previous studies which have stated that the run is the most important of the three events (Millet *et al.,* 2000; Bentley *et al.,* 2008; Chapman *et al.,* 2008). Furthermore, based on the results of the current research, it is apparent that improved running economy allows for a faster mean race speed, which is a key determinant of performance. Thus it can be concluded that for a triathlete to obtain optimum performance, the athlete must be able to maximise their running economy after cycling in such a way that increased race running speed is possible. This is most likely achieved by training specifically for transition between cycling and running, but also accounting for factors which may influence running economy.

CHAPTER VI

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The ability to transition effectively between disciplines is a key determinant of success in any competitive multisport event. Within triathlon, the initial transition occurs between swimming and cycling, and the final transition occurs between cycling and running. The latter of the two has been identified as having the greatest influence on overall triathlon success. This transition has also been identified as the most difficult to master, due to the demands placed on similar muscles of the leg. Consequently, there is an apparent lack of coordination when running after cycling which has been related to leg muscle fatigue. Furthermore, running after cycling has important cardiorespiratory effects, which may influence overall performance, and therefore need to be taken into account when training for triathlon.

Due to the recent rise in triathlon popularity, there has been a growth in the number of single sport runners and cyclists who have crossed over and taken up triathlon. Although prior cycling or running experience will have no detrimental effects on recreational triathletes, for those seeking to obtain optimum performance there may be some influence of their single sport habituation on their triathlon performance. Furthermore, this influence may be directly related to the transition between running and cycling, and may affect the ease with which these athletes manage the transition.

It is therefore important that an understanding of the effects of prior cycling on subsequent running ability and efficiency be developed such that triathlon performance can be optimised through training modifications and recommendations. Furthermore, recommendations need to be made for single sport runners and cyclists, as to which of these single sport athletes are more suited to triathlon, as well as how they should go about achieving their own optimum performance.

The purpose of the current study was therefore to investigate the different effects that a simulated cycle-run transition would have on habituated triathletes, runners and cyclists. The intention of which was to provide insight and understanding into the biomechanical, physiological and perceptual changes associated with this transition, as well as into how each of the previously mentioned athlete groups coped with this transition.

6.1 SUMMARY OF PROCEDURES

The current study was conducted within the University of Pretoria High Performance Centre Biokinetics Laboratory, and within the Physiology laboratory in the Human Kinetics and Ergonomics Department at Rhodes University. 35 volunteer subjects took part in the current research (11 triathletes, 12 runners, 12 cyclists). The runner and cyclist groups were required to have no triathlon or transition experience. Subjects were required to attend two testing sessions. During the first session the researcher gave a detailed verbal explanation of the procedures which would be carried out, and any queries were addressed. Following this, anthropometric data (stature, mass, age) were obtained. Finally subjects were required to perform a test for Maximal Aerobic Power. This test was preceded by a standardised warm up protocol as suggested by Lamberts *et al.,* (2009). The test itself was performed at a starting work rate of 2.50W.kg^{-1} body mass, after which the load increased by 20W each minute until the subject could not sustain a cadence greater than 70rpm, or was volitionally exhausted. MAP was determined as the mean power output during the last completed minute of the MAP test.

The second session was conducted a minimum of 24 hours after the first, and consisted of both experimental protocols, a control run and a transition run (which included a prior high-intensity cycle bout). Subjects were fitted with all necessary equipment, and were then required to perform a 'control' run at 15km.h^{-1} for 7 minutes. Following this, subjects were allowed to rest until a reference heart rate had been obtained, after which they were required to cycle for 20min on a stationary bicycle, at a power output equivalent to 70% of their MAP measured in session 1. Immediately following this cycle bout, subjects performed a 'transition' run under the same conditions as the previous 'control' protocol.

The following data were recorded for minute 3 and minute 6 of each of the running protocols:

Heart rate (bt.min^{-1})

Oxygen consumption (mlO$_2$.kg^{-1}.min^{-1})

Energy expenditure (kcal.min^{-1})

Muscle Activity (mV)

> The following muscles were tested: vastus lateralis, rectus femoris, biceps femoris, gastrocnemius, tibialis anterior.

Vertical acceleration (m.s^{-2})

Stride rate (strides.min^{-1})

Stride length (m.stride^{-1})

Basic descriptive statistics relevant to each variable assessed were computed, providing general information regarding the sample. Students T-Tests and 1-way ANOVAs were calculated to determine if any significant differences existed either between conditions or between groups respectively.

6.2 SUMMARY OF RESULTS

BIOMECHANICAL RESPONSES

There was a high degree of inter- and intra-group variability for all 5 muscles measured during the current study. These high levels of variability resulted in few statistically significant differences being found with this parameter. However, when considering muscle activity as a whole (mean activity for all 5 muscles), significant differences ($p<0.05$) were found between minute 3 and minute 6 of the control run within the triathlete group. More importantly, however, there seemed to be a common trend amongst all three groups, as muscle activity initially decreased before finally increasing at minute 6 of the transition run. This may be explained by the presence of anticipatory regulation, governed by the central nervous system.

Although not statistically significant, muscle activity was the least affected by the transition for the triathlete group, followed by the cyclists and then the runners.

During the control run the triathlete groups mean stride rate was significantly ($p<0.05$) higher than either of the other two groups, however the cycle protocol had the effect of reducing this statistical difference during the transition run. This was largely due to a significant decrease in triathlete stride rate after the cycle protocol. Stride length, being inversely related to stride rate, produced similar results. Responses once again equated to each other for all three subject groups, and triathletes once again showed the only significant change ($p<0.05$) as a result of the transition, with a significant increase in stride length. Vertical acceleration was relatively unchanged between protocols, with the running group consistently the lowest, followed by the triathletes and finally the runners. The effects of the transition on gait responses in the triathlete group is interesting, although there is a preservation of running economy from control to transition in this athlete group. It therefore appears likely that the triathlete groups' alterations in gait patterns were made in an attempt to preserve their movement economy while running.

