Visual Information Acquisition, Decision-making, Pacing and Performance during Time Trial Cycling

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Abstract

Pacing research attempts to explain how effort varies during athletic events to produce the best performance without premature fatigue. Little is understood about the cognitive processes leading to pacing decisions and behaviour. The aim of this thesis was to measure cyclists' visual behaviour, using eye-trackers, to determine information acquisition patterns during cycling time trials (TT).

The first study found experts looked at primary information longer than novices during 10 mile TTs, with speed being the primary information source for experts, and distance was the primary information source for novices. A follow-up study confirmed that speed was the preferred source of information for experienced cyclists, and that pacing and performance decrements were observed when removing preferred information sources. In a third experiment, it was found that limiting the availability of preferred information to 15 sec every 10% and 20% of a 5 km TT, had no effect on performance compared to continuously available preferred information. In a final study an attempt was made to measure cyclists' visual behaviour during a road time trial because the laboratory studies are limited by ignoring balance, navigation and collision avoidance demands on visual attention. It was found that cyclists were looking at the road for an average of above 50 % of over all time. Cyclists spent approximately 20% of the overall time seeking performance information, in which 7/10 chose speed as the primary information.

It is concluded that difference in information acquisition processes exist between novice and expert cyclists with experts affording more attention to speed and novice to distance. Furthermore, performance remains relatively unaffected by limiting the availability of preferred feedback information, which may be important so that during road-based TT's, the capacity to attend to balance, navigation and collision-avoidance cues exist.

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List of Abbreviation

ATP - Adenosine triphosphate
AIS - Active Information Search
BP - Blood pressure
Ca^{2+} - Calcium ions
CG - Central governor
CGM - Central governor model
CNS - Central nervous system
CPT - Cold Pressor Test
EMG - Electromyography
EPO - Erythropoietin
ETL - Estimated Time Limitation
H^+ - Hydrogen ions
HR - Heart rate
iEMG - Integrated electromyography
La - Lactate
P_i - Inorganic phosphate
PO - Power output
PIE - Exercise induced pain
PO_2 - Partial pressure of oxygen
ROF - Rate of Fatigue

RPE - Rating of perceived exertion

SR - Sarcoplasmic reticulum

TT - Time trial

VO_{2max} - Maximal oxygen consumption

VO - Oxygen consumption

1 CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Pacing strategy, or the variation of speed and power during exercise, is an important contributor to the performance of all endurance exercise. The pace and performance of endurance exercise has been found to be influenced by physiological, psychological, environmental and experiential factors (Noakes, 2011). Researchers have attempted to account for the development of fatigue during endurance exercises, and the limits of performance indicate the role of peripheral mechanisms or central mechanisms. More recent theories, such as the central governor model (CGM) (Noakes *et al.*, 2006) and the Psychobiological Model (Marcora, 2008), have emphasised the interactions between physiological and psychological mechanisms that are responsible for perceptual experience and pace regulation during exercise. Following the conception of the CGM, another theory of central regulation of exercise intensity was proposed. Amann *et al.* (2009) proposed a similar system of central control, according to which peripheral fatigue is monitored through the central nervous system (CNS). However, St Clair Gibson *et al.* (2001) stated that no single physiological system can explain the catastrophic failure experienced throughout exercising; further, Noakes (2011) added that no single variable can predict a subject’s performance.

The pacing strategy adopted by the athlete also entails practical implications with regard to their performance. Athletes are required to constantly employ their available energy effectively in order to fulfil optimal performance goals and avoid fatigue during exercise. The decision whether to maintain the current effort level or to shift to a different level is highly important for the achievement of the ideal performance level and to avoid premature exhaustion.

The objective behind the acquisition of an optimal pacing strategy is to enhance performance and avoid task failure that can be realised by making decisions based on the most relevant available information (Renfree *et al.*, 2014). There is an agreement in the existing literature that pacing strategy is influenced by different elements such as the veracity of performance feedback information (Mauger *et al.*, 2009b; Faulkner *et al.*, 2011), the duration of the event (Albertus *et al.*, 2005), and environmental conditions (Racinais *et al.*, 2015). Different types of pacing strategies have been identified and employed by athletes to perform at their optimum level depending on the duration of the event. Smits *et al.* (2014) stated that pacing is considered as a continuous decision-making process. Moreover, in their most recent study, Smits *et al.* (2016) discovered that the availability of the type of performance information could alter the pacing decision, and therefore, lead to a different pacing strategies.

The process of decision-making in performance is of great interest for athletes. To date there has been a dependence on the deception methods to explain how athletes use performance information to make pacing decision. However, such an approach limits our understanding of decision making in athletic pace, since it only presents the outcome of the pacing-related decision. Therefore, a more direct method of measurement of the information athletes seek and employ during self-paced exercise, and whether an alteration in performance information would lead to a different pacing or performance, would facilitate our understanding of pacing decisions. This could be achieved through the application of using eye-tracking technology that would constitute a more sophisticated and direct method of the assessment of eye movement and thus determining the information athletes consult during self-paced exercise.

1.1.1 Research aims

The purpose of the research presented in this thesis is to collect direct evidence, pertaining to the way in which cyclists acquire information during a time trial (TT) with the use of eye tracking technology. The specific aims of the research are to:

- To measure and compare the differences with regard to information acquisition behaviour between experienced and novices cyclists during a TT.
- To determine whether variance in performance and pacing strategy is associated with different information acquisition behaviours.
- To examine the effect reduction in the duration and frequency of exposure to preferred feedback during a cycling TT has on the pacing strategy and performance of experienced cyclists.
- To measure information acquisition behaviour, pacing and performance during a non-laboratory road-based cycling TT.

1.2 Pacing strategy

In cycling, maintaining the highest speed for a specific period is the central aim in TTs, and planning an optimal pacing strategy in relation to energy expenditure requires knowledge of systematic variations in pacing strategy. Foster *et al.* (2003) suggests that it is fundamental for athletes to spend their available energetic resources effectively in order to realise their optimal performance level, so that all energy reserves are utilized before finishing a race, but not too long before the end of a race, which a meaningful slow down can occur (Foster *et al.*, 2003; DeKoning *et al.*, 1999; Hettinga *et al.*, 2007; Roelands *et al.*, 2013; Tucker & Noakes, 2009). An initial extremely high/slow intensity may limit the achievable Power Output (PO) in the later stages of the race, resulting either in premature fatigue or unused energy at the end of the event, and therefore underachievement. During events in which the aim is to complete a given distance as fastest as possible, some sort of pacing strategy must be employed to avoid a premature fatigue (St Clair Gibson *et al.*, 2006). Pacing strategy is defined as ‘the variation of speed over the race by regulation the rate of energy expenditure’ (Hettinga *et al.*, 2006). Depending on the expected duration of the upcoming exercise bout, athletes select their pacing strategy before the start of the event; Noakes argues that ‘only the CGM can explain this, because it allows the initial pace to be set by the brain “in anticipation” of the expected duration of the exercise bout’ (Noakes, 2007). Indeed, athletes try to alter their pacing strategy throughout an event by coordinating their momentary Rate of Perceived Exertion (RPE) with the expected RPE (Foster *et al.*, 2012). Furthermore, Swart *et al.* (2009) state that any change in the pacing strategy is regulated by the CGM that transmits a signal to the brain via CNS (St Clair Gibson *et al.*, 2006; St Clair Gibson & Noakes, 2004; Noakes *et al.*, 2004), and thus maintain the exercise. Therefore, it can be concluded that pacing has a direct relation with the rate of development of fatigue and performance. It has been stated that pacing behaviour is influenced by both internal and external feedback information (Parry *et al.*, 2012; Jones *et al.*, 2013).

Pacing strategy can be evaluated be two methods; ‘the first method is through observation of selected exercise intensity during either laboratory TT or during competitive events. In the second method, pacing strategy can be examined, by asking athletes to start a trial either faster or slower than the self-pace’ (Tucker & Noakes, 2009).

1.2.1 Type of pacing strategy

The term ‘pacing’ has been employed to represent performance time or velocity and not the actual PO generated (Abbiss & Laursen, 2008). Roelands *et al.* (2013) established a distinction between ‘pace’ and ‘pacing strategy/pattern’ as terms, stating that ‘pace’ ‘is the distribution of speed, power output or energetic reserves’, that may be altered by different, while ‘pacing strategy’ refers to ‘the self-selected strategy or tactics that the athletes adopt, basically from the beginning of an event’.

Pacing is expected to be important to an athlete’s capacity to regulate their fatigue, particularly in events that require different kinds of pacing strategies. A group of different pacing strategies may be more beneficial to achieve optimum performance, in comparison to a global pacing strategy (Abbiss & Laursen, 2008). In fact, several different pacing strategies have been described as suitable strategy for different event durations (Foster *et al.*, 1994). This section briefly examines the different types of pacing strategies utilised in athletic competitions, including negative, positive, all-out, even, variable, and parabolic strategies.

1.2.1.1 Negative Pacing

Negative pacing strategies are beneficial when a rise in speed gradually takes place during an event. This strategy is generally demonstrated in middle-distance events, when PO and velocity (Foster *et al.*, 2004) increased towards the end of event (Figure 1-1). This may be due to an increase in motor unit recruitment and the exploitation of anaerobic energy reserve (Tucker *et al.*, 2004). Mattern *et al.* (2001) present that a considerable decrease in blood lactate concentrate in the first 9 minutes of a 20 km cycling TT was because of the application of a negative pacing strategy by the participants. The selection of a negative pace facilitates athletes' performance during middle-distance exercises by decreasing the supernumerary oxygen consumption (VO_2 max) (Sandals *et al.*, 2006), and lowering the rate of carbohydrate depletion (Abbiss & Laursen, 2005).

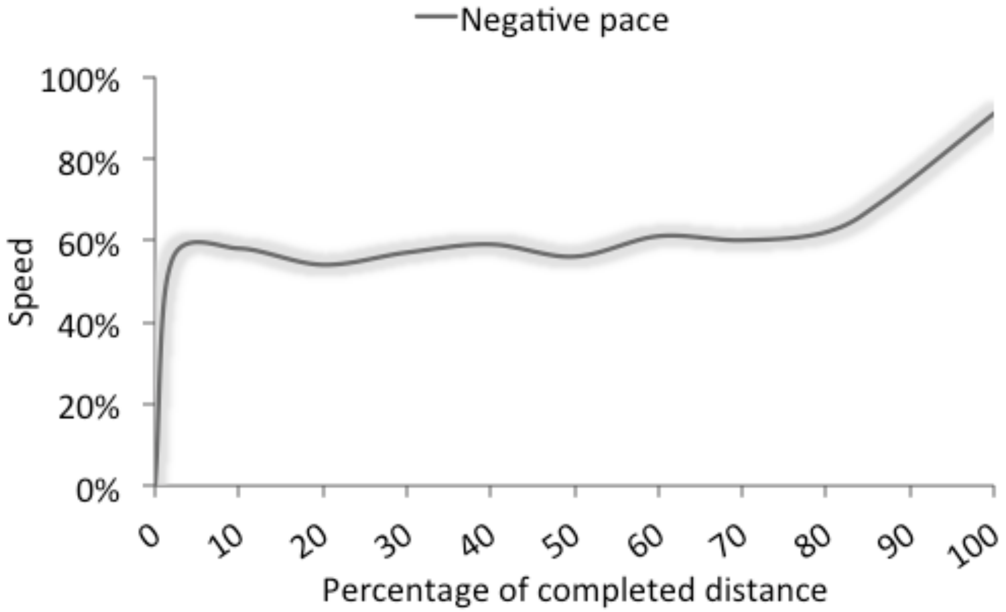


Figure 1-1 Negative pacing strategy

1.2.1.2 Positive Pacing

An athlete's pacing strategy is considered positive when speed exhibits progressive decreases during an event (Figure 1-2). It has been demonstrated that a positive pacing strategy results in an increase in VO_2 (Sandals *et al.*, 2006) and an increase in RPE (Thompson *et al.*, 2003) throughout the start of the exercise. Bailey *et al.* (2011) found that performance was considerably enhanced with a fast-start pacing strategy throughout 3-minutes of high-intensity exercises due to the acceleration of oxygen kinetics and the attainment of maximum oxygen uptake. This type of strategy rarely succeeds and results in a gradual lowering of exercise intensity as a result of derangement or perturbation in physiological homeostasis such as fatigue; however, in 2001, Ben Kimondiu won the LaSalle Bank Chicago Marathon using a high pacing strategy at the beginning of the race (Foster *et al.*, 2004). Moreover, Sandals *et al.* (2006), who studied the influence of pacing strategies on VO2 during middle-distance bouts, reported that elite athletes applied positive pacing strategies in 800 m running event. They performed at 107% of their speed at the beginning of the race, while it was at the average of 97.3% of the final 200 m of the race.

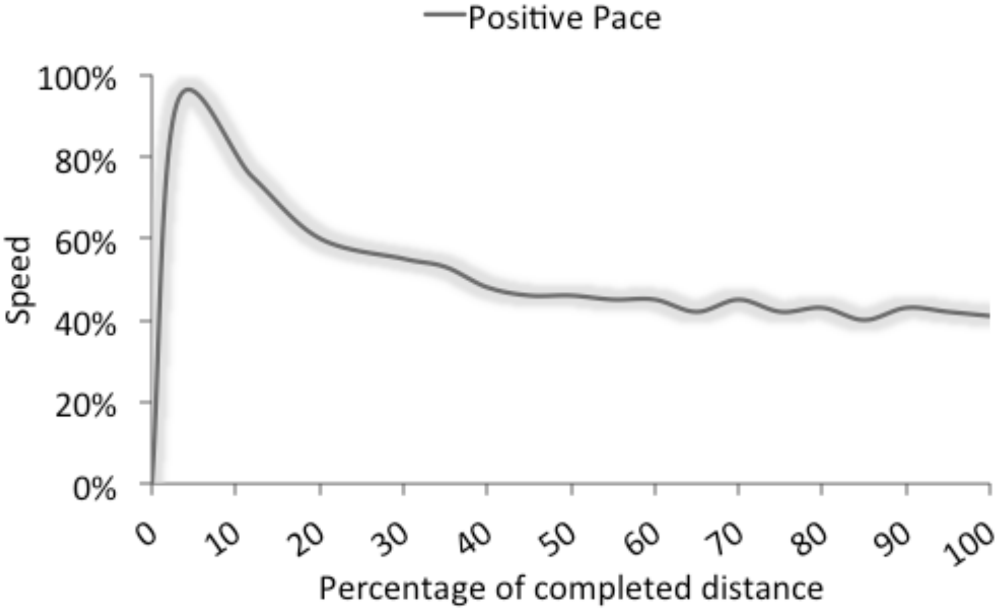


Figure 1-2 Positive pacing strategy.