Thus, it is apparent that the transition from cycling to running has no significant effects on the muscle activity responses of each group, but each athlete groups gait responses may provide valuable insight into the biomechanical effects of the transition. The triathlete group significantly altered their gait responses, possibly in an attempt to preserve running economy, which may lead to important performance effects.

PHYSIOLOGICAL RESPONSES

Heart rate responses within each condition showed only minor changes, suggesting that a plateau in physiological responses was achieved by minute 6 of each condition. There were, however, significant increases ($p<0.05$) in heart rate at minute 3 as a result of the cycle-run transition for both the runner and cyclist groups, while the triathlete group only showed a significant increase at minute 6. This may be related to transition experience, as the two single sport groups were significantly affected ($p<0.05$) by the transition, while the triathletes were not. However, by minute 6, triathletes were significantly affected, which indicates that their advanced experience with the transition from cycling to running may be transient in nature.

The transition between cycling and running had a similar effect when considering the oxygen consumption responses of each group. Although the triathlete and cyclists groups mean oxygen consumption during the control run were significantly higher than the runners, these differences were again nullified by the transition. However, this was largely due to the statistically significant ($p<0.05$) increase in oxygen consumption for the running group. By minute 6 of the transition run, the running group recorded the highest mean oxygen cost. Once again, the largest effects of the transition from cycling to running were experienced by the runner and cyclists groups.

Relative energy expenditure data ($kcal.kg^{-1}\cdot min^{-1}$) followed a similar trend as both heart rate and oxygen consumption. Triathletes were again relatively unaffected by the transition between cycling and running, while the runner and cyclist group recorded increases in energy cost as a result of the transition. In the case of the running group, this difference was statistically significant ($p<0.05$)

It is apparent, based on the current results, that running economy is significantly affected by the transition between cycling and running for the cyclist and runner groups. However, running economy is also closely linked to both running speed and triathlon race performance. Further research is necessary to determine the duration of the effects of the transition on running economy, as the current protocol focused only on a short term running bout post-cycle. It may be necessary to measure the running economy of all three groups over a longer duration to determine the long-term effects of the cycle bout, as well as to determine if any changes occur once athlete become familiar with transition running.

PSYCHOPHYSICAL RESPONSES

All three athlete groups reported an increase in central Rating of Perceived Exertion (RPE) between minute 3 and minute 6 of the control run, while just the runners and cyclists reported an increase at the same intervals of the transition run. All three groups, however, reported a significant increase in perceived difficulty as a result of the transition from cycling to running. That said, by minute 6 the triathletes no longer perceived the transition run to be harder than the control, while the runner and cyclist groups RPE ratings continued to increase as they became more fatigued towards the end of the protocol.

Local RPE ratings showed that only the runner and cyclist perceived an increase in leg muscle demand between intervals in both the control and transition protocols. That said, all three subject groups perceived a significant ($p<0.05$) increase in the demands placed on the leg muscles as a result of the transition from cycling to running. Although the perceptual responses of all three groups did not correlate with their physiological results, it does appear that athletes more experienced with the transition from cycling to running may perceive the transition run to be easier than those inexperienced in this transition.

6.3 CONCLUSIONS

Based on the results of the current study, it is possible to draw conclusions based purely on the factors measured, as well as to the practical significance inherent to the results.

From a purely statistical perspective, it is possible to conclude that the transition from running to cycling had a limited effect on the biomechanical responses of any of the tested athlete groups, although it is apparent that the gait responses of the triathlete group was significantly affected by the transition. It is possible, however, to conclude that this may well be as a result of these athletes having greater experience with the transition, as although their gait responses decreased post-transition, they merely equated to those of the single sport cyclists and runners, while they were the least affected of the three subject groups from a physiological perspective.

It is also apparent, from a statistical standpoint, that athlete type does not play a significant role in transition performance, as no differences were recorded between the three groups for any of the measured variables. It is interesting to note, however, that differences in oxygen consumption and stride rate were evident during the control run, but not after the transition. Thus, it is apparent that the transition from cycling to running had the effect of reducing the variability between groups, rather than increasing it.

However, when researching performance factors, it is often more important to determine practical, rather than statistical, significance, as athletic performance does not require statistical significance between individuals. Although it is difficult to establish practical significance based on biomechanical factors, physiological variables can be useful in determining the practical significance of the current study.

Running economy, described as the relationship between steady state oxygen consumption and running speed, has been shown to decrease both as a result of the effects of a prior cycling task and as a result of the onset of both biomechanical and physiological fatigue. Within a homogenous group of subjects, as in the current study, running economy is an excellent indicator of endurance performance, as the runner with the best economy will consume less oxygen at a given workload, allowing them to run faster at the same intensity, or to run for longer at the same speed. Based on the results of the current research, that triathlon experience plays an important determining factor in triathlon performance when compared to single sport runners and cyclists. Furthermore, it is apparent that cyclists may be more suited to triathlon than single sport runners, as they appear to transition from cycling to running with greater effectiveness.

6.4 RECOMMENDATIONS

The following practical recommendations can be made based on the current research:

The muscle activity and running economy of the triathlete group are the least affected by the cycle-run transition. This may indicate that triathletes aiming to achieve optimal performance should incorporate cycle-run transition training into their standard training programme. This is an important consideration as the results of the current research indicate that the improvement of running economy post-cycle is linked to improved performance. Thus, the optimisation of running economy as a precedent to optimised running speed should be a focus of this cycle-run transition training

Although the results of the current research indicate that single sport cyclists are more suited to the crossover into triathlon, this implication may be limited to the transition only. It is likely that as the run continues, the runners may become more familiarised to the task, and may improve in their responses. The cyclists on the other hand, may be expected to decrease as the run continues, as they are moving further away from a habituated task. Focused training on the transition from cycling to running is still necessary for both of these groups in order to improve both transition and triathlon performance.

It is evident, based on the results of the current research that the transition from cycling to running is an important factor in triathlon competition, and it is strongly recommended that this transition be further researched to better the understanding of this key determinant of triathlon success.

Although every effort was made to ensure that all subject met the performance requirements set out prior to this research beginning, subject availability resulted in the reduction of some of these parameters, particularly those regarding the performance level of the runner and cyclist groups, where sub-elite athletes were included in the study. Future research should focus primarily on either elite or recreational level athletes in order to provide further validity to the study. Furthermore, as subjects were signed up on a voluntary basis, a sample group of 35 athletes was used in the current research. In order to further increase validity and statistical power of future research, a larger sample size is recommended.

In order to properly quantify the effects of the transition on triathlon performance, it is recommended that future research assess the influence of factors such as age, gender, anthropometrical variables and training modalities on athletes' ability to transition effectively. As each of these factors may, in fact, play an important role in determining the success with which athletes negotiate the cycle-run transition.

Furthermore, muscle activity measured during the current research can be explored further. Muscle activity during the transition should be further researched in terms of the contribution of muscles not specifically tested during this study, as well as to incorporate factors such as recruitment pattern analysis and co-activity. The effects of the central nervous system on muscle activity during the transition should also be further established. It is apparent that the central nervous system does play a role in triathlon success and transition ability, consequently it may be important to determine the extent of this involvement. This may potentially alter training modalities such that the influence of the central nervous system may be positively magnified.

This study made use of 7 minute running protocols and a 20 minute cycle protocol. While these protocols were adjusted to ensure as close a representation of real life triathlon demands, there may be differences between these protocols and actual triathlon. For example, it may be necessary for future research to take into account pacing strategies, drafting, race tactics and course/route specific demands.

Although laboratory testing allows for rigorous control of as many extraneous variables as possible, the responses which occur in laboratory settings may not be truly representative of what may occur *in situ*. It is therefore recommended that future research attempt to gain an understanding of the transition from cycling to running with specific reference to *in situ* analysis.

The sport of triathlon is also made up of several different distance events (sprint, Olympic, half-ultra and ultra-triathlons). Each of these places different demand son the body, and each discipline has a varying effect dependent on the race distance. The current research focused on the Olympic distance event, but future research should account for each distance and its specific effects on the transition.

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APPENDIX A: GENERAL INFORMATION

Equipment Check List

Letter to Subject

Consent Form

K4b^2 preparation and calibration check list

Equipment Check List

Administration

Letter to Subject

Consent Form

Data Sheet

Data collection Equipment

Stationary bike

Heart Rate Monitor

Skinfold Callipers

Sliding Callipers

Tape Measure

Scale

Stadiometer

Data Logger

Laptops

K4

Stopwatch

Accelerometer

RPE Scale

LETTER OF INFORMATION FOR THE SUBJECT

Dear _______________________________,

Thank you for your interest in participating in this study, your assistance in completing this investigation is greatly appreciated. This letter explains the aims of the project, as well as the potential risks and benefits involved. Please read it carefully and sign the accompanying consent form. If you are under the age of 21 you are encouraged to disclose to your parents/guardians that you intend to participate in this study, with all the available information in the explanation below.

AIM OF THE STUDY

The aim of this study is assess the biomechanical and physiological alterations that occur as a result of the cycle-run transition in competitive triathlons, and their effects on run performance. Furthermore, the project aims to determine the extent to which triathlon experience affects these alterations, by comparing the results of experienced triathletes to those of athletes who are equally experienced in single-discipline running or cycling. Finally, anthropometric data will be taken in order to determine if body shape has any effect on triathlon run performance, which may aid in the identification of the 'ideal' body shape for successful triathlon competition.

PROCEDURES

You will be required to attend two testing sessions, the first of which will last approximately 1 hour, while the second will last approximately 2 hours. During the first session all anthropometric data will be collected, after which you will perform a standardised warm up before completing a test to determine Maximal Aerobic Power (MAP). You will also be required to complete a short questionnaire regarding your training history.

Your MAP will be utilised in the second session in order to standardise cycle intensity for each subject individually. During the second session, muscle activity levels will be analysed using electromyography which requires the use of electrodes, which will be attached to several leg muscles, allowing us to record the electrical activity in the muscles. Running kinematics will be measured through both video analysis as well as accellerometry, which involves placing a small sensor on your lower back, which records kinematic data by analysing your Centre of Mass displacements. Furthermore, your physiological responses will be captured by the K4b^2 Ergospirometer which utilises a mask placed over the nose and mouth and provides a breath by breath analysis of your physiological responses. Finally, your perceptual responses will be measured using the Rating of Perceived Exertion (RPE) scale, on which you will be asked to rate both your ‘Central’ (Cardiovascular System) RPE and your ‘Local’ (Muscular system) RPE.

Once all the above equipment has been attached and secured, you will be required to complete the first test condition or ‘Control Run’. This requires you to run for 7 minutes at a speed of 15km.h^{-1}. Following this you will be given approximately 20 minutes to allow recovery before completing the second test condition or ‘Transition Run’. The ‘Transition Run’ protocol requires you to first cycle for 20 minutes at 70% of your MAP recorded during the first session, followed by an identical 7 minute run at 15km.h^{-1}. Biomechanical, physiological and perceptual data will be collected throughout the run phase of each condition

.

RISKS AND BENEFITS

It is unlikely that you will experience any injuries during this study as the protocols involved are strictly controlled to ensure that you are exposed to the least possible risk. Possible risks include slight muscular discomfort or fatigue. If you feel unable to complete any protocol you may stop the test at any point. Please report any symptoms such as dizziness, nausea or breathing difficulty, to the researcher immediately.

In the unlikely event of incurring an injury during the study, the Human Kinetics and Ergonomics Department will be liable for any costs which may ensue and will reimburse the subject to the full amount i.e. doctors consultation, application of anti-inflammatory medication etc. The Department will also assist in applying rehabilitation sessions for the injury if need be. The Department will, however, waiver any legal recourse against the researcher or Rhodes University in the event the injury is proved to be self inflicted or due to the negligence of the subject themselves.

It is important to reiterate that the likelihood of incurring injury during this study is highly unlikely.