1.2.1.3 Even Pacing

Research suggests that under stable environmental conditions, an even pace is considered the optimal strategy for prolonged event with duration exceeds 2 minutes, such as swimming, rowing, skiing, and cycling. An even pacing strategy should, theoretically, optimise performance through the maximization of the sustainable speed during bouts and minimization of kinetic energy losses (G. Atkinson, Peacock & Law, 2007). Padilla *et al.* (2000) found that cyclists can preserve a fixed velocity throughout the trial when the speed of a 1-hour cyclist's track world record was tested; the cyclist's speed exhibited extremely limited fluctuation from the base speed 53.04 km/h. However, based on an examination of pacing strategies in 3 different conditions of a 5000 m rowing event, Lander *et al.* (2009) suggest that even pacing can not constitute the optimal strategy for such an event duration (1-hour cycling).

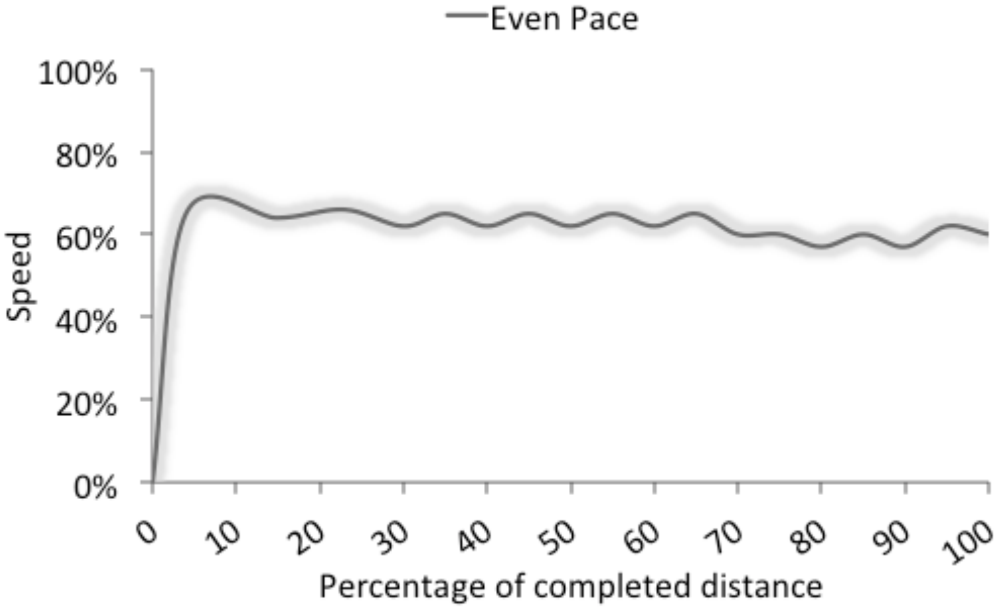


Figure 1-3 Even pacing strategy.

1.2.1.4 ‘All-Out’ Pacing

All-out pacing is an optimal strategy employed during short-distance events, as it minimises the time spent on acceleration before the peak velocity is reached (Corbett *et al.*, 2009; DeKoning *et al.*, 1999). In this type of pacing, the velocity starts to decrease gradually after reaching its peak (Figure 1-4). In some events, such as 100 m running, the energy and time cost associated with the acceleration phase can be extremely high. Elite athletes attempt to dedicate more than half of the event to the acceleration phase (Abbiss & Laursen, 2008). Tibshirani (1997) demonstrated that elite athletes spend 50-60% of the competition in the acceleration phase during a 100 m sprint. Furthermore, due to the slower ending velocity, the kinetic energy wasted in the all-out pace strategy is minimal in comparison to that observed in the constant pace (DeKoning *et al.*, 1999).

Research has proved that all-out strategy entails enhanced peak power and average power in compare to the even strategy in a 2-minutes kayaking ergometer performance (Bishop *et al.*, 2002). Similarly, DeKoning *et al.* (1999) reported that during a 1000 m cycling TT, the optimum performance was obtained with an all-out pacing strategy.

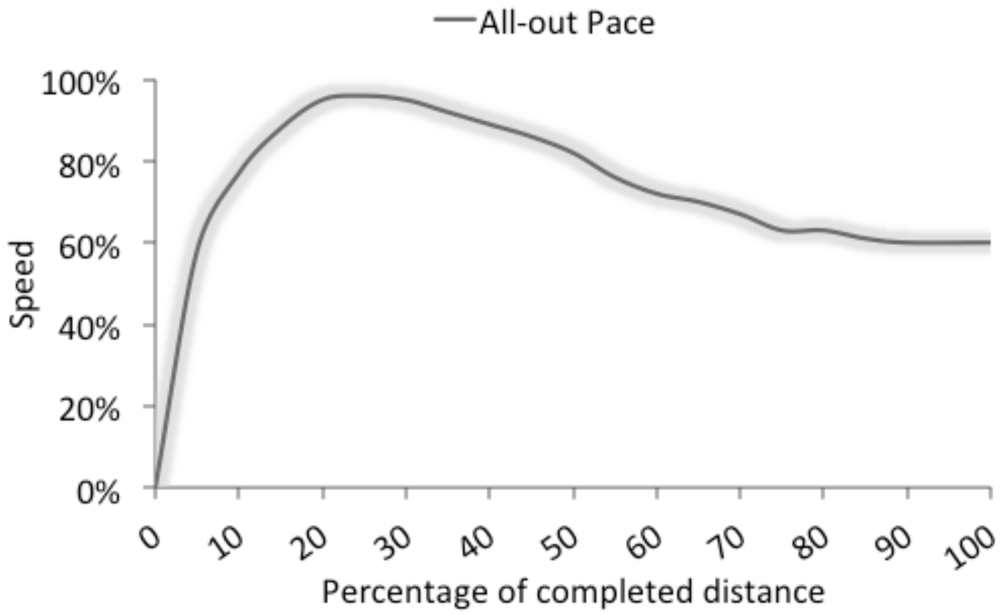


Figure 1-4 'All-out' Pacing strategy.

1.2.1.5 Parabolic-Shaped Pacing

Many researchers who examined the allocation of work through middle- and long-distance events observed a variation in pace between the first and second half of a bout (van Ingen Schenau *et al.*, 1992). In such events, athletes frequently reduce their speed during an exercise bout, and subsequently tend to accelerate the speed again in the latter section of the event (Tucker *et al.*, 2004; Thompson *et al.*, 2003). This approach results in a U, J, or reverse J-shaped pacing strategy (Abbiss & Laursen, 2008) (Figure 1-5). This might be a result of the adoption of both a positive and negative pacing strategies during an event. Foster *et al.* (2012) has surveyed a numerous number of distinct patterns of pacing strategies through the duration of several different bouts, stretching from 2 minutes to several hours, and observed that, on an average, the U-shaped pattern was the most widely applied. Elite rowers throughout the 2000 Olympic games, and 2001-2002 British Indoor Rowing Championship were examined. The study revealed that in both races, athletes employed the reverse J-shaped strategy; they started out in the first 500 m at an extremely very fast pace, and subsequently, slow down throughout the following 1000 m. Interestingly, they raised their speed in the last 500 m of the bout (Garland, 2005). Moreover, Mauger *et al.* (2012) analysed 264 elite athletes in 400 m freestyle swims (~4 min duration). The study revealed that athletes most commonly employed parabolic strategy, or a fast start followed by an even pace.

It was discovered that elite track cyclists adopted a parabolic pacing strategy in a 3 km and 4 km pursuit event (Corbett, 2009). This observation suggests that parabolic strategy is prevalent in event listing (~3-4 min) durations. This strategy has frequently been frequently mentioned in discussion regarding the CGM and teleoanticipation, since it was employed to support regulatory afferent feedback and the anticipatory/feedforward control, which was used to explain and understand the CGM and teleoanticipation.

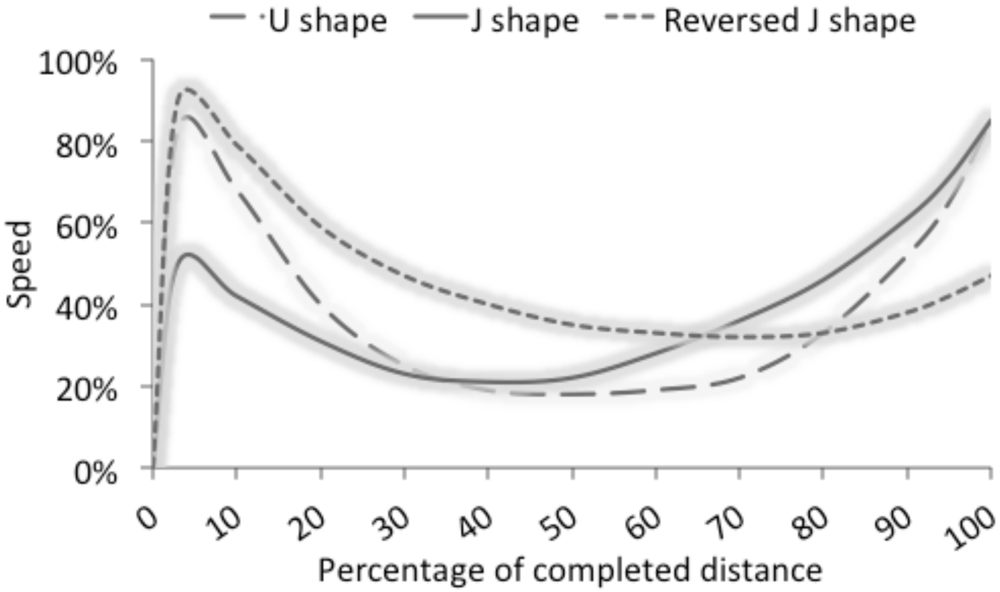


Figure 1-5 Parabolic pacing strategy.

1.2.1.6 Variable Pacing

Athletes are faced with numerous external factors during an exercise bout that renders the application of a constant PO impossible. Consequently, they alternate between pacing strategies. Due the enduring nature of some events, certain external factors can alter during a race (Foster *et al.*, 2004); for example environmental conditions such as wind (Atkinson & Brunskill, 2000) and peripheral temperature (Tucker, Marle, *et al.*, 2006). Swain (1997) demonstrated that a course terrain affects pacing, suggesting that a rotation between ascent and descent every 1 km in a 10 km cycling TT improved the overall performance. Furthermore Atkinson & Brunskill (2000) tested the influence of wind on overall performance during a 10 mile TT on a self-paced, constant, and variable pacing strategy; they found that the overall time was progressed in variable pacing when the power output was raised by 5% in headwind and reduced by 5% in tailwind condition, in comparison to self-paced and constant strategy. Garland (2005) found that a variable pacing strategy with 2.5% descent and ascent in a 40 km course improve the overall time compared to constant output strategy. Cangley *et al.* (2011) examined a 4 km undulating TT for 20 cyclists in 4 occasions, two TTs on an average constant power of 255 W, and two TTs on variable power on average of 260 W. Significant differences in completion time were discovered between the groups, the variable power groups showed a better performance. This suggests that in TT where the gradient is not constant, better performance time can be produced through the application of a variable strategy.

1.3 Fatigue

Fatigue is a natural physical phenomenon that involves numerous complex mechanisms takes place in our daily lives and in different way, but is still far from understood. Zafeiridis *et al.* (2010) defines fatigue as the participation of several systems such as muscular and cardiovascular systems and factors such as cognitions and psychology. In sports, fatigue constitutes a complex state that occurs during physical activities due to the interaction between physiological systems and mental performance (Lambert *et al.*, 2005). All the explanations offered earlier provide definite evidence with regard to fatigue being a complex phenomenon that is caused due to multiple factors.

The term fatigue may be understood differently, and it is difficult to arrive at a global implications. Noakes (2011) suggests that fatigue may affect any part of one's body and may be caused by a failure to maintain homeostasis, either directly in the active muscle (peripheral fatigue) or indirectly in the CNS (central fatigue). The physical term of fatigue has been defined as a reduction in force and power production abilities (Asmussen, 1979; Edwards, 1983). Furthermore, Bigland-Ritchie & Woods (1984) define fatigue as any exercise-induced reduction in the ability to exert muscle force or power, regardless of whether or not the task can be sustained. Enoka & Duchateau (2008) state that fatigue simply takes place when several physiological operations fail to produce the required force and PO. Therefore, the occurrence of fatigue is a highly complex issue, and during physical activities, multiple factors are certainly involved in this regard(Fitts, 1994).

Researchers attempt to define the causes of fatigue in order to assist coaches, sport scientists, and athletes to determine the most suitable approach of training that could improve their performance. Several researches have examined fatigue perception and its effects on performance (Abbiss & Laursen, 2005; Joseph *et al.*, 2008; St Clair Gibson *et al.*, 2001; Lepers *et al.*, 2002); however, till date, no single variable has sufficiently explained exercise-induced fatigue, and the phenomenon of fatigue continues to occupy the present debate in the domain of exercise performance area.

1.3.1 Peripheral Fatigue

Peripheral fatigue can be defined as a decrease in force caused by changes at the neuromuscular junction (Gandevia, 2001), or mechanisms that originate in the muscle fibres (Glace *et al.*, 2013). The classic theory of peripheral fatigue postulates that fatigue is the result of skeletal muscle 'anaerobiosis' (Hill, 1924), suggesting that anaerobiosis develop when active skeletal muscles oxygen requirement exceeds heart’s capacity to deliver it, leading to the generation of energy from the ‘anaerobic’ process that results in a more lactic acid accumulation, and therefore, termination of exercise. Since then, theories of peripheral fatigue have mainly focused around causative factors, such as accumulation of intramuscular metabolites.

1.3.2 Central Fatigue

Central fatigue can develop at the spinal cord or supraspinal level (Gandevia, 2001; Davis & Walsh, 2010). It can be defined as a failure of mechanisms proximal to the motor neurons, and therefore, a reduction in neural drive towards the muscles, resulting in a decline in force production or tension development (Davis & Walsh, 2010; Enoka & Stuart, 1992). The idea of central fatigue as a limiter of exercise intensity has been developed based on the mechanisms proposed by peripheral fatigue models (Noakes et al., 2005). The view that Adenosine Triphosphate (ATP) depletion is not related to fatigue (Noakes & St Clair Gibson, 2004), and that of the ‘black box calculation’ in which exercise intensity is influenced by factors such as training and pervious experience (St Clair Gibson & Noakes, 2004). The exact mechanisms of central fatigue are still unknown. However, the principle assumption with regard to central fatigue concentrates on the chemicals changes in the brain, such as serotonin, which it is known to effect motivation, sleep, mood, and appetite (Meeusen *et al.*, 2006). It has been found to influence the regulation of numerous behavioural and physiological functions; it could have both negative and positive effects on performance; while in a high proportion of serotonin relative to dopamine favours decreased performance, a low proportion enhance performance (Davis & Bailey,1997)

Other neuromodulators have also been found to influence fatigue during exercises such as cytokines and ammonia (Meeusen *et al.*, 2006), as well as the subconscious ‘central governor’ (CG) that acts as a protective mechanism to cause the ‘shut-down’ of the periphery if homeostasis is threatened (Noakes and St Clair Gibson, 2004; St Clair Gibson and Noakes, 2004). However, in spite of the efforts that have been made in the last 50 years to comprehend the phenomenon of fatigue, no precise explanation exists.

Further, it is more probable that both central and peripheral factors constitute causative factors of fatigue. However, a comprehensive and extensive examination of the theoretical mechanisms behind fatigue exceeds the scope of this thesis. Therefore, a brief overview of the most popular theories with regard to central fatigue that have received the greatest support are covered in the following section.

1.3.2.1 Teleoanticipation

Ulmer (1996) found the concept of teleoanticipation that suggests that for an athlete to achieve a shorter completion time and avoid early fatigue, their energy consumption per unit of time requires to be regulated with respect to a finishing point. He suggested an integrative control system for the optimisation of physical performance, that includes of different levels of control in the CNS, and peripheral physiological systems. Further, he stated that the 'Teleoanticipation' is a subconscious process, and this subsequently became a key component for the CGM (Lambert *et al.*, 2005). The central regulator utilises external feedback and signals from the muscles to alter intensity and optimise performance. Therefore, continuously feedback information regarding performance time, muscular metabolism, and intensity is required. Ulmer et al., (1996) found that the effectiveness of teleoanticipation process requires feedback and experience. Experience entails the comparison of the athletes' current feeling to that experienced in the previous event. The afferent input would supply the teleoanticipation centre with all the available information, if the algorithm indicated a mismatching between the current pacing and the endpoint of the event that would either allow to a premature or catastrophic fatigue, then further efferent would be amended to increase or decrease PO.

A further prerequisite for the effective function of feedback, feed-forward and anticipatory mechanisms to work effectively is the knowledge of the end-point, which it can be used to regulate the work rate. However, St Clair Gibson & Noakes

(2004) stated that the teleoanticipation cannot work effectively in open-loop events where the end-point is unknown.

Several studies have investigated the mechanisms involved in teleoanticipation. In a study by Ulmer (1996), two groups of participants were recruited; the first group was tested for swimmers' ability to grade their swimming intensities in steps of 90%, 80% and 70% of their individual maximum. The second group was recruited to test swimmers ability to arrive at a precise estimate of the time taken to swim 50 m at 90% or 70% of their maximum velocity. Ulmer et al. (1996) found that, depending on the given intensities, the swimmers demonstrated the ability to accurately time the swimming velocity, as well as to predict times required for known distances. It was concluded that this was a result of the behavioural feedback system that concerns both the physiological and psychophysiological adaptive processes. The concept of teleoanticipation was later explored through the introduction of a deliberate mismatch in actual and expected exercise intensity. With this experiment, it was found that both anticipation and subconscious interpretation of exercise intensity serve as its important regulators (Hampson *et al.*, 2004). Furthermore, Albertus *et al.* (2005) showed that incorrect distance feedback did not affect the completion time in 20 km cycling TT, suggesting that multiple afferents signals from a variety of sensory cues that were unrelated to distance feedback, were responsible for the exercise task and adoption of pacing strategy.

1.3.2.2 Central Governor Model of Fatigue

The CGM, which has been proposed to explain fatigue in relation to exercise, states that the CG controls the brain's physical activities functioning. The governor makes adjustments in skeletal muscle motor unit recruitment through the continuous alteration of pacing strategies**.** The CGM has redefined the expression of fatigue as exhibited here: 'fatigue should no longer be considered as a physical event but rather a sensation or emotion separate from an overt physical manifestation' (Noakes *et al.*, 2005). Therefore, the model proposes that it may be more correct to understand fatigue as a sensory perception, rather than a physical event, that results from the complex integration of physiological, biomechanical, and other sensory feedback from the periphery**.** The CGM proposed by Noakes & St Clair Gibson (2004) with regard to prolonged exercise, suggests that the brain regulates PO during a competition in an anticipatory manner to protect the body against severe or catastrophic. This is achieved through the modulation of the motor unit recruitment in accordance to expected competition duration, to ensure that an exercise task is completed successfully, and the motor unit is submaximal recruitment. This model was proposed based on the assumption that the recruitment of additional units could pose a threat to the level of amplitude required for the preservation of homeostasis, and could cause either a premature termination or physiological failure. The CG determines the sustainable work rate and creates a complex dynamic system through the integration of peripheral messages. This leads to constant interactions between numerous physiological processes from different systems. Further, according to the CGM, the sensation of fatigue does not entail a direct result of metabolite accumulation in the periphery as it was believed previously; it forms a homeostatic mechanisms' conscious interpretation regarding the current level of activity with respect to future exercise capacity (Tucker et al., 2004). The work level 'allowed' by the CG function through a 'black box' control centre that constantly makes calculations based on information regarding the environment, and event, as well as body's status (which is gained through afferent feedback). Any change in environment, event or body status would result in a recalculation and thus a change in the work rate allowed by the CG.

A considerable numbers of studies that support the CGM come from the exercise in the heat (Nybo & Nielsen, 2001a; Tucker, *et al.*, 2006) and altitude (Calbet *et al.*, 2003; Peltonen *et al.*, 2001; Noakes *et al.*, 2006). The supporting research draws from the observation that limitations experienced in exercises under both conditions precede any metabolic regulation failure. Tucker *et al.* (2004) examined PO, RPE and Electromyography (EMG) in hot and cool conditions during two self-paced 20 km cycling TT. The study observed a reduction in the PO and Integrated Electromyography (iEMG) activity in the hot condition; however, the reduction occurred before there was any abnormal increase in rectal temperature, heart rate (HR) or perception of effort. They suggested that this might be due to an adaptation that constitutes a part of an anticipatory response, that adjusts muscle recruitment and PO, to reduce heat production, thus ensuring that thermal homeostasis is maintained during exercise in the heat. At extreme altitudes, exercise is terminated due to severe dyspnea, Noakes *et al.* (2001 and 2004) state that in such circumstances, no substantial evidence exists to establish that homeostasis is threatened in any other organ, and cardiovascular function is fully suitable for a particular level of exercise. The low muscle lactate concentrations and submaximal cardiac output indicate that muscle hypoxia cannot be present. This phenomenon is employed by the CGM: stating that the CNS would use to determine the level of work that could be sustained, according to the anticipated endpoint, to maintain the homeostasis and avoid failure. Although, these arguments form the most direct support with respect to CGM, they also offer evidence regarding performance limitation in special environments. Further, in relation to normal competition conditions in which hyperthermia or hypoxia are not present, this model furnishes less robust support.

1.3.2.3 The Anticipatory-RPE Model

A further model to determine work rate regulation during exercise has been proposed by (Tucker and Noakes, 2009). The anticipatory-RPE model works under the assumption that exercise performance is regulated by the conscious RPE in order to protect the athletes from catastrophic failure and ensure optimal performance. Such a regulation is accomplished through the comparisons to prior experience, anticipation of endpoint, and physiological feedback, where the expectation regarding the exercise duration is utilised to set an initial work rate in subconscious ‘template’ for the rate of increase in RPE. Afferent feedback during exercise generates a conscious RPE that is continuously matched against the subconscious template, resulting in adjustments in performance. A study found that perceived exertion is associated with the internal sensations of the body during physical activities (St Clair Gibson *et al.*, 2003; Hampson *et al.*, 2001). Hampson *et* *al.* (2001) show that during incremental exercise, RPE was linearly related to HR and respiratory rate; however, St Clair Gibson *et al.* (2003) found that RPE might differ in similar physiological efforts. furthermore, perceived exertion may differ during exercise based on the environmental context, whereby afferent signals are integrated with external feedback about the environment (St Clair Gibson *et al.*, 2003).

Furthermore, a positive linear correlation between event duration and RPE during steady-state exercise was discovered (Noakes, 2004; Eston *et al.*, 2007). Joseph *et al.* (2008) investigated the relationship between RPE and the relative distance during TT at different distances: 2.5, 5, and 10 km respectively. It was found that RPE increased similarly at 20%, and 80% of the relative distance, regardless of the distance performed. Pervious models (St Clair Gibson & Noakes, 2004; Tucker, 2009; DeKoning *et al.*, 2011; Corbett *et al.*, 2012) have suggested that RPE constitutes the central regulator of pacing strategies. However, Faulkner *et al.* (2008) studied the relationship between HR and pacing strategy with the rate of perceived exertion. Nine participants completed a 13.1 mile half marathon followed by a 7-mile road race a week later, in which HR, RPE, and separate mile time were recorded. The study found that there were no differences in RPE when it was expressed against the percentage of time. This might indicate that RPE, at time, may fail to correctly indicate failure in performance. Furthermore, in a recent review by Micklewright *et al.*, (2016) stated that according to the dual process theory, RPE does not constitute the sole source of information for the formation of pacing-related decisions; instead, it is one of the other factors that might be adapted to regulate pace.

1.4 Factors influence pacing strategy

Many factors, either related to the internal state of the body or the external environment, have been found to influence pacing strategy. These factors are explored in the following subsections.

1.4.1 Internal factors

1.4.1.1 Energy substrate and Oxygen level

During endurance exercises, pacing is sensitive to alterations in muscle substrate utilisation. It is altered by the dietary intervention that results in different amounts of energy storage before exercise or altered substrate utilisation during exercise (Tucker & Noakes, 2009). The role of glycogen concentration as a regulator of pacing strategy has been suggested by Rauch *et al.* (2005). They found that a high-carbohydrate diet lead to an increase in the muscle glycogen content that enhance the cycling TT performance. However, individuals may respond differently to the energy substrate availability, rendering drawing conclusions with regard to its effect on pacing strategy difficult. For example, a study by Havemann *et al.* (2006) found that only 5 out of 8 participants showed improvement in performance when they were provided with high carbohydrate diet for 7 days.

The oxygen level of the inhaled air also affects pacing strategy (Brosnan *et al.*, 2000). A decrease in oxygen tension (hypoxia) leads to impaired performance, which is often attributed to a decrease in oxygen availability, and therefore, a decrease in sustainable aerobic system and greater dependence on anaerobic system, that, in turn, leads to an early development of muscle fatigue (Linossier *et al.*, 2000). While an increase in oxygen tension (hyperoxia) leads to improvement in performance that has been attributed to several factors such as reduction in blood lactate accumulation (Graham *et al.*, 1987), increase in VO_2, and ATP production (Wilber *et al.*, 2003), and increased muscle activation result in greater POs (Tucker *et al.*, 2007).

1.4.1.2 Biofeedback and Neurofeedback as internal factors

The application of biofeedback has been discussed earlier in the context of sports. Biofeedback is considered a sensitive technology or tool that employs instruments to measure mental, biological, or physical activities in order to provide information regarding the state of biological functions that are normally out of conscious control ‘voluntary control’. Most of these studies have addressed the effects of biofeedback in lowering performance anxiety, growth of muscle strength (Sandweiss, 1985), decrease in fatigue, and regulation of HR (Zaichkowsky & Fuchs, 1988). In exercise tasks, the internal feedback can be provided regarding the performance, function by monitoring HR, pH, $VO_{2,}$ respiration, blood pressure and neural muscle feedback. For example Perski & Engel (1980) studied the ability of participants to reduce the cardiovascular response during exercise. They found that participants who were provided feedback could lower their HR by approximately 20%, in comparison to the control group who exercised without receiving any feedback. Similarly, Goudas *et al.* (2007) studied the influence of different types of internal feedback and goals on performance. The study involve Eighty-two participants, in which they were asked to perform two submaximal endurance tests. After the first trial participants were assigned in to four different groups; participants in the first group were asked to lower their average HR, as they received HR feedback every minute. The second group’s participants were asked to both lower their average HR and improve their performance as they received HR feedback every minute. Participants in the third group were asked to enhance their performance time while individual concurrent feedback was provided; while participants in the fourth group were asked to do perform their best with blind feedback. The study revealed that participants who were provided HR feedback and asked to lower their average HR exhibited a significant increase in performance. The results of this study indicate that participants who concentrate on internal body signals can improve their performance. Factors such as VO_2 and ventilation (VE) have also been examined as internal factors that could affect performance. Caird *et al.*, (1999) studied biofeedback and relaxation ability to decrease the submaximal oxygen consumption and improve the running economy of long distance runners’. The study found that after six weeks of the relaxation program, participants were able to lower their $VO_{2,}$ HR, and VE, when they were asked to run for 10 minutes at 70% of the peak velocity as feedback regarding while HR, VE, and VO_2 was provided. This indicates that psychophysiological is instrumental with regard to the improvement of the running economy. However, Baig *et al.* (2013) found that the use of biofeedback regarding of VO_2 is only beneficial in the case of low intensity exercises. A review by Amann & Secher, (2010) revealed that the neural feedback regarding a limb muscle under fatigue is crucial in determining performance in endurance exercises. Fatigue in a limb muscle may either be caused due to the restriction of central motor output at cognitive level or through the prevention of premature fatigue through the optimization of oxygen O_2 delivery that influence circulation and pulmonary ventilation. It is evident that some type of bio and Neurofeedback might determine endurance exercise performance; however, it is not clear whether athletes or cyclists utilise such information to pace themselves during competition, or whether such information helps them to change their pacing-decisions; therefore, further research is required in this area.