Personal benefits derived from this study may include broadened knowledge regarding individual performance parameters, as well as an increased understanding of the science behind the sport in which you take part. On a broader scale, the results of the current study may enable the researcher to apply specific training or racing principles to the competitive scenario, potentially allowing for performance improvements.

Yours sincerely,

Devin Cripwell (MSc Student – Department of Human Kinetics and Ergonomics).

SUBJECT INFORMED CONSENT FORM

I, ______________________________, do hereby consent to participate in the study entitled: " THE BIOMECHANICAL AND PHYSIOLOGICAL ALTERATIONS ASSOCIATED WITH THE CYCLE-RUN TRANSITION IN COMPETITIVE TRIATHLON: INFLUENCE OF TRIATHLON EXPERIENCE". I agree that I have been fully informed, both verbally and in writing, of the procedures involved in this study. I have also been made aware of any potential risks associated with the test protocol including muscle discomfort or fatigue.

I realise that whilst my anonymity will be protected at all times, my results may be published or used for scientific and statistical purposes. I understand the conditions with which I am expected to comply for the duration of the tests, and any queries I have with regards to this have been answered to my satisfaction.

By voluntarily consenting to participate in this research I accept joint responsibility together with the Human Kinetics and Ergonomics Department, in that should any injury be sustained, the department will cover any fees incurred and take steps to rehabilitate the injury. I do however waive any legal recourse against the researcher, or against Rhodes University, and will take full responsibility in the event the injury is shown to be self-inflicted. I will inform the researcher immediately if at any point I experience distress or abnormality, and am fully aware that I may withdraw from this study at any time.

I have read and understood the above information, as well as the information provided in the letter accompanying this form. Signed at the Department of Human Kinetics and Ergonomics, Rhodes University, on ___/___/2010.

SUBJECT:________________________(NAME)______________________(SIGN)

WITNESS:_______________________ (NAME)______________________(SIGN)

RESEARCHER:___________________(NAME)_____________________(SIGN)

K4b^2 PREPARATION AND CALIBRATION CHECK LIST

K4b^2 is set up and turned on 45 minutes before calibration to allow sufficient time to warm up.

Calibration procedure:

Control panel check, ensures that all computer and K4b^2 connections are functioning.

Room air calibration check.

Delay calibration check.

Gas calibration check.

Three litre turbine calibration check.

Final preparation, with subject:

Fit and adjust harness to the subject.

Fit and adjust face mask to the subject; ensure mask is secure.

Fit and adjust heart rate strap around subject’s chest.

Remove K4b^2 from electrical power source and connect to batteries.

Fit battery pack and unit to harness.

Secure any loose cabling with masking tape.

Run final air calibration before fitting unit to face mask.

Allow subject to rest and monitor responses.

APPENDIX B: DATA COLLECTION

RPE Scale

Subject Data Sheet

Rating of Perceived Exertion (RPE) Scale (Borg GAV, 1970)

RATINGS 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	

DATA COLLECTION SHEET

Full Name:________________________________ Code:_________

Date of Birth: ____________ (dd/mm/yyyy)

Session 1

TRIATHLON SPECIFIC BACKGROUND

How many years have you been involved in competitive triathlons?

____

Of the three disciplines, which forms the majority of your training background before triathlon? (Rank order)

____

Which is your preferred discipline?

If known, please list your personal best 10km run time, as well as your last 5 competitive 10km run times

Personal Best	
1	
2	
3	
4	
5	

ANTHROPOMETRIC DATA

Stature (mm)			
Mass (kg)			
Leg Length (mm)			
Thigh Circumference (mm)			
Calf Circumference (mm)			
Biceps Circumference (cm)			
Femur Width (cm)			
Humerus Width (cm)			
Calf Skinfold (mm)	1	2	Ave
Tricep Skinfold (mm)	1	2	Ave
Subscapular Skinfold (mm)	1	2	Ave

Suprailiac Skinfold (mm)	1	2	Ave
Abdominal Skinfold (mm)	1	2	Ave
Thigh Skinfold (mm)	1	2	Ave
Chest Skinfold (mm)	1	2	Ave

Body Density:_____

Body Fat: _______%

MAXIMAL AEROBIC POWER (MAP) TEST

Lamberts and Lambert Submaximal Cycle Test (LSCT)

Age Predicted HR_{MAX}	60% HR_{MAX}	80% HR_{MAX}	90% HR_{MAX}

MAP Test

Starting Power Output ($2.50 W.kg^{-1}$)	
Maximal Aerobic Power (MAP)	
Maximal Heart Rate	

APPENDIX C: RESULTS

BIOMECHANICAL RESULTS

- 1-Way ANOVA tables
- T-Test tables

PHYSIOLOGICAL RESULTS

- 1-Way ANOVA tables
- T-Test tables

PERCEPTUAL RESULTS

- 1-Way ANOVA tables
- T-Test tables

BIOMECHANICAL RESULTS

Tibialis Anterior

1-Way ANOVA

Univariate Tests of Significance for TA3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	3.186357	1	3.186357	16.96816	0.000250
Group	0.656591	2	0.328296	1.74826	0.190295
Error	6.009101	32	0.187784		

Univariate Tests of Significance for TA6 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	2.496675	1	2.496675	16.84735	0.000273
Group	0.454014	2	0.227007	1.53182	0.232057
Error	4.594012	31	0.148194		

Univariate Tests of Significance for TA3 Transition (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	1.264495	1	1.264495	21.44351	0.000062
Group	0.098375	2	0.049187	0.83413	0.443767
Error	1.828028	31	0.058969		

Univariate Tests of Significance for TA6 Transition (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	1.466248	1	1.466248	20.19351	0.000091
Group	0.151485	2	0.075743	1.04314	0.364386
Error	2.250906	31	0.072610		

T-test (Between protocols)

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
TA3 Control	0.129841	0.039546								
TA3 Transition	0.121933	0.059564	11	0.007908	0.067468	0.388730	10	0.705624	-0.037418	0.053234