1.4.1.3 Pain

It has been theorised that an athlete's ability to tolerate Exercise-Induced Pain (EIP) constitutes a critical factor in successful performance (Anshel & Russell, 1994). Pain has been determined to be a significant part of training and performance in various sports including cycling. It can contribute to a reduction in work rate that is obvious in an athlete's pacing strategy (Mauger *et al.*, 2014). Pain has an important role in protecting the body from damage; the EIP might provide important perceptual information that helps athlete to decide whether to increase or decrease their work rate or to stop exercising (Mauger, 2013). Several studies have investigated the relationship between pain and exercise. For example, Hollander *et al.* (2010) found that partial vascular occlusion alters level of pain and the rate of perceived exertion for a given exercise intensity. More recently, Astokorki & Mauger (2017) investigated the relationship between experimental measures of pain (Cold pressor Test (CPT)), exercise-induced performance tolerance, and performance during 10 mile cycling TT. The study found that a high tolerance for EIP provides an important advantage for performance; it further states that EIP plays an important role in endurance performance of moderate duration; furthermore, the study found that during fixed-intensity performance, time exhibited a relation with the amount of pain experienced. Future research should consider self-paced exercise to examine the effect of pain on performance and pacing.

1.4.1.4 Rating of perceived exertion

Perception of effort appears to be an important factor in the regulation of exercise performance. Borg's 6-20 RPE scale has been widely accepted as a valuable and reliable scale for the evaluation of exercise tolerance and the magnitude of exertion for athletes and healthy adult populations (Borg, 1998). Earlier, it was known that the integration of multiple afferent signals from a variety of perceptual cues such as cardiopulmonary factors (VE, HR, VO_2), and metabolic/peripheral factors creates perceived exertion. However, Faulkner & Eston (2007) provides evidence that RPE may represent the integration of multiple afferent signals interpreted in both feedforward and feedback manner, in relation to expected sensations in accordance to distance knowledge and previous experiences. Therefore, RPE could represent the association between subjective sensations of effort and the physiological changes that emerge during exercise (Tucker & Noakes, 2009).

1.4.2 External factors

A considerable amount of research has been conducted on studying the effects of different types of external feedback on pacing and performance. Information such as time on task, event distance, number of repetitions and performance feedback has been found to influence pacing and performance; these factors are explored in the following subsections.

1.4.2.1 Knowledge of distance

Event distance appears to be one of the most important factors that affects pacing. Alterations in the event duration might have a significant impact on the responsible mechanisms of fatigue and, thus, athletes' pacing (Abbiss & Laursen, 2005). According to the teleoanticipation theory (Ulmer, 1996), intensity and pace are predetermined in a feed-forward manner, meaning pace and PO are subjected to constant adjustment via a ‘black box’ located in the brain. Such a processes seem to exhibit a dependence on both knowledge of the duration and previous experience (Mauger *et al.*, 2009a). Baden *et al.* (2005) found that the expected duration of a run influences both pace and perceived exertion, with longer expected distances resulting in slower pace and lower RPE. This study provides evidence that knowledge of task duration constitutes an important determinant with regard to pacing strategy. Tucker & Noakes (2009) have stated that athletes distribute energy according to the event duration and that any mismatch between expected and actual distance from the endpoint leads to incorrectly allocation of physiological resources and diminished performance. Faulkner *et al.* (2011) predicted that athletic performance would be influenced by feedback regarding event distance. Thirteen participants were asked to perform 4 self-paced 6 km treadmill TT with accurate, inaccurate (premature and delayed), and no distance feedback. The study revealed no differences in completion time or RPE between accurate and inaccurate distance feedback conditions. However, when no distance feedback was provided, a considerable lower completion time was observed suggesting that participants tend to preserve energy when the event duration is unknown.

Albertus *et al.* (2005), Palmer *et al.* (1998), and Nikolopoulos *et al.* (2001) observed that when the duration of an exercise is known, false information regarding distance feedback appears to have no influence on the overall performance of well-trained athletes. This suggests that the selection of pacing strategy is based on the perceived distance and not the actual distance. In addition, Mauger *et al.* (2009a) observed a shorter completion time in a 4 km cycling TT when accurate feedback was provided, compared to when no feedback was provided in the first TT. However, participants displayed a progressive improvement in their completion times in the last three trials when no distance feedback was offered. The study demonstrates that cyclists with sufficient previous experience, even with for unknown distances, can complete a 4 km cycling TT in a competitive time frame. This indicates that distance-related feedback is not essential in the development of an appropriate pacing strategy, and that previous experience has a greater potential to influence pacing strategy in comparison to knowledge of the distance to be covered. This evidence suggests that distance feedback has a greater likelihood of affecting the pacing strategies of novice athletes, since it provides objective information regarding the endpoint. However, Williams *et al.* (2012) observed no differences in completion time among different groups during a 4 km cycling TT, in which, untrained athletes were provided with either distance-related information and feedback or neither.

The above-mentioned studies indicate that inconsistent results have been reported with regard to pacing strategy and performance when knowledge was blinded or misleading; further, it suggests that no specific mechanism can interpret the outcome correctly, especially in relation to self-pace exercises. A visual investigation of the factors that athletes are concerned with during self-paced exercise and the way in which such information affects their performance and pacing decisions might expand our understanding regarding the implication of the presentation of such information for pace.

1.4.2.2 Performance feedback

Pacing strategy, as it has been defined earlier, implies the manipulation of PO in a competition exercise, in order to facilitate the realisation of a suitable dissipation distribution of speed and energy over the bout, in a manner that allows an effective performance (Mauger *et al.*, 2009a). Throughout the bout, pace and PO are continuously regulated, and such a regulation process appears to be dependent on previous experience and knowledge of the task. This section discusses the influence of performance-related information such as speed/time and PO on pacing and performance. Indeed, it is important to observe that speed and PO cannot be similarly evaluated in the examination of athletes' pacing strategies; further, a non-linear relationship exists between them, especially in non-flat tracks. Mauger *et al.* (2009b) showed that an accurate performance feedback related to 'lap times' leads to improved performance. A considerably shorter completion time was observed during a 4 km TT when subjects had received correct lap time feedback, in comparison to a baseline TT or when participants had received a false lap time feedback. The study revealed that accurate performance feedback leads to increased speed at the start and the end of the 4 km TT. Furthermore, Micklewright *et al.* (2010) suggested that cyclists may choose to pace themselves according to the speed and PO feedback if their experience supports this as a successful strategy.

Deception has also been employed to manipulate the given time at different intervals during exercise; this has been achieved through the provision of inaccurate feedback to examine the influence of performance time feedback on pacing regulation. Beedie *et al.* (2012) examined the effects of false time feedback on performance. Trained athletes were given a 5% positive-false (ahead of the true value), and 5% negative-false (with regard to the true value) time elapsed feedback at every mile during a10 mile cycling TT. The study observed no differences in PO and completion time. However the emotional and physiological responses were found to be influenced by false time feedback, in which lower oxygen uptake, higher blood glucose, happiness, and calmness were associated with false-positive feedback. Stone *et al.* (2012) noted a shorter completion time by 1% in a 4 km TT when cyclists were informed that they were cycling against their previous performance, in fact, their performance was manipulated to display a profile of 102% of their actual cycling performance (baseline).

Performance intensity has also been investigated as an external factor that effects pacing and performance. Hampson *et al.*, (2004) found that deception with regard to exercise intensity has no influence on athletes HR or RPE. Similarly, no differences in performance (time to exhaustion), and HR were found in an open-loop exercise using exercise intensity deception (Pires & Hammond, 2012). The results from these studies suggest that manipulation in exercise intensity does not affect the RPE regulation and overall performance. The availability of task related information has also found to effect the effort distribution during self-paced exercise, suggesting that athlete form pacing decision based on the most relevant information (Renfree *et al.*, 2014). Smits *et al.* (2016) recently investigate the effect of task related information feedback on pacing and performance. In the present study, participants were either presented with full performance information feedback (including information regarding factors such as speed, PO, HR, cadence, elapse time and covered distance) or no feedback during a 20 km cycling time trial. Although, no differences between groups were observed in both performance time and RPE, pacing strategies employed by the two groups showed divergence, especially towards the end of the TT. . While this study reported that such a difference in pacing strategy is more likely to be a result of the absence of the distance feedback, the researchers could not ignore the presence of other performance-related information that could have contributed to a change in pace. Therefore, a more sophisticated methodology is required to measure and identify the contribution and integration of each type of performance-related information into the decision-making process.

1.4.2.3 Environmental conditions

Environmental conditions were also examined as an external factors related to pace and performance. According to this, a failure of motor unit recruitment takes place after the body temperature reaches a critical value of approximately 40 $^{\circ C}$ (Nybo & Nielson, 2001), suggesting that in conditions of heat, the brain is unable to recruit motor units to allow the continuation of exercise at the same intensity. Tucker *et al.* (2004) noticed a decrease in average PO and completion time after 20 km cycling TT in the hot condition compared to the cool condition. However, the study found that a reduction in PO occurred before the rectal temperature reached 40 °C. This is similar to Morrison *et al.*s' (2004) study in which isometric force production and voluntary activation percentage exhibited a decreased even at a body temperature lower than 39°C. Tucker, *et al.* (2006) investigated the regulation of exercise performance under hot and cool conditions during a predetermined stable RPE. The study found a significant decrease in PO in the heat condition compared to the normal and cool conditions, and a higher rate of heat storage at the start of the trial during in the heat condition. This suggests that both skin afferent feedback and the rate of heat storage together regulate the exercise intensity in the heat through the reduction of the exercise load to ensure that excessive heat accumulation does not occur.

Deception with regard to the information conveyed about the body and core temperature has also been believed to influence pacing and performance. Deceiving participants about their core temperature could create a mismatch between the anticipated and true perception of exercise thermal stress that could lead to an improved performance. Castle *et al*., (2012) examined the influence of deception of ambient and core temperatures on 30 minutes of self-paced cycling during hot-humid conditions. The distance covered in heat conditions was lesser than that covered in the controlled trial; however, an improvement was observed in this respect when the participants thought their body temperature was cooler, and they were exercising in a cooler environment. The study suggests that the application of deception feedback creates a lower RPE, and consequently, improves performance; furthermore, the result reveals that deception negated the decline in performance in the heat condition (Castle *et al.*, 2012).

Other environmental factors such as wind (Abbiss *et al.*, 2006; Atkinson & Brunskill, 2000) and topography (Atkinson *et al*., 2007) have also been found to influence on pace and performance. A variation in PO is required to produce an ideal pace in exercise that entail external resistance such as traveling uphill or into a headwind. For example, during a laboratory-based study, Atkinson, Peacock, & Passfield, (2007) and Atkinson & Brunskill (2000) found that the best cycling performance was achieved when athletes increased PO while the external resistance was high (cycling uphill or into a headwind) and decreased PO while the external resistance was low (cycling downhill and or into a tailwind), compared to a freely-paced trial.

1.4.2.4 The presence of a competitor

External information such as competitor behaviour and drafting possibilities might also influence the decisions regarding the energy expending strategy over the race, and consequently, participants’ tactics and pacing. The presence of an opponent has been investigated earlier and found to influence performance (Bath *et al.*, 2012; Tomazini *et al.*, 2015; Corbett *et al.*, 2012; Lambrick *et al.*, 2013; Emily L Williams *et al.*, 2015; Konings *et al.*, 2016). In a head-to-head competition, the target is to beat other opponents (Corbett et al., 2012). This leads to an increase in concentration with respect to other competitors and direction of attention away from the internal feeling of fatigue (Williams *et al.*, 2015); in addition, an increased level of motivation has also been suggested to explain athlete's improved performance due to the presence of an competitor (Peveler & Green, 2010).

Williams *et al.* (2015) discovered a positive effect of the presence of a direct opponent on performance during a 10 mile TT in comparison to a solo performance. This suggests that the presence of competition increased cyclists' motivation to perform faster in a TT and contributes to changes in their adopted pacing strategies. Furthermore, Konings *et al.* (2016) has recently investigated the effect of opponents' behaviour on athletes' pacing and performance. The study found that the behaviour of the opponent appeared to influence the decision regarding pacing strategy, highlighting interaction with the environment as a significant determinant of pacing. However, the presence of a competitor appears to be crucial. Peveler & Green (2010) found that starting 1 minute behind (chasing) an opponent or in front (leading) of an opponent did not influence performance; however, a differences in pacing strategy were found across trials.

The presence of competitors during cycling also assists athletes to draft behind another competitor, providing them an opportunity to conserve energy; this influences the determination of the self-selected pacing strategy (Brisswalter & Hausswirth, 2008). For example, Hausswirth *et al.* (1999) observed a reduction in HR, oxygen uptake, and pulmonary ventilation when athletes were drafting 0.2–0.5 m behind a lead cyclist, in comparison to a non-drafting situation. Therefore, the presence and position of other competitors plays a significant role in the determination of the pacing strategy.

It is evident from the previous session that a number of internal and external factors could affect the process of pacing decision and performance. Feedback deception and blinding experimental methods have been employed to understand the way in which internal and external information affects pacing and performance and athletes utilise such information to pace themselves. The process of blind or deception methodology is concerned with the effects of information alteration or removal on athletes' pace. The significance of a particular kind of information can be determined by assuming that a change in pacing and performance occurs after the alteration or removal of that source of information. The application of this approach, with its various limitations, explained in section 1.6.3 of this thesis, to investigate pacing decision limits our understanding of the phenomenon. Therefore, a more direct method of assessment of the information athletes seek and the way in which such information could be interpreted during self-paced exercises would immensely facilitate our understanding of pacing decisions

1.5 Performance Regulation

Two central models have been mainly employed to explain the factors that limit the regulation of exercise performance, the homeostatic failure model and the anticipatory regulatory model CGM. The first model suggests that limitations in exercise occur as a result of physiological changes in metabolism, energy provision, cardiovascular system, and body temperature among many others. According to this, demand exceeds capacity in one or more systems, causing them to fail. Noakes (2008) termed the model of exercise physiology that limits performance as 'brainless', since no role of the brain was observed in the determination of the exercise performance during laboratory testing for the measurement of the VO2 max (Noakes, 2008). In contrast, the anticipatory CGM model allows feedback from the periphery to influence the magnitude of the feedforward central drive that determines the extent of skeletal muscle recruitment. Kayser (2003) stated that exercise begins and ends in the brain, suggesting that athletes' conscious brain forms the final decision regarding the time of exercise termination. Thus, psychological and not purely physiological factors can presumably influence that decision. The process of exercise termination, as proposed by the CGM, differs from the traditional peripheral fatigue model, according to which the brain, and not the exercising muscles, constitutes the site of the catastrophic failure (Noakes, 2011). However, this crucial role of brain function during exercise can be identified only during self-paced exercises (Abbiss *et al.*, 2006; Joseph *et al.*, 2008; Tucker, Lambert, *et al.*, 2006).

Most theories regarding pacing emphasise on the RPE during the exercise competition and the way in which the interpretation of the RPE to affords energy to the remaining distance of events (St Clair Gibson & Noakes, 2004; St Clair Gibson et al., 2006). A positive relation has been observed between the RPE and the event duration during both fixed intensity and self-paced exercise (Parry et al., 2012). Tucker (2009) provides details about the conscious/subconscious RPE, suggesting that conscious RPE is constantly compared to a subconscious ‘template RPE’ during an exercise competition, in which an athlete is continuously compares the way they feel at a specific moment with their expectation pertaining to the same and ensure that the maximal possible level of RPE does not occur before the end of exercise. Further, he suggests that if the expected RPE is high at the end of a bout, the intensity of exercise must be reduced. Furthermore, DeKoning *et al.* (2011) suggest that pacing strategy is regulated based on the remaining duration and the momentary feeling, RPE ‘Hazard score’ that represents the hazard of a competitively catastrophic collapse faced by the athlete. The introduction of the hazard score was a significant step forward, since it incorporates both RPE and the relative amount of competition to be completed, and represents the fluctuation in uncertainty in relation to event duration. For instance, individuals nearer to the finish line can take greater risk. However, it does not allow any individual flexibility or adaption with regard to the type of information employed to make pacing decisions, since it is completely dependent on RPE and endpoint as the only two factors generally responsible the regulation of pacing behaviour. Despite the number of models that emphasize the role of RPE in performance regulation, there is some evidence question these assumptions. For instance, Baden et al. (2011), found that the physiological fatigue does not vary or alter when the RPE was higher in misinformed group comparing when subjects were provided accurate information regarding the exercise requirement. In addition, Renfree et al. (2014), suggested ‘that if self-paced exercise performance is regulated via the conscious RPE, then some individuals may be likely to make poor decision regarding selecting of muscular work rates early in an exercise bout when RPE is typically low’ (Renfree *et al.*, 2014).

The effective responses also has an effect on pacing strategies and performance regulation. Several researchers have shown that affective responses are related to, or dependent on, exercise intensity. Low-intensity exercise has been associated with pleasant and positive emotions, whereas high intensity exercise has been associated with unpleasant and negative emotions (Acevedo *et al.*, 2003; Kilpatrick *et al.*, 2007; Sheppard & Parfitt, 2008). Hence, there is a negative relation between the intensity of exercise and RPE, and the affective responses; therefore, when the exercise intensity increases the RPE increases as well, while the positive affective responses (pleasant) reduce. It is evident that different models have been suggested in with regard to performance regulation and pacing decision, some focused on RPE, other on knowledge of distance or remaining time as the central regulators of exercise. The investigation of information acquisition behaviour would facilitate our understanding of the role of visual behaviour in performance regulation and pacing decision and provide an alternative to the previous prevalent methods of deception. Eye-tracking enables the collection of information regarding the way in which athletes seek information during an exercise trial, as well as the way in which they learn information application to pace themselves and form pacing decision.

1.6 Decision-making

The achievement of optimal performance is expected to depend on effective tactics and decision-making even in individual TTs (Renfree *et al.*, 2014). However, environmental conditions and physiological responses alter sometimes in unpredictable ways during an endurance task that influences continuous decisions about whether to maintain the current effort or make adjustments. Such a strategy is affected by athletes’ current physical abilities, environmental factors (Racinais *et al.*, 2015), and previous experience (Smits *et al.*, 2014; Micklewright *et al.*, 2010; Edwards & Polman, 2013). In addition to the previous factors, an athlete may also consider other competitors' strategies to form their own decision (Renfree & St Clair Gibson, 2013; Hettinga *et al.*, 2017; Konings *et al.*, 2016). Indeed, decision-making is key determinant in pacing that can facilitate athletes' regulation of their physiological reserves in the optimal way for performance. Decision has been defined as an individual's ability to select an action from a number of possible actions in order to achieve a task aim (Hastie, 2001). Decision-making theories have been developed in different areas such as economics, ecology and psychology. The role of decision-making in effort regulation has been discussed (St Clair Gibson *et al.*, 2006; Renfree & St Clair Gibson, 2013; Renfree *et al.*, 2014; Smits *et al.*, 2014; Micklewright *et al.*, 2016); however, no real attempts have been made to apply decision-making theories towards the comprehension of optimal pacing strategies or tactics.

Decision-making in sports constitutes a complex and dynamic process. Johnson (2006) proposed that in sports, both the internal dynamics, pointed to the physiological information collected during exercise, and external dynamics, such as the effect of environment and changes in the situation 'performance', are affected by and considered in decision-making (Johnson, 2006). Decisions may need to be made under different conditions of certainty and uncertainty, which may be unprompted or intended; therefore, it is proposed that decision-making draws from either rational or heuristic processes (Bar-Eli *et al.*, 2011).

Rational decision-making theory, as it is described by Simon (1955) can be considered in pacing decision only when certain norms are fulfilled. It requires information pertaining all potential outcomes of the task and information about the probabilities of each outcome. This information would present a demand on an individual's cognitive process (Simon, 1978). According to this theory, in endurance exercises, such as cycling and running, an individual must attend to and appraise many sensory cues that includes feedback information about the afferent physiological, performance (such as remaining distance and elapsed time), environment and competitors and also assess the knowledge regarding all possible behaviours, including the assessment of risk ‘the likelihood of individual facing physiological failure’ reward behaviour ‘the individual motivation to achieve a particular performance’ of each behaviour (Renfree *et al.*, 2014). The theory of rational decision-making proposed that an individual must possess perfect knowledge with regard to all relevant alternatives, and the decision is made through the interpretation of feedback and awareness about all available outcomes. Such information is not available to participants in a competitive sports environment (Renfree *et al.*, 2014), due to the complexity of the internal and external information, especially, information about competitors and their selected strategy. Therefore, in such a complex environment, when information about athletes’ physiological state and weather is continuously changing, athletes may be more likely to make decisions based on other principles such as the ‘Heuristic’. The heuristic was unknown until the mid-1970s, when Tversky & Kahneman (1974) found that decision-making is influenced by irrational, which means that individuals are strongly affected by the way a question is presented. For instance, in a sport competition with a 45% probability of success may appear more desirable compared to one that has a 55% chance of failure. Heuristic decision-making suggests that humans consider limited fragments of a whole piece of information that implies that in such a strategy some irrelevant available information is ignored; consequently, the decision is made more quickly and accurately (Tversky & Kahneman, 1974). Gigerenzer & Gaissmaier (2011) proposed that in complex situations, such as sports, it would be impossible to fully consider in the numerous sources of feedback in a deliberative way, and in such instances, individuals tend to make decisions based upon selective cues. These cognitive shortcuts are termed as heuristics. In fact, they can lead to the information of good decisions in several contexts and enhanced decisions in others, compared to those given by more deliberate approaches (Vickrey *et al.*, 2010). Renfree *et al.* (2014) suggested that it appears more logical to classify sports competitions as environments in which some irrelevant information is ignored from the ‘large world’ environment, rather than as one that requires perfect knowledge reading all relevant behaviour and probabilities from a ‘small-world’ environment.

1.6.1 Decision Making in Prolonged Exercise

It is important for athletes to maintain a suitable pacing strategy in order to achieve an optimal performance level. St Clair Gibson *et al.* (2005) proposed that the degree of physiological disturbance sustained throughout an exercise competition may be based on decisions related to metabolic values that would allow the brain to calculate the desired response to preserve physiological homeostasis after the metabolic disruption. It is suggested that the estimation of the afferent feedback and environmental conditions must occur as a result of continual alterations in this information. According to St Clair Gibson *et al.* (2005), ‘teleoanticipatory’ processes oscillate between certainty and uncertainty, resulting in observable fluctuations in pace. Tucker & Noakes (2009) supported the idea that pacing is influenced by uncertainty that entails in which uncertainty occurs after an alteration in feedback; further, once appropriate levels of work rate are resolved, a period of certainty follows. This was investigated by Swart *et al.* (2009), who found that increases in RPE during a 40 km cycling TT were related to certainty regarding the end-point of the event and expected exercise duration. This suggests that the rate of increase in RPE is not constant, but varies according to endpoint certainty and elapsed distance.

Certain models regarding pacing have understated the influence of external information on pacing. In particular, sufficient attention has not been paid to the integration of external and internal information on perceptual experience and decision-making in self-paced exercises (Parry *et al.*, 2012). Smits *et al.* (2014) initiated a framework that suggests decision-making in endurance exercise as an essential part of the pacing process, dependent on interactions and association between perception and action. Furthermore, it was suggested that the bodily and environmental information should also be considered in the anticipation of factors such as personal goals and certainty about the endpoint (task duration).

1.6.2 Pacing decision and deception

As previously mentioned, the purpose of an optimal pacing strategy through exercise is to boost performance and prevent exceeding the physiological limits (Hampson *et al.*, 2001). In the previous section, I discussed the way in which performance is regulated to avoid failure and achieve an ideally performance via the CGM, the teleoanticipatory system, and the RPE model. I also highlighted the relation between pacing strategy and feedback and feed-forward mechanisms. Athletes need to continuously modify their pace in order to complete the race without experiencing a physiological failure. Most pacing models involve the athlete monitoring external feedback about their progress and performance during an event. A considerable amount of emphasis has been placed on the knowledge of the endpoint 'event duration' or time on pacing and performance regulation. Blind experimental and feedback deception have been employed to highlight the importance of distance knowledge in pacing strategy and the way in which athletes utilise information to select the right strategy and pace themselves (Les Ansley *et al.*, 2004; Albertus *et al.*, 2005; Baden *et al.*, 2005; Billaut *et al.*, 2011; Eston *et al.*, 2012; Faulkner *et al.*, 2011; Mauger *et al.*, 2009b; Nikolopoulos *et al.*, 2001) previous performance (Stone *et al.*, 2012), previous experience (Micklewright *et al.*, 2012; Mauger *et al.*, 2009a) and performance time (Thomas & Renfree, 2010; Morton, 2009). The underlying assumption of such approaches is that if the pace changes when the provided performance feedback are either deceptively manipulated or removed (blinding), it is possible to gauge the importance of such information and the way in which athletes use it to regulate their efforts. Existing research in the area of deception has critically examined the contribution of feedback pacing strategy (Jones *et al.*, 2013). In the following section, the limitations of such approaches with regard to understanding pacing decisions are discussed.

1.6.3 Limitation of the current pacing approach

Experimental approaches to understanding the way in which athletes use information to pace themselves (to make deductions about the significance and role of particular types of performance information) have been based upon the effect on pace if that information is altered (deception) or removed (blinding). The concept behind such approaches is that if any associated changes in performance or pacing strategy change occur, then conclusions can be made about the role of the manipulated information. Such approaches led to increased emphasis on event duration in various pacing models. However, several limitations to this approach have been raised including the following:

- Focusing on singular sources of information (such as endpoint) in understanding athletes' interpretation and reaction and ignoring the investigation of the other internal and external information that athletes actually seek, and the interpretation and conjunction of such information. For example, the importance athletes place on singular performance information such as distance and speed to make pacing decisions could potentially vary according to the number of factors involved such as environmental conditions or the remaining distance.

- The importance of feedback information, both internal and external, might change during an exercise bout. For instance, athletes may pay more attention to PO at the beginning of the race, and become more interested in the HR or remaining distance later. This was ignored or not investigated in previous deception studies.

- The inability to examine changes in pace as a result of expected or unexpected alterations in environmental conditions, since most of the previous studies were laboratory experiments.

- All the previous deception studies failed to understand differences in individuals' feedback preferences that might vary according to past experience. For instance, an athlete might rely on HR to guide himself and regulate the effort, while another could use speed or distance as the anchor.

In a recent review by Micklewright *et al.*, (2016), subconscious versus conscious pacing quagmire has been discussed. In particular, Micklewright et al (2016) highlight the lack of proper definition application in various subconscious, unconscious, and conscious terms, as well as the dynamic and interactive nature of subconscious, preconscious, and conscious that is well established in psychodynamic theory, but till date, has been left largely neglected. A distinction can be made between ‘subconscious’ and ‘unconscious’, defending the subconscious as a ‘mental process operating outside consciousness’ (Micklewright *et al.*, 2016), while the unconscious implies a group of unaware and inaccessible information in individuals’ minds (Freud, 1913; Micklewright *et al.*, 2016). In addition, there is a ‘preconscious’ that forms the site of information they are unaware about that could be made accessible through the conscious, if individuals’ attention is voluntary or involuntary drawn to it. Moreover, it has been stated that no matter whether pacing is consciously, subconsciously, or unconsciously regulated, such an approach or knowledge would not advance our understanding of pacing and performance regulation and that such mechanisms form a one-dimensional mechanism. In review by Smits *et al.* (2014) and Renfree *et al.* (2014) the importance of the decision-making process has been highlighted as an essential mechanism of pacing behaviour. Furthermore, Micklewright *et al.* (2016) suggested that pacing is a multidimensional process, in which all factors should be considered, including conscious versus subconscious control to explore pacing regulation. The recent framework suggested the dual process theory as an alternative process that distinguishes intuitive and deliberative cognitive processes. The notion of the dual process is that individuals are not always fully rational when making decisions, and that decision is influenced by other factors such as previous experience and environmental factors. Such a process might contribute to the development of our understanding of pacing mechanisms. Decision-making process involves several common processes including the acquisition of information, the integration and interpretation of information, and decision implementation. In the Electronic Supplemental Materials (S1) Micklewright *et al.* (2016) argue that information acquisition and decision-making in athletic pacing should be investigated through the adoption of process-tracing methods that are more sophisticated in comparison to previous deception and blinding methods. The focus of this thesis is on visual information acquisition processes for cycling TTs. Eye tracking methodologies were employed as an alternative to deception and blinding.

1.7 New approach of information acquisition and preferences

The processing of visual information is essential for navigation in sports event. It is an important part of acquisition of external information, including performance feedback. Measurement of what athletes seek during a certain tasks, such as cycling, facilitates the understanding of information acquisition patterns. Such an approach provides an alternative to deception and blinding methods that were employed earlier to study the information acquisition process. Therefore, direct methods for the assessment of information acquisition during the performance of a certain task is needed. Eye tracking is a process-tracing method that could be applied to investigate information acquisition processes; it helps to collect detailed information about the way in which individuals seek information. Eye tracking would enable us to measure the fixation duration and frequency of the point of interest (where the individual is looking); such a measurement would reveal the environmental or informational cues cyclists consider important during the performance of a certain task. In this section, I briefly describe eye movement and the mechanisms of visual information acquisition.