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
TA3 Control	0.308025	0.381093								
TA3 Transition	0.251595	0.325820	12	0.056430	0.116918	1.671946	11	0.122707	-0.017856	0.130716

	Group=Cyclists T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
TA3 Control	0.371127	0.561717								
TA3 Transition	0.205508	0.249961	11	0.165619	0.364227	1.508110	10	0.162451	-0.079073	0.410310

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
TA6 Control	0.111165	0.032176								
TA6 Transition	0.109294	0.064217	10	0.001871	0.074391	0.079551	9	0.938335	-0.051345	0.055087

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
TA6 Control	0.309943	0.421412								
TA6 Transition	0.250202	0.332994	12	0.059741	0.134978	1.533209	11	0.153467	-0.026020	0.145502

	Group=Cyclists T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
TA6 Control	0.305595	0.397463								
TA6 Transition	0.260555	0.315077	11	0.045039	0.334496	0.446579	10	0.664695	-0.179678	0.269757

Gastrocnemius

1-way ANOVAS

Univariate Tests of Significance for GS3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.587884	1	0.587884	73.45346	0.000000
Group	0.006308	2	0.003154	0.39409	0.677521
Error	0.256112	32	0.008003		

Univariate Tests of Significance for GS3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.587884	1	0.587884	73.45346	0.000000
Group	0.006308	2	0.003154	0.39409	0.677521
Error	0.256112	32	0.008003		

Univariate Tests of Significance for GS3 Transition (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.342805	1	0.342805	124.3556	0.000000
Group	0.000682	2	0.000341	0.1238	0.884019
Error	0.085456	31	0.002757		

Univariate Tests of Significance for GS6 Transition (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.353077	1	0.353077	41.54489	0.000000
Group	0.005265	2	0.002632	0.30974	0.735885
Error	0.263459	31	0.008499		

T-tests (between protocols)

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
GS3 Control	0.148989	0.099877								
GS3 Transition	0.105454	0.038079	11	0.043536	0.079054	1.826494	10	0.097734	-0.009573	0.096645

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
GS3 Control	0.124767	0.096842								
GS3 Transition	0.094477	0.018310	11	0.030290	0.100427	1.000318	10	0.340747	-0.037178	0.097758

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
GS3 Control	0.124767	0.096842								
GS3 Transition	0.094477	0.018310	11	0.030290	0.100427	1.000318	10	0.340747	-0.037178	0.097758

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
GS6 Control	0.133497	0.060631								
GS6 Transition	0.091663	0.021466	10	0.041834	0.048039	2.753847	9	0.022336	0.007469	0.076199

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
GS6 Control	0.120372	0.095238								
GS6 Transition	0.092884	0.023916	11	0.027488	0.100601	0.906217	10	0.386136	-0.040097	0.095073

Group=Cyclists
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
GS6 Control	0.141086	0.125721								
GS6 Transition	0.119343	0.151692	12	0.021743	0.214618	0.350946	11	0.732258	-0.114619	0.158104

Biceps Femoris

1-way ANOVAS

Univariate Tests of Significance for BF3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.756839	1	0.756839	37.89889	0.000001
Group	0.006174	2	0.003087	0.15458	0.857413
Error	0.639039	32	0.019970		

Univariate Tests of Significance for BF6 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.589297	1	0.589297	13.54981	0.000879
Group	0.087000	2	0.043500	1.00020	0.379367
Error	1.348226	31	0.043491		

Univariate Tests of Significance for BF3 Transition (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.186618	1	0.186618	223.7865	0.000000
Group	0.000266	2	0.000133	0.1597	0.853038
Error	0.026685	32	0.000834		

Univariate Tests of Significance for BF6 Transition (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.215906	1	0.215906	55.37337	0.000000
Group	0.005231	2	0.002616	0.67086	0.518313
Error	0.124771	32	0.003899		

T-tests (between protocols)

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
BF3 Control	0.152032	0.134078								
BF3 Transition	0.076941	0.042025	11	0.075091	0.120636	2.064475	10	0.065891	-0.005953	0.156135

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
BF3 Control	0.129236	0.130560								
BF3 Transition	0.071907	0.022825	12	0.057329	0.127081	1.562736	11	0.146407	-0.023414	0.138073

Group=Cyclists
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
BF3 Control	0.160256	0.157181								
BF3 Transition	0.070397	0.017303	12	0.089859	0.162227	1.918789	11	0.081320	-0.013216	0.192933

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
BF6 Control	0.085615	0.034284								
BF6 Transition	0.095132	0.112807	10	-0.009517	0.118640	-0.253668	9	0.805452	-0.094387	0.075353

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
BF6 Control	0.085615	0.034284								
BF6 Transition	0.095132	0.112807	10	-0.009517	0.118640	-0.253668	9	0.805452	-0.094387	0.075353

Group=Cyclists
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
BF6 Control	0.202226	0.334890								
BF6 Transition	0.070999	0.021921	12	0.131227	0.331369	1.371839	11	0.197444	-0.079315	0.341770

Vastus Lateralis

1-way ANOVAS

Univariate Tests of Significance for VL3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	1.383523	1	1.383523	17.26640	0.000226
Group	0.107642	2	0.053821	0.67169	0.517902
Error	2.564096	32	0.080128		

Univariate Tests of Significance for VL6 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	0.545842	1	0.545842	40.30686	0.000000
Group	0.005853	2	0.002926	0.21609	0.806868
Error	0.419807	31	0.013542		

Univariate Tests of Significance for VL3 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	0.258019	1	0.258019	91.50834	0.000000
Group	0.010346	2	0.005173	1.83462	0.176592
Error	0.087408	31	0.002820		

Univariate Tests of Significance for VL6 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	0.377777	1	0.377777	44.59361	0.000000
Group	0.057071	2	0.028535	3.36837	0.047453
Error	0.262618	31	0.008472		

T-tests (between protocols)

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VL3 Control	0.226599	0.219251								
VL3 Tran	0.111364	0.073109	11	0.115235	0.180977	2.111815	10	0.060856	-0.006347	0.236817