1.8 Visual Behaviour

In order to react appropriately during a certain task, individuals need to perceive and interpret the environment correctly. Vision constitutes the predominant sense for information acquisition pertaining to the external environment. Individuals need to use their eye movement, in an effective pattern, to direct a centralised region of visual acuity towards task relevant information (Land & Fernald, 1992). The way that eyes are used to seek and pick-up relevant information from the scene to guide action or performance is known as visual strategy (Henderson, 2003;

Williams *et al.*, 2004). Visual strategy ensures that high quality visual information is available when it is required; it also simplifies a variety of difficulties in this regard. Visual search behaviour is typically examined through the use of an eye movement system. Eye movement provides a sensitive, real-time behavioural index of an on-going visual (Henderson, 2003), and that variables such as eye movement latency and duration reflect the importance of the information relevant to the task. In order to obtain such information, the eyes need to move to the object of interest (point of regard); different types of eye movements are known; the functions of each type of eye movement are introduced below.

1.8.1 Eye movement types

The major eye movements that the human eye performs are saccades. Saccades are rapid, ballistic movements of the eyes frequently used in gaze shift (Wang & Stern, 2001), with velocities as high as 700°/s (Carpenter, 1988). During everyday activities, about three saccadic eye movements are made per second (Foulsham *et al.*, 2011); such movements are made largely unconsciously; however, they can be easily observed by looking at the eyes of another person while performing a certain task. Visual sensitivity is reduced during eye movement, and this phenomena is called saccades suppression (Matin, 1974). During saccades, only a blur can be perceived, and no new information can be obtained, since the eyes move very quickly across the stable visual (Rayner, 1998). Saccades range in amplitude from the small movements made while reading, for example, to the much larger movements made while gazing around a room. It can be elicited voluntarily, but takes place reflexively whenever the eyes are open, even when fixated on a target.

Saccades constitute the method we employ to relocate our direction of sight; a small change in visual direction is made by saccades only, while a greater change is made with the assistance of head movements (Land, 2004). Between saccades, the eyes remain relatively still; during this period, visual information can efficiently be taken; this phenomena is termed as fixation (Rayner, 1998). The eyes should remain completely still during fixation, except for some micro eye movements (Duchowski, 2007; Holmqvist *et al.*, 2011). The duration of each fixation is supposed to represent the amount of cognitive processing, whereas the point of fixation is assumed to indicate areas of interest (Williams, 2002). Holmqvist *et al.* (2011) states that fixation can last up to several seconds.

In addition to saccades, there are three other types of eye movement: *smooth pursuit*, *vergence,* and *vestibular* eye movement. *Smooth pursuits* occur when the eyes follow a target/object that moves smoothly and not too quickly (Rayner, 1998; Duchowski, 2007). For instance, following a ball passed slowly between two football players would entail such a movement. However, smooth pursuit movement in the absence of a moving target is difficult and requires highly trained observers. Unlike the previous two types of eye movements in which both eyes move in the same direction, *Vergence* movements entails the movement of both eyes towards each other aligning the fovea, in order to fixate on a nearby or far away object. This type of eye movements is responsible for the generation of convergent and divergent eye movements. An additional type of eye movement is the *Vestibulo-ocular*. This type of eye movements occurs when the eye fixates on a target and the head moves from side to side. In this movement, the eyes move the same distance as the head, but in an opposite direction.

Although these types of eye movements are important, saccades eye movements are more relevant in the typical information processing tasks (Rayner, 1998); in addition, Hayhoe & Ballard (2005) and Foulsham (2014) stated that saccades eye movements and fixation become important measures of assessing visual attention. Furthermore, Micklewright *et al.* (2016) has suggested that measurement of saccades eye movement and fixation can reveal the importance of the information acquisition processes involved in self-paced exercise tasks and that both eye fixation and fixation frequency could be used to indicate the importance of a certain point of interest.

In sports activities, various factors have been found to affect the visual behaviour and information selection processes, such as performer’s skills’ level, the task, and the surrounding environmental constraints (Williams *et al.*, 1999; Davids, 2002; Williams *et al.*, 2004). The aims of the task determines the usefulness of information, and therefore, the search pattern; moreover, the number of relevant objects in a task may affect the visual search behaviour (Huys & Beek, 2002). Therefore, depending on the task function, researchers have divided the manner of search of visual behaviour employed by athletes, focusing on externally-paced tasks, that is, a task or skill determined by factors outside the control of the performer that requires a fast anticipation, decision-making, and reaction (Singer, 2000), for example, team ball games and table tennis. Whereas, others have focused their efforts on self-paced activities, such as shooting a rifle or free throw in basketball, considering it as a stable actions.

1.8.2 Externally paced tasks

Several studies have investigated the visual search strategy in externally paced sports activities such as football. In these activities, a wide focus of attention appears to be beneficial in attending to relevant cues and extraction of information from a dynamic and open environment (Williams *et al.*, 1994). Williams *et al.* (1994) found skilled football players to be quicker than less skilled players in predicting the destination of the impending pass, when they were asked to anticipate the direction of an opponent’s pass using a dynamic film displayed on a large video screen. Moreover, the skilled players demonstrated better search strategies by making themselves aware of opponents’ positions and movements (Williams *et al.*, 1994). In a follow-up study, Davids & Williams (1998) investigated the search patterns one-versus-one and three-versus-three football players, using an eye movement system. Differences in search behaviour were found in the one-versus-one situation, with more fixation time spent on the opponents hip and the ball for the skilled players, in comparison to the less skilled, concluding that the hip region furnishes important information about the direction of the opponents’ movement (Williams & Davids, 1998). Furthermore, these studies reveal that search pattern differs even within the task, depending on the number of players involved in the action, the distance between them, and the distance between the player and the ball. For instance, in situations such as three-versus-three, the player may have relatively more time to search for relative information; therefore, this might result in different fixation durations than one-versus-one situation. Visual search strategies of basketball, tennis, and cricket players were also investigated. Singer *et al.* (1998) observed a considerable variability in search behaviour between skilled tennis players, in which some players tracked the ball during the first portion of its flight and then picked up the ball after it bounced, while other players fixated on the first portion of the ball flight before moving the eyes to the expected ball bouncing area. The key point of the above discussion is that different tasks and situations lead athletes to demonstrate different visual strategies and that eye saccades movement, fixation frequency, and duration in such a dynamic task in which external factors determine the performance differ from those adopted during self-paced task.

1.8.3 Self-paced tasks

The selective visual search strategy in self-paced tasks differs significantly from those in externally paced tasks. In such activities, the individual may pick up information from fewer sources of information prior to initiating the action to maintain the required level of concentration, so as not to be distracted by irrelevant task information (Williams *et al.*, 2004). It is been known that in such tasks, the period preceding the initiation of the action is rather important, suggesting that this period represents the time spent in programming the ensuring response (Singer, 2000). Vickers, (1996: p 348) has identified this period as a ‘quite eye period’ defined as a ‘portion of the final fixation from onset to the first observable movement of the hands into the shooting action’; this might indicate the time spent by the individual to self-regulate to reach an optimal state of mental preparedness. Williams *et al.* (2004) examined the role of the 'quite eye period' in experienced and novices billiard players. The study showed that the quiet eye period in experienced players was longer than novices; further, an association between longer quiet eye period and successful shots were observed. The gaze behaviour was also examined in basketball players during the performance of free throws shots (stable action) and a jump shots (dynamic action) (DeOliveira *et al.*, 2008). The study reported that the low- style shooters looked at the target for half the time in the dynamic shot task, in comparison to the free shot, indicating differences in visual behaviour according to the task constrains.

In cycling the visual behaviour has also been examined; for instance, Vansteenkiste *et al.* (2013) studied cyclists' visual behaviour for three different speeds in three different lane width. The study found that both, cycling speed and lane width had an effect on fixation location that shifted towards the near pathway on narrow lanes, towards irrelevant areas on wider lanes, and towards the goal at a higher cycling speed. In a follow-up study, Vansteenkiste *et al.* (2014) examined the influence of high and low quality road on visual behaviour during cycling. The study found that gaze was evenly distributed over different areas of interest on a high-quality road, while it was shifted towards the cycling path on a low quality road, suggesting that such a pattern is due to the dynamic stability, meaning that participants require more steering adjustment during low-quality paths, comparing to high-quality paths. Visual behaviour was also investigated during cycling around a curve (Pieter Vansteenkiste *et al.*, 2013) and among children cyclists (Vansteenkiste, Cardon & Lenoir, 2015). Zeuwts *et al.* (2016) has also studied gaze behaviour during cycling; however, the study was designed to compare cyclists' eye-movement in the laboratory and real life as a validity and reliability study. To my knowledge, no previous research has studied visual behaviour to understand information acquisition as part of the perceptual-action processes in regulating pace during cycling. Eye tracking technology has provided useful insights about the role of visual behaviour in several domains; such a tracing methodology would help understand the information pick-up strategy that cyclists use during cycling, and thus, the information processing that results in decision-making. In the following section, I will briefly describe the eye tracking technology.

1.9 Eye-tracking

The study of eye-tracking was introduced over 100 years ago; however, it was not until 1970s when eye-tracking technology expanded rapidly, allowing eye movement measurements to be more accurate and more easily attainable. Advances in eye-tracking technology has enabled researchers to investigate the link between eye movements and cognitive processes (Jacob & Karn, 2003). Eye-tracking is a method that involves the process of watching where a person is looking; it detects and tracks the features of the eyes and their movements. The eye-tracking technology has been used to study and investigate human behaviour by observing and measuring eye movement, since it provides an insight into visual search pattern, problem-solving, and decision-making (Jacob & Karn, 2003; Mele & Federici, 2012). The technology of eye-tracking is used to observe and register eye movements activities, so that where a person looks at any given time and the order in which the eyes move ‘average fixation & fixation frequency’ from one location to another can be measured (Poole & Ball, 2005). Eye-movements are thought to reflect the interaction between perceptual and cognitive processes (Richardson & Johnson, 2008). The measurement of eye movements using eye-tracking devices has therefore been of great interest to researchers, especially, those interested in revealing information about acquisition patterns and/or understanding the way in which visual information relates to other cognitive or behavioural processes. For example, Grant & Spivey (2003) used headband-mounted eye-tracking devise to study the relationship between eye movements and problem-solving; the result showed that certain patterns of eye movement occurred when participants were close to solving the problem.

Different types of eye-trackers are available, such as the EyeLink system (desk-mounted), and the SensoMotoric Instruments, SMI head-mounted, or eyeglass high-speed cameras. These types of eye-tracking differ based on the manufacturer, hardware, recording software, and presentation tools. Each type is suitable for different settings and aims and offer different advantages; for instance the EyeLink 1000 desk mount’s benefit is that no electronics are near the participant’s head as the camera is placed 40-70 cm far from the eyes. However, visual fixations are straightforward, because the tracker operates in a fixed reference frame; this limitation made it suitable for certain experimental contexts. Advances in mobile eye-tracking equipment and analysis allow for investigating eye movements during natural behaviour and everyday lives. Recently, the SMI eye-tracking glasses was designed to be used in different environmental studies, capable of performing eye-tracking in board daylight; such a development leads eye-tracking to be used widely in both laboratory and field based studies in different areas including sports; a variety of eye-tracking methods and measures are comprehensively reviewed elsewhere (Holmqvist *et al.*, 2011).

Eye tracking has been used in areas such as neuroscience, psychology experimental, human factors, computer science (Mele & Federici, 2012), social cognition, and decision-making (Richardson & Johnson, 2008). It has also been used to investigate psychological processing. Rayner (1998) studied eye movement in reading using an eye tracker, and found that textual, contextual and typographical factors may affect eye movement performance, as well as the average duration of eye fixation during study. Eye-tracking has also been used task with natural scenery, such as driving, sports, virtual reality (Foulsham, 2014; Zeuwts *et al.*, 2016), daily activities (making tea) (Land *et al.*, 1999). In addition, Alnæs *et al.* (2014) have used eye-tracking to measure the pupil size, mental effort, and brain activity during multiple objects tracking. Alley *et al.* (2014) used an advanced eye-tracking technology to understand the way users interact with and attend to personal activity information; they compared the attention of feedback and recall out-come during tailored physical activity advice in video versus text format using a modern version of 'TobiiX 120' eye tracker. Similarly, eye-tracking has been incorporated into numerous decision-making studies. Glaholt & Reingold, (2009) studied the role of eye movement and looking behaviour in visual decision process, and more recently, Gidlöf *et al.* (2013) monitored the visual behaviour of costumer in natural environment (Supermarket) during decision-making. In a review, Glaholt & Reingold (2011) suggest eye-movement monitoring as a valuable methodology of tracing information in the process of decision-making. The technology of eye-tracking has also been used as a methodology to optimize performance and visual behaviour. In sports, Land & McLeod (2000), showed the way in which cricket players predict the ball's timing and placement through knowledge supplied by eye fixation, and they were able to differentiate between perfect and poor batsmen through a stumpy latency for the first eye movements. The technology of eye-tracking has also been used to differentiated in visual behaviour and eye movements between novices and experienced athletes in different sport activities such as tennis (Goulet *et al.*, 1989) and basketball (Wu *et al.*, 2013).

In the last decade, eye-tracking technology has advanced significantly, and improved from having monocular to binocular tracing function. Both Gidlöf *et al.* (2013) and Micklewright *et al.* (2016) have agreed that recent advances in eye tracking technology have improved the mobility of devices, the resolution of the eye movement measurements, and rendered the eye-tracking useful in laboratory as well as in the field based studies. While, as previously discussed, developments in pacing theory have largely drawn upon deception and blinding experimental methods, mobile eye-tracking provides an opportunity to make direct measurements of the external referents that endurance athletes attend to. Further details of eye tracking technology and its application in pacing research are presented in methodology chapter section 2.3.7.

1.10 Summary of the literature review

Ultimately, athletes who can better tolerate a particular intensity are more likely to perform at a greater level than those athletes who cannot. Pacing strategy and the ability to control the rate of fatigue are known to be major contributors to maximising performance of moderate and long duration athletic events. As proposed by the CGM (Noakes *et al.*, 2006; Noakes *et al.*, 2004; St Clair Gibson & Noakes, 2004; St Clair Gibson *et al.*, 2006; Lambert *et al.*, 2005; Tucker, 2009), pacing strategy is thought to reflect homeostatic control resulting from anticipatory/feedforward and feedback mechanisms.