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VL3 Control	0.226599	0.219251								
VL3 Tran	0.111364	0.073109	11	0.115235	0.180977	2.111815	10	0.060856	-0.006347	0.236817

	Group=Cyclists T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VL3 Control	0.247998	0.419568								
VL3 Tran	0.080570	0.053904	12	0.167427	0.371272	1.562156	11	0.146543	-0.068468	0.403323

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VL6 Control	0.137506	0.102103								
VL6 Tran	0.131971	0.115544	10	0.005534	0.111004	0.157667	9	0.878200	-0.073873	0.084942

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VL6 Control	0.110209	0.087356								
VL6 Tran	0.073097	0.015860	11	0.037113	0.083510	1.473941	10	0.171267	-0.018990	0.093215

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VL6 Control	0.110209	0.087356								
VL6 Tran	0.073097	0.015860	11	0.037113	0.083510	1.473941	10	0.171267	-0.018990	0.093215

Rectus femoris

1-way ANOVAS

Univariate Tests of Significance for RF3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	4.17346	1	4.173460	13.10866	0.001003
Group	0.96075	2	0.480374	1.50883	0.236485
Error	10.18798	32	0.318374		

Univariate Tests of Significance for RF6 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	2.891158	1	2.891158	11.14417	0.002203
Group	0.637903	2	0.318952	1.22942	0.306328
Error	8.042400	31	0.259432		

Univariate Tests of Significance for RF3 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.808620	1	0.808620	14.60206	0.000577
Group	0.133612	2	0.066806	1.20638	0.312527
Error	1.772069	32	0.055377		

Univariate Tests of Significance for RF6 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	0.774998	1	0.774998	15.66995	0.000393
Group	0.122690	2	0.061345	1.24036	0.302816
Error	1.582643	32	0.049458		

T-tests (between protocols)

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RF3 Control	0.138895	0.106895								
RF3 Tran	0.072170	0.028826	11	0.066725	0.102470	2.159677	10	0.056140	-0.002115	0.135565

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RF3 Control	0.349885	0.393634								
RF3 Tran	0.159756	0.221979	12	0.190129	0.305339	2.157032	11	0.053982	-0.003874	0.384132

	Group=Cyclists T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RF3 Control	0.548034	0.872264								
RF3 Tran	0.224452	0.333267	12	0.323582	0.545913	2.053293	11	0.064608	-0.023275	0.670438

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RF6 Control	0.113047	0.072028								
RF6 Tran	0.066273	0.032092	10	0.046774	0.079482	1.860982	9	0.095664	-0.010083	0.103632

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RF6 Control	0.310221	0.399601								
RF6 Tran	0.172638	0.228879	12	0.137584	0.294516	1.618262	11	0.133897	-0.049543	0.324711

	Group=Cyclists T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RF6 Control	0.454784	0.753128								
RF6 Tran	0.207658	0.301078	12	0.247126	0.455086	1.881116	11	0.086673	-0.042022	0.536273

Stride Rate

1-way ANOVAS

Univariate Tests of Significance for RATE3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	249608.0	1	249608.0	13870.76	0.000000
Group	178.7	2	89.4	4.97	0.013235
Error	575.8	32	18.0		

Univariate Tests of Significance for RATE6 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	236818.8	1	236818.8	14548.92	0.000000
Group	147.6	2	73.8	4.53	0.018725
Error	504.6	31	16.3		

Univariate Tests of Significance for RATE3 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	243707.0	1	243707.0	14805.81	0.000000
Group	70.0	2	35.0	2.13	0.135970
Error	526.7	32	16.5		

Univariate Tests of Significance for RATE6 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	241971.1	1	241971.1	14853.31	0.000000
Group	115.0	2	57.5	3.53	0.041211
Error	521.3	32	16.3		

T-tests (between protocols)

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RATE3 Control	87.72727	4.244783								
RATE3 Tran	85.54545	5.027199	11	2.181818	3.060006	2.364790	10	0.039628	0.126078	4.237558

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RATE3 Control	82.50000	4.981785								
RATE3 Tran	82.50000	4.602371	12	0.000000	3.516196	0.000000	11	1.000000	-2.23408	2.234085

	Group=Cyclists T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RATE3 Control	83.33333	3.339388								
RATE3 Tran	82.50000	1.930615	12	0.833333	3.459725	0.834388	11	0.421814	-1.36487	3.031538

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RATE6 Control	86.80000	3.994441								
RATE6 Tran	85.00000	3.829708	10	1.800000	2.347576	2.424672	9	0.038316	0.120646	3.479354

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RATE6 Control	82.00000	4.748205								
RATE6 Tran	82.00000	4.670994	12	-0.000000	3.190896	-0.000000	11	1.000000	-2.02740	2.027399

	Group=Cyclists T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
RATE6 Control	82.50000	3.205110								
RATE6 Tran	81.83333	2.622744	12	0.666667	2.870962	0.804400	11	0.438206	-1.15746	2.490789

Stride Length

1-way ANOVAS

Univariate Tests of Significance for LENGTH3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	307.5499	1	307.5499	13980.25	0.000000
Group	0.2173	2	0.1087	4.94	0.013506
Error	0.7040	32	0.0220		

Univariate Tests of Significance for LENGTH6 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	302.2867	1	302.2867	14271.06	0.000000
Group	0.1862	2	0.0931	4.39	0.020886
Error	0.6566	31	0.0212		

Univariate Tests of Significance for LENGTH3 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	314.6527	1	314.6527	14732.17	0.000000
Group	0.0816	2	0.0408	1.91	0.164497
Error	0.6835	32	0.0214		

Univariate Tests of Significance for LENGTH6 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	316.9939	1	316.9939	15312.09	0.000000
Group	0.1427	2	0.0713	3.45	0.044117
Error	0.6625	32	0.0207		

T-tests (between protocols)

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
LENGTH3 Control	2.855638	0.134111								
LENGTH3 Tran	2.931658	0.173204	11	-0.076020	0.109788	-2.29653	10	0.044516	-0.149777	-0.00226