There are several factors that influence the pacing strategy, some of which relate to internal physiological changes that occur during exercise and others to external environmental and performance feedback. Most of the pacing models have emphasised on the importance of the knowledge of the endpoint in regulating pacing strategy that has been mainly derived from deception or/and blinded studies of performance feedback information (Jones *et al.*, 2013). However, Renfree *et al.* (2014), have suggested that pacing is a decision-making process; they states that pacing can be regulated by making-decision based on the most relevant information. Moreover, a recent review has initiated a framework according to which pacing is a continuous decision-making process that depends on the interaction between perception and action (Smits *et al.*, 2014).

A new direction of multidimensional process in studying and understating pacing strategy has been recently proposed by Micklewright *et al.* (2016). The framework suggests the dual process theory as an alternative for investigating the control of athlete pacing. One aspect of the dual theory is the information acquisition process, which it could be measured via measuring eye movement. Action selection is an important part of the decision-making process (Smits *et al.*, 2014), and such an action is affected by the availability of information such as certainty about exercise duration and knowledge of the end point that have been (as previously mentioned) indirectly measured. The available information may be assessed differently by participants depending on the performance type, task objectives and expertise. Visible information might be at different level of interest between subjects, a piece of information could be important for one person but not at all to another (Gidlöf *et al.*, 2013). Recent advances in eye-tracking technology have improved the mobility of devices, using such technology with cyclists both in the laboratories and outdoors would allow us understand what sort of information is more important for participants. Therefore, through a series of novel studies, this thesis will explore the concept of measuring eye movement ‘fixation duration and frequency’ to determine what athlete look at during performance which will help to reveal the information acquisition pattern, unexplored by the previous information manipulation studies, and determine its importance in revealing the informational cues participants consider as important during self-paced exercise, and whether such information alter pacing and performance.

2 CHAPTER 2: Methodology

2.1 Introduction

The general methods employed within this series of studies are outlined in this chapter. Specifics relating to their application are contained within the respective chapters.

2.2 Pre-test procedures

2.2.1 Ethical approval

Institutional ethics approval was obtained from the Essex University School of Biological Science. All participants were provided with information sheets that described the purpose of the study, for each study, and gave written informed consent to participate (appendix 1).

2.2.2 Participants

Tow types of participants were included in this thesis, novices and experienced cyclists. The experienced cyclists were recruited from the University of Essex cycling club, Colchester Rovers cycling club, VC Revolution cycling club and Clacton-on-Sea cycling club. The experienced cyclists had previous cycling experience of participating in competitive 10-mile time-trials and in real cycling competitions. Experienced cyclists were included in study (1,2,3 and 4). Nine participants were recruited for more than one study, in which three participants participate in study (1&2), two participants in study (1&3), three participants in study (2,3&4), one participant in study (1&4). Novice cyclists were recruited from the University of Essex staff and student population and, although they could all ride a bicycle, they had never trained for, or participated in competitive cycling events of any kind. In study 1, an attempt to neutralize confounding physical conditioning variables was achieved by recruiting novice participants who had engaged in aerobic training (not competitive cycling) for a similar history and weekly duration as those in the experienced condition. Perfect matching of aerobic fitness was not possible but participants in both groups were well conditioned with the primary differentiating factor being their experience of competitive cycling. Detailed information about participants is given in each chapter.

2.2.3 Pilot studies and experimental protocol testing

The intended methods of data capture in the series of planned studies presented significant technological and design challenges that required, what turned out to be, extensive protocol and pilot testing. Mobile eye-tracking during high intensity cycling, albeit in a controlled laboratory environment, had several associated challenges including: i) difficulties in keeping the device calibrated during the entire time trial due to interference from head movement or perspiration; ii) establishing the best way of displaying feedback or selected feedback to participants with sufficient angular separation and position such that it was possible confidently derive information acquisition behaviour from the eye-tracker data; iii) synchronization of the eye-tracker with other instruments such as the SMI power crank, heart rate monitor and cycling ergometer. For the field-based study the challenges were even greater given that the calibration, information display and synchronization issues had to be sufficiently resolved such that they could be replicated during road-based time-trial cycling. An overview of the protocol and pilot testing is given below.

Protocol testing was carried out to determine the best method of displaying feedback to participants so that it was easy for them to view and of sufficient size and separation for the eye-tracker to capture clear video of the scene and differentiate between information feedback categories. Initial intentions were to display information feedback only to participants without any video simulated cycling course, obscured using a bespoke letterbox projector filter (Figure 2-1). However, during pilot testing it was found that, in the absence of video course simulation, participants tended to look continuously at other objects in the laboratory including projected performance feedback. To avoid such effects influencing information acquisition behaviour, it was decided to present video simulation together with the various performance feedback information and thus the projector letterbox filter was not used.

With regard to size and separation of the projected course and information, it was found that projecting information onto a 2.1 x 1.5 m screen with the participant positioned on the cycle ergometer approximately 3 m away and with each feedback source approximately 0.25 m apart, This provided a clear and easily readable image with sufficient angular separation between information sources. It was also found that by offsetting the screen to the right of the cycle ergometer, participants would have to make a head movement to look at feedback sources thus adding confidence that the eye-tracking data represented deliberate attempts to acquire information rather than gaze behaviour because of natural field of vision.

Figure 2-1 The initial experiment design.

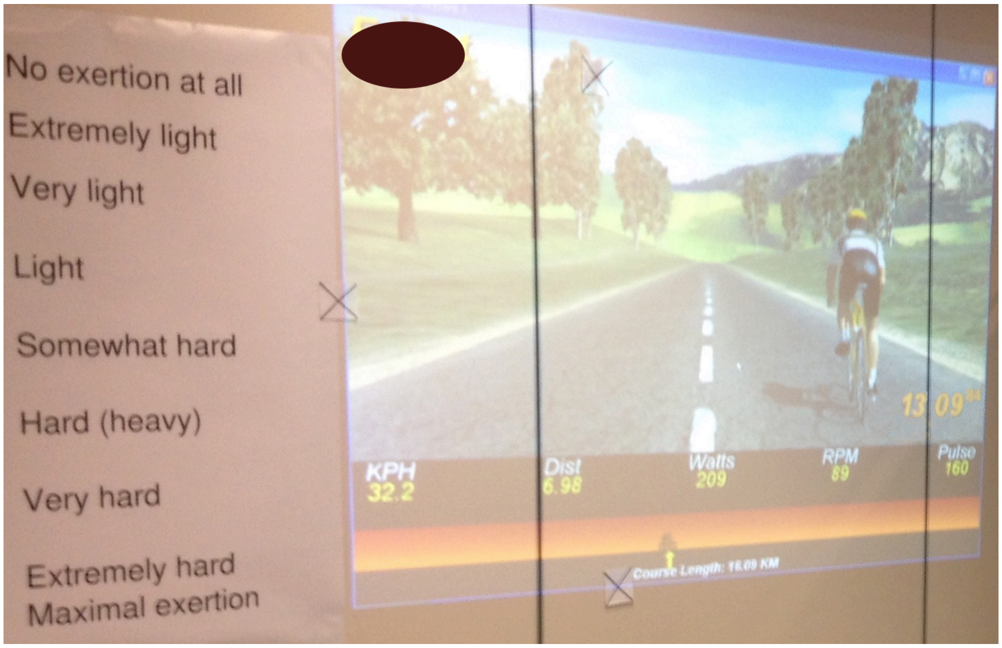

[redacted]

Figure 2-2 A simulation video of a flat time trial cycling course with presented information. .

A further issue we faced during the pilot study was perspiration knocking out the calibration of the eye-tracker, the likelihood of which increased with time trial progression. The issue was that if a small droplet of perspiration came into contact with any of the eye-tracker optics or associated recording scene recording equipment, it would knock out calibration or render the video data unusable. To resolve this all participants during all trials were asked to wear a sport headband (figure 2-3). However, participants differ in the sweating level, and even the headband was not effective to minimize the issue for a few participants. Therefore, some participants were exclude from some of the studies. Further information about number of participants excluded from each study is explained under participants' section in the experimental chapter.

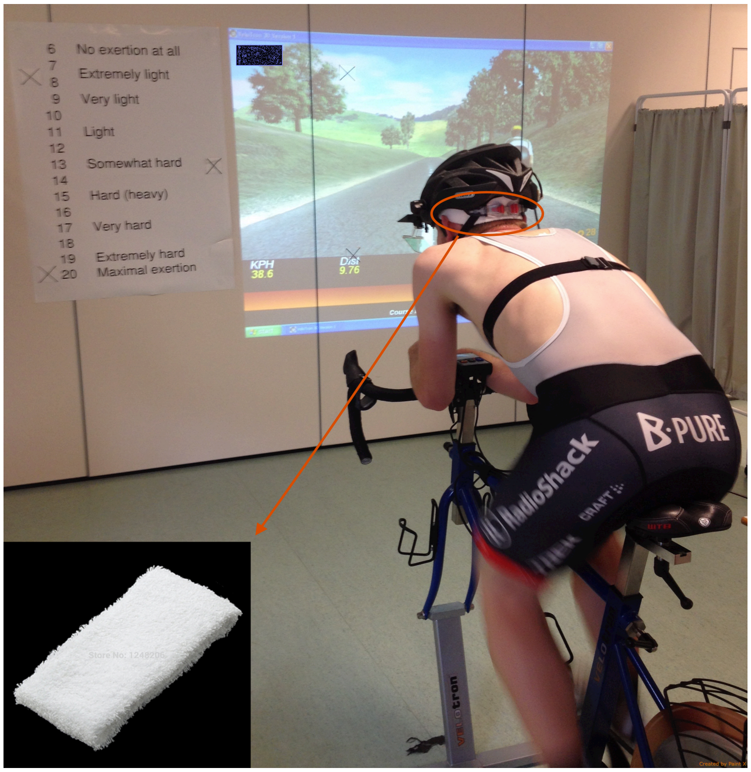


Figure 2-3 Participant during a 10 mile TT wearing a sport headband to protect the eye camera screen from sweat.

During pilot studies, we notice a further practical issue of using eye-trackers during exercise is the possibility of losing calibration as a result of sudden head movements that leads to a move in the device. This problem was minimized by: A) Making sure that the device is well fitted to the participants head. B) In case of losing calibration the device was readjusted by the researcher, therefore; the researcher had to carefully observe the experiments and closely monitor the recording device (computer).

One of the most common issues in using the eye tracking in general as well as in exercise tasks is the difficulty or impossibility calibrating the device to some participants. Therefore, five participants, in total, were recruited but not included in the studies due to difficulty calibrations.

During lab experiment, the calibration was checked before the start of the TT, a few times during experiment by asking subjects to look at a certain point such as on of the calibration sign or any other point using a laser-pen and at the end of experiment. However, during the road experiment the calibration was checked before and after the TT.

Numbers of pilot studies were also conducted for the field study ‘road bike study’. The aim of the pilot studies was to measure the reliability and accuracy of the SMI eye-tracking device during road cycling time trial. During the first two pilot studies, we found that the SMI device did capture gaze behaviour during a 10 mile road time trial with sufficient quality of data. It did however become apparent that displaying various types of feedback information on a single device did not provide sufficient separation to confidently discriminate between the information sources participants were looking at. In order to improve separation, a special rig was constructed making it possible to display each performance information category on a separate device. Thus, several devices were mounted on a secondary handle bar (See subsection 6-2-4).

A final difficulty of the field study was associated with the cycling position that caused some participants to glance forwards while in a face-down position i.e. looking over the glasses frame. Because of the vertical range limitations of the eye tracker, this resulted in device momentarily not being able to track the eye position which causing short periods of data blackout. This issue was minimized by asking participants to look through the middle of the eye glasses to make sure that the scene camera is in a good recording position. While this did improve data capture, it did not completely eradicate eye-tracking blackouts which, for analysis purposes, were categorized as unknown eye gaze as explained in subsection 6-2-4.

2.2.4 Final laboratory design

The cycle ergometer was positioned such that the handlebar stem riser was 3 m perpendicular to the plane of the screen. The projected screen size was 2.1 m wide by 1.5 m high with the bottom border of the projection running 1 m above and parallel to the floor. The screen was offset to the right of the natural forward field of vision of the cyclists with a vector displacement of 8° at 3.03 m for the left border of the projection and 40° at 3.91 m for the right border (visual arc 32°).

Incorporated into the projection beneath the simulated time-trial video, were five fields of real-time feedback information which, presented from left to right, were speed (km.hr^{-1}), elapsed distance (km), power output (W), pedalling cadence (r.min^{-1}) and heart rate (b.min^{-1}). The row of five feedback information fields were 0.375 m above and parallel to the bottom border of the projection or 1.375 m above the floor. The vector displacement of the centre of each information field from the handlebar stem riser was speed (9.5°, 3.04 m), elapsed distance (18.1°, 3.16 m), power output (26.0°, 3.34 m), pedalling cadence (32.9°, 3.57 m) and heart rate (38.9°, 3.86 m). Elapsed time (min:sec) was displayed above the heart rate field (3.0°, 0.2 m). Angular separation of the information fields was at its most acute 3° (elapsed time – heart rate) and at its least acute 8.6° (elapsed distance - speed), well beyond the manufacturer-defined eye-tracker spatial resolution of 0.1˚ and gaze position accuracy within the nearest degree. An A0 sized RPE scale was also displayed to the left of the projector screen.

Figure 2-4 The final laboratory design.

2.2.5 Experimental design

Studies (1,2 and 3) were conducted in the Sports Science laboratories at the University of Essex. A three-way mixed experimental design was employed in study (1), while a repeated measure design was used in study (2 &3). The repeated measure design is advantageous in that fewer participants are needed to achieve the required statistical power compared to an independent groups design due to less unsystematic variation between groups (Field, 2005). There is however greater potential for learning, fatigue and order effects, and any potential confounding variables must be strictly controlled. To achieve this, the order of experimental trials in study (2,3) was randomized and counterbalanced and practice trials were included where appropriate. Repeat trials were conducted at the same time of day ± 1 hour, separated by a minimum of 3 and a maximum of 10 days, and all were conducted within an allotted time frame for each study. A descriptive ‘exploratory’ design was used in study 4. Prior to each visit, participants were required to refrain from caffeine (for at least 6 hours), alcohol (for at least 6 hours), exhausting exercise (for at least 24 hours), which were addressed in information sheet that was sent to all participants (appendix 3).

2.3 Apparatus and procedures

2.3.1 Anthropometry

Stature was measured to the nearest cm using a wall-mounted stadiometer (Seca, Bonn, Germany) using the stretch stature method (Marfell-Jones *et al.*, 2006) Briefly, this required participants to stand with heels, buttocks and the upper part of the back in contact with the stadiometer. The participants’ head was then aligned in the Frankfort plane. The participant was instructed to inhale and hold a deep breath whilst the experimenter applied gentle upward lift through the mastoid processes and adjusted the headboard to make firm contact with the vertex (Marfell-Jones *et al.*, 2006). Body mass was assessed to the nearest 0.5 kg using a precision balance scale (Seca 200, Vogel and Halke, Germany) with participants wearing lightweight exercise clothing and no footwear.