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
LENGTH3 Control	3.040162	0.178400								
LENGTH3 Tran	3.039125	0.172759	12	0.001037	0.128791	0.027896	11	0.978245	-0.080793	0.08286

Group=Cyclists
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confiden +95.000
LENGTH3 Control	3.004616	0.125776								
LENGTH3 Tran	3.031822	0.070815	12	-0.027206	0.129389	-0.728379	11	0.481600	-0.109416	0.0550

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
LENGTH6 Control	2.885479	0.127876								
LENGTH6 Tran	2.946396	0.128858	10	-0.060917	0.077354	-2.49033	9	0.034404	-0.116253	-0.005581

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
LENGTH6 Control	3.058215	0.178087								
LENGTH6 Tran	3.057836	0.173660	12	0.000380	0.118084	0.011146	11	0.991307	-0.074647	0.075407

Group=Cyclists
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
LENGTH6 Control	3.034601	0.120831								
LENGTH6 Tran	3.057880	0.098401	12	-0.023278	0.108176	-0.745444	11	0.471632	-0.092010	0.045453

PHYSIOLOGICAL VARIABLES

Heart Rate

1-Way ANOVAS

Univariate Tests of Significance for HR3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	907072.7	1	907072.7	5719.626	0.000000
Group	55.2	2	27.6	0.174	0.841076
Error	5074.9	32	158.6		

Univariate Tests of Significance for HR6 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	923206.5	1	923206.5	4940.899	0.000000
Group	27.3	2	13.7	0.073	0.929637
Error	5792.3	31	186.8		

Univariate Tests of Significance for HR3 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	1024022	1	1024022	9200.326	0.000000
Group	223	2	111	1.000	0.379171
Error	3562	32	111		

Univariate Tests of Significance for HR6 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	1047466	1	1047466	7790.342	0.000000
Group	94	2	47	0.351	0.706449
Error	4303	32	134		

T-tests (between protocols)

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
HR3 Control	162.7939	13.23437								
HR3 Tran	168.2076	9.43494	11	-5.41378	12.10173	-1.48371	10	0.168705	-13.5438	2.716274

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
HR3 Control	160.8511	10.79542								
HR3 Tran	174.4092	10.58152	12	-13.5581	12.08861	-3.88519	11	0.002541	-21.2388	-5.87735

Group=Cyclists
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
HR3 Control	159.7181	13.62293								
HR3 Tran	170.9621	11.44097	12	-11.2440	10.61215	-3.67034	11	0.003687	-17.9866	-4.50133

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
HR6 Control	165.0337	15.40251								
HR6 Tran	171.8146	10.34356	10	-6.78089	7.778136	-2.75684	9	0.022227	-12.3450	-1.21675

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
HR6 Control	166.5967	12.15986								
HR6 Tran	174.1949	11.72950	12	-7.59811	9.910895	-2.65573	11	0.022357	-13.8952	-1.30103

Group=Cyclists
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
HR6 Control	164.5433	13.58718								
HR6 Tran	174.4429	12.46864	12	-9.89961	9.034110	-3.79598	11	0.002964	-15.6396	-4.15961

Oxygen Consumption

1-way ANOVAS

Univariate Tests of Significance for VO2 3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	46373.21	1	46373.21	2787.539	0.000000
Group	80.70	2	40.35	2.426	0.104518
Error	532.35	32	16.64		

Univariate Tests of Significance for VO2 6 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	46831.69	1	46831.69	2042.956	0.000000
Group	50.62	2	25.31	1.104	0.344196
Error	710.63	31	22.92		

Univariate Tests of Significance for VO2 3 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	56087.03	1	56087.03	3198.304	0.000000
Group	1.51	2	0.75	0.043	0.958007
Error	561.17	32	17.54		

Univariate Tests of Significance for VO2 6 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	57389.01	1	57389.01	2268.707	0.000000
Group	1.55	2	0.77	0.031	0.969918
Error	809.47	32	25.30		

T-tests (between protocols)

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VO2 3 Control	37.99148	4.715608								
VO2 3 Tran	39.86426	4.128748	11	-1.87278	4.080327	-1.52226	10	0.158919	-4.61398	0.868422

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VO2 3 Control	34.36955	3.630892								
VO2 3 Tran	40.35034	3.413071	12	-5.98079	2.216707	-9.34633	11	0.000001	-7.38922	-4.57237

Group=Cyclists
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VO2 3 Control	36.93039	3.872535								
VO2 3 Tran	39.97965	4.885624	12	-3.04926	4.701988	-2.24649	11	0.046173	-6.03676	-0.061761

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VO2 6 Control	38.58362	5.666225								
VO2 6 Tran	40.05557	4.398834	10	-1.47195	4.395388	-1.05900	9	0.317194	-4.61622	1.672325

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VO2 6 Control	35.61804	5.066328								
VO2 6 Tran	40.82094	4.870687	12	-5.20290	2.488709	-7.24205	11	0.000017	-6.78415	-3.62164

Group=Cyclists
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
VO2 6 Control	37.55007	3.558969								
VO2 6 Tran	40.36046	5.731241	12	-2.81039	5.167582	-1.88395	11	0.086259	-6.09371	0.472936

Energy Expenditure

1-Way ANOVAS

Univariate Tests of Significance for EE3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	6666.150	1	6666.150	1643.243	0.000000
Group	0.164	2	0.082	0.020	0.979982
Error	129.814	32	4.057		

Univariate Tests of Significance for EE6 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	6687.303	1	6687.303	1353.714	0.000000
Group	0.987	2	0.494	0.100	0.905199
Error	153.139	31	4.940		

Univariate Tests of Significance for EE3 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	7236.454	1	7236.454	1577.510	0.000000
Group	14.247	2	7.124	1.553	0.227158
Error	146.792	32	4.587		

Univariate Tests of Significance for EE6 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	7405.604	1	7405.604	1273.397	0.000000
Group	11.661	2	5.831	1.003	0.378161
Error	186.100	32	5.816		

T-tests (between protocols)