2.3.2 Questionnaires

In all studies, participants were asked to fill out physical activity readiness questionnaire “PAR-Q’ (appendix 2). The questionnaire fit people between 15-69 years and consists of 7 questions, participants were asked to read and answer the questions carefully and honestly. Participants were excluded from the study if they had answer ‘YES’ to one or more questions. Participants were also asked to complete a questionnaire about their training history; the questionnaire was designed by the researcher and was aimed to collect information about participant's previous experience and training history (appendix 4).

2.3.3 Cycling time-trials

A majority of studies assessing the biological basis of self-pacing have used laboratory based simulated cycling time-trials. This paradigm allows for the high frequency capture of data whilst the athlete competes in an exercise task that is more ecologically valid than an externally controlled protocol such as an incremental or constant load task (Marino, 2010). Cycling exercise also allows for conscious and subconscious oscillations in power output through variations in cadence, the force exerted by the individual and changing the gearing ratio. The controlled environment of the laboratory increases the reproducibility of such trials, although does not mimic the effects of wind, gradient and other ambient conditions experienced during outdoor TT(Swain, 1997).

Endurance cycling time-trials range in distance from 1 to 4 km in track cycling, and from 3 to 100 km in road cycling (Jeukendrup *et al.*, 2000). In road, cycling distances of 16.1 km and 40 km are common, and triathlon sprint and Olympic distance events have 20 and 40 km time-trials respectively. Consequently most researchers have employed cycling time-trials of between 4 and 40 km to study self-pacing (Atkinson & Brunskill, 2000; Smith *et al.*, 2001; Les. Ansley *et al.*, 2004; Greg Atkinson *et al.*, 2007; Ham & Knez, 2009).

Several cycle ergometers are now commercially available that allow for the high frequency capture of power output and cadence data in both laboratory and field settings. The cycle ergometer used in the series of studies one, two and three (study four was a field based and thus utilized a unique protocol) was the Velotron Pro cycle ergometer (Racermate Inc, Seattle, USA) (Figure 2-4). The Velotron Pro is an electromagnetically braked cycle ergometer that uses an eddy current braking system around a large diameter copper flywheel to control resistance. An adjustable electronic gearing system is available to the cyclists and operated through computer-controlled software (Velotron Coaching Software 2008, Racermate Inc.).

The ergometer is calibrated using an “Accuwatt” run down procedure. This requires deceleration of the flywheel from a speed of 36 km·h^{-1}. The rate of decline of angular velocity of the flywheel is used to confirm calibration within the range of the factory settings. The manufacturer claims the accuracy of this system in measuring power output is ± 1.5%. Abbiss *et al*. (2009) assessed these claims during constant load, incremental load and repeated sprint protocols using a calibration rig. During constant load and incremental trials the ergometer was accurate to < 2%, and measurement error was similarly very low (< 1%) over a range of intensities between 150-600 W, with more error at intensities above and below this range. During trials with repeated rapid accelerations to power outputs up to 1700 W, the ergometer under-reported the initial surge in power by up to 55%, probably as a consequence of having to accelerate a heavy flywheel (Abbiss *et al.*, 2009). The Velotron Pro ergometer thus provides accurate measurements of power during trials where the fluctuations in power are relatively minor, but does not provide an accurate measurement of peak power. Velotron outcomes were downloaded via a notepad file then converted to an excel sheet and were calculated as an average of either 4-km segment in study 1 or 1-km segments in study (2,3).

The 16.1 km ‘10-mile’ time trial task was performed in study 1 and 4, The 16.1 km time-trial duration was selected as this is a common format used in the UK and one which the experienced cyclists used in this study were most accustomed. While 5 km time trial task was performed in study two and three, this distance was selected due to the huge amount of data and gaze video in which the researcher had to analyse it frame by frame for every single participants and for multiple time trials, which required a considerable effort and takes a lot of time.

Figure 2-5 Velotron Cycling Ergometer used in experiments.

2.3.4 SRM Training system

The SRM POWER COTROL7 system was used in study 4 to measure the performance (figure 2-5). The SRM power meter was installed to the original crank, and the cadence magnet was positioned on the underside of the bottom bracket and between 21-51 mm from the centre pointe. The speed sensor was also installed into the fork, while the speed magnet was attached to the spoke of the front wheel; all the devices were attached according to manufacture instructions by a professional technician. All the sensors were paired to the power control according to the manufacture instructions. Before each time-trial the SRM was calibrated to the power control. All the data was downloaded and exported to an excel file using the SRM software program.

Figure 2-6 SRM power control 7.

2.3.5 Bike computers

Three VDO bike computers were also used in study 4 (Figure 2-6). The sensors were attached to the bike wheel; the computers were used to provide participants with performance information, but no outcome data was used. The accuracy of the devices was tested during pilot study.

Figure 2-7 VDO bike computer used in study 4.

2.3.6 Psychophysiological measurement

2.3.6.1 Heart rate

Heart rate (HR) was recorded in study (1,2,3 and 4) during all cycling time trials every (120) milliseconds using a chest strap Polar Accurex Plus heart rate monitor (Polar Electro. Kempele, Finland) connected via wireless to the Velotron software in study (1,2 and 3) which heart rate data was exported with Velotron data. The heart rate data was recorded every (0.5) second in study 4 using SUNNTO AMBIT 3 PEAK. The data was downloaded online via movescont.com and exported as an excel file after the trial.

2.3.6.2 Rate of perceived exertion

Participants were asked to provide an overall rating of perceived exertion in study (1 and 2) using the Borg 6-20 RPE scale. All subjects were familiarised with the RPE scale, which was explained in accordance with published standardised instruction (Appendix 5).

2.3.6.3 Rating of fatigue

Participants in study ‘3’, were asked about rating of fatigue using the ROF scale that consists of 11 numerical points which range from 0-10. In which 0 represent ‘NOT FATIGUED AT ALL’ and 10 represent ‘TOTAL FATIGUED & EXERTION NOTHING LEFT’. Subjects were familiarized with the ROF scale according with published standardized instruction, currently in press (Appendix 6).

2.3.7 Procedure

Before each time-trial, participants were asked to refrain from ingesting caffeine for at least 6 hours, alcohol for 24 hours and food for 2 hours prior to testing. Participants were also asked not to train or engage in heavy physical work for 24 hours before testing. On the first laboratory attendance, each participant had their body mass and stature measured and was briefed as to the requirements of the trial but not the purpose of the study. Participants also completed a short training history questionnaire, and physical activities readiness questionnaire (previously mentioned). After all tests had been completed, participants were debriefed about the purpose of the study.

2.3.8 Gaze and visual behaviour

Two main devices were used to measure visual behaviour.

2.3.8.1 SMI-iViewX

A SensoMotoric Instruments SMI iViewX Head Mounted monocular Eye Tracking Device (HED) was used in study (1 and 2) (Figure 2-7, A). This device consists of two camera lens mounted on a cycling helmet, the right camera record the eye movements of the participant left eye (Figure 2-7, A1), while the left camera record the scene on which the participant is looking at (Figure 2-7, A2). The system tracks eye movements using pupil and corneal reflex so that each participant's centre of vision can superimposed onto the recorded scene, thus enabling timed measurements to be made of what they were looking at (Figure 2-2 B). The monocular HED has a sampling rate of 50 Hz, and a gaze tracking position accuracy (0.5-1 degree). According to the experimental goals, a wide-angle lens (3.6mm) was used for the scene camera. The eye tracker was calibrated on the participants' left eye using the same distance of the presented information an in accordance with the manufacturer's instructions.

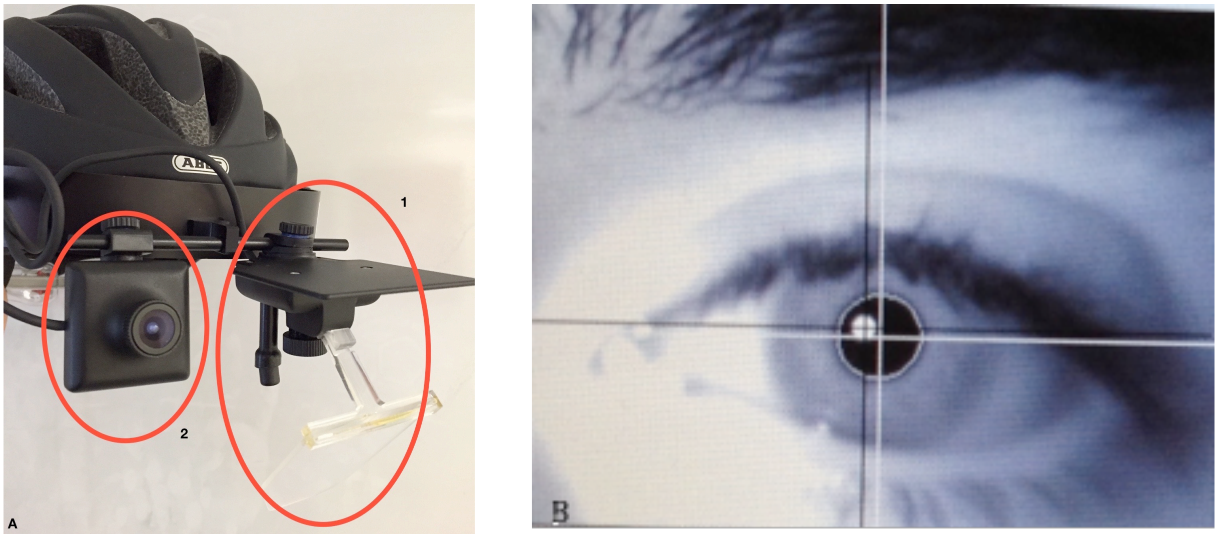


Figure 2-8 SMI-iViewX device, (A) the scene and the eye camera, (B) eye pupil a corneal reflex.

2.3.8.1.1 Calibration

In order to relate the pupil position to a point in the subject’s view, a calibration is required. Three different types of calibration are available with this software (3, 5, and 9) points. Five distinctive targets (sticker shaped like x) were used in study (1,2). A wall was used to display the target points, which was about 2.5 m far from the Velotron. After taking subjects to the right position on the Velotron, they were asked to wear cycling helmet and then instructed to look at the centre point (X1 in Figure 2-8). When the white crosshair, marks the pupil, and the black crosshair, marks the corneal reflex, become close, the cross on the computer will surround by a diamond shape which indicates a stable fixation, in this point the calibration must be accepted and move to the second point (Figure 2-8). This procedure was repeated with the all-remaining points in the same way. When the calibration is completed a gaze cursor will display indicating the gaze position, upon a successfully completion of the calibration, the recording become ready to start.

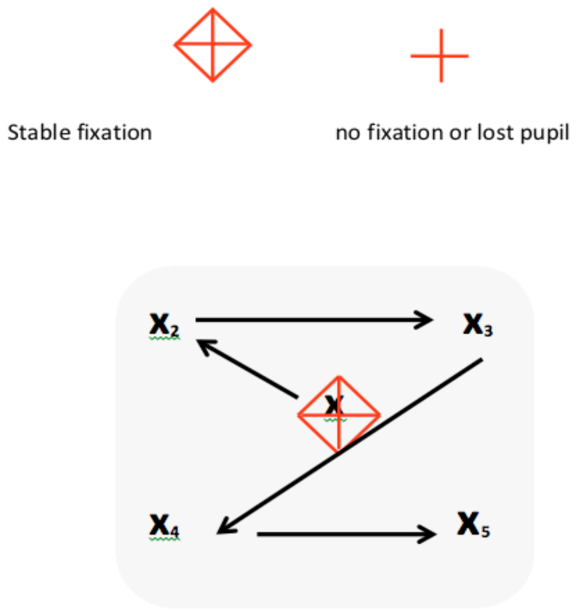


Figure 2-9 Display eye stable and unstable fixation and calibration order

2.3.8.2 SMI-iView ETG

The iView ETG system provides a human interface that is a non-invasive video-based glasses-type eye tracker with integrated audio recording. This device can be worn as a normal eyeglasses and included 3 cameras, a high definition scene camera and two eye cameras (Figure 2-9), with eye tracking technology that capture the eye movement of participant wearing it. The device also comes with convertible eyeglass and an exchangeable nose rest. This device is characterized by a quick and easy set-up and easy to wear as a pair of glasses. A further feature of this device is that it comes with a recording unit (based on Samsung Galaxy S4) make it easier for field design experiments. The binocular SMI device has a gaze tracking accuracy of 0.1 degree for over all distances (automatic parallax compensation), a gaze tracking range angle of 80 degree horizontally and 60 degree vertically, and a sampling rate of 120 Hz binocular.

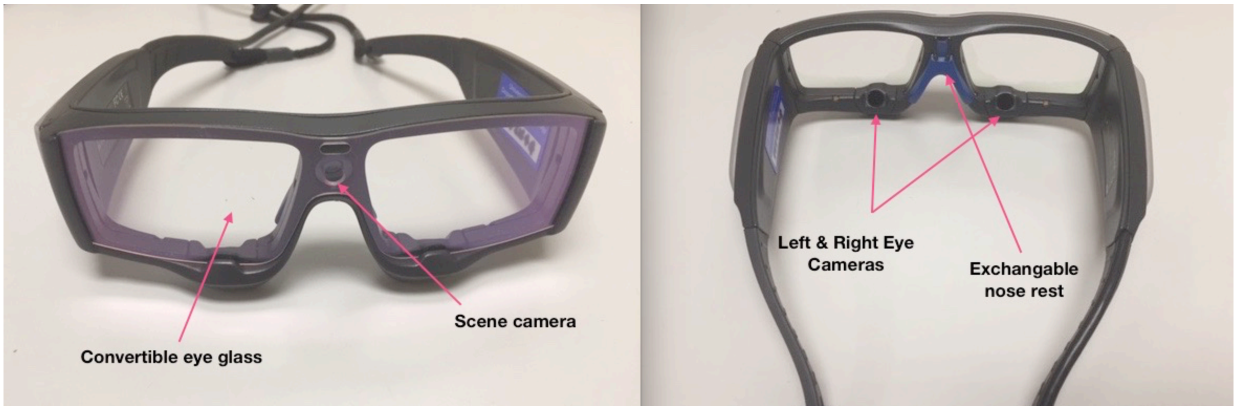