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
EE3 Control	13.83167	1.555132								
EE3 Tran	13.91610	1.196266	11	-0.084424	1.294358	-0.216325	10	0.833083	-0.953985	0.785138

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
EE3 Control	13.73537	2.206033								
EE3 Tran	15.24738	2.521289	12	-1.51201	1.198462	-4.37038	11	0.001117	-2.27347	-0.750539

Group=Cyclists
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
EE3 Control	13.89985	2.111352								
EE3 Tran	14.21509	2.415310	12	-0.315243	1.439626	-0.758555	11	0.464062	-1.22994	0.599452

Group=Triathletes
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
EE6 Control	13.96454	1.763920								
EE6 Tran	13.96882	1.336276	10	-0.004286	0.915395	-0.014805	9	0.988511	-0.659119	0.650548

Group=Runners
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
EE6 Control	14.30714	2.653493								
EE6 Tran	15.34766	2.995512	12	-1.04052	0.943869	-3.81882	11	0.002849	-1.64023	-0.440814

Group=Cyclists
T-test for Dependent Samples (New Data with Logs.sta)
Marked differences are significant at p < .05000

Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
EE6 Control	14.02398	1.996225								
EE6 Tran	14.34481	2.450870	12	-0.320833	1.555085	-0.714686	11	0.489693	-1.30889	0.667221

PERCEPTUAL VARIABLES

Central RPE

1-way ANOVAS

Univariate Tests of Significance for CENTRAL3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	4301.969	1	4301.969	1161.119	0.000000
Group	2.182	2	1.091	0.294	0.746902
Error	118.561	32	3.705		

Univariate Tests of Significance for CENTRAL6 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	4986.817	1	4986.817	998.8670	0.000000
Group	6.763	2	3.381	0.6773	0.515347
Error	154.767	31	4.992		

Univariate Tests of Significance for CENTRAL3 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	5962.551	1	5962.551	1077.376	0.000000
Group	0.787	2	0.394	0.071	0.931495
Error	177.098	32	5.534		

Univariate Tests of Significance for CENTRAL6 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	Degr. of - Freedom	MS	F	p
Intercept	6873.199	1	6873.199	831.3020	0.000000
Group	0.396	2	0.198	0.0239	0.976374
Error	264.576	32	8.268		

T-tests (between protocols)

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
CENTRAL3 Control	11.45455	1.863525								
CENTRAL3 Tran	13.27273	2.370270	11	-1.81818	1.940009	-3.10835	10	0.011092	-3.12150	-0.514866

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
CENTRAL3 Control	10.91667	2.020726								
CENTRAL3 Tran	13.00000	1.906925	12	-2.08333	1.621354	-4.45114	11	0.000977	-3.11349	-1.05317

	Group=Cyclists T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
CENTRAL3 Control	10.91667	1.880925								
CENTRAL3 Tran	12.91667	2.712206	12	-2.00000	2.088932	-3.31662	11	0.006872	-3.32724	-0.672756

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
CENTRAL6 Control	12.80000	1.988858								
CENTRAL6 Tran	14.20000	2.973961	10	-1.40000	1.955050	-2.26449	9	0.049810	-2.79856	-0.001441

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
CENTRAL6 Control	11.75000	2.137331								
CENTRAL6 Tran	14.16667	2.405801	12	-2.41667	1.378954	-6.07096	11	0.000081	-3.29281	-1.54052

	Group=Cyclists T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
CENTRAL6 Control	11.91667	2.503028								
CENTRAL6 Tran	14.00000	3.190896	12	-2.08333	2.151462	-3.35441	11	0.006427	-3.45031	-0.716360

Local RPE

1-Way ANOVAS

Univariate Tests of Significance for LOCAL3 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	4382.626	1	4382.626	1257.196	0.000000
Group	0.047	2	0.023	0.007	0.993287
Error	111.553	32	3.486		

Univariate Tests of Significance for LOCAL6 Control (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	4801.676	1	4801.676	1550.272	0.000000
Group	1.866	2	0.933	0.301	0.742086
Error	96.017	31	3.097		

Univariate Tests of Significance for LOCAL3 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	6127.348	1	6127.348	1361.490	0.000000
Group	4.671	2	2.335	0.519	0.600099
Error	144.015	32	4.500		

Univariate Tests of Significance for LOCAL6 Tran (New Data with Logs.sta) Sigma-restricted parameterization Effective hypothesis decomposition

	SS	**Degr. of - Freedom**	**MS**	**F**	**p**
Intercept	6796.686	1	6796.686	1168.323	0.000000
Group	12.812	2	6.406	1.101	0.344744
Error	186.159	32	5.817		

T-tests (between protocols)

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
LOCAL3 Control	11.18182	2.040499								
LOCAL3 Tran	12.72727	2.611165	11	-1.54545	1.572491	-3.25960	10	0.008580	-2.60187	-0.489041

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
LOCAL3 Control	11.16667	2.167249								
LOCAL3 Tran	13.58333	1.831955	12	-2.41667	1.564279	-5.35172	11	0.000233	-3.41056	-1.42277

	Group=Cyclists T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
LOCAL3 Control	11.25000	1.288057								
LOCAL3 Tran	13.41667	1.880925	12	-2.16667	1.585923	-4.73261	11	0.000617	-3.17431	-1.15902

	Group=Triathletes T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
LOCAL6 Control	11.70000	1.828782								
LOCAL6 Tran	13.40000	2.458545	10	-1.70000	1.251666	-4.29497	9	0.002005	-2.59539	-0.804612

	Group=Runners T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
LOCAL6 Control	12.25000	1.864745								
LOCAL6 Tran	14.50000	2.236068	12	-2.25000	0.965307	-8.07435	11	0.000006	-2.86333	-1.63667

	Group=Cyclists T-test for Dependent Samples (New Data with Logs.sta) Marked differences are significant at p < .05000									
Variable	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
LOCAL6 Control	11.83333	1.585923								
LOCAL6 Tran	14.25000	2.454125	12	-2.41667	1.831955	-4.56975	11	0.000804	-3.58064	-1.25270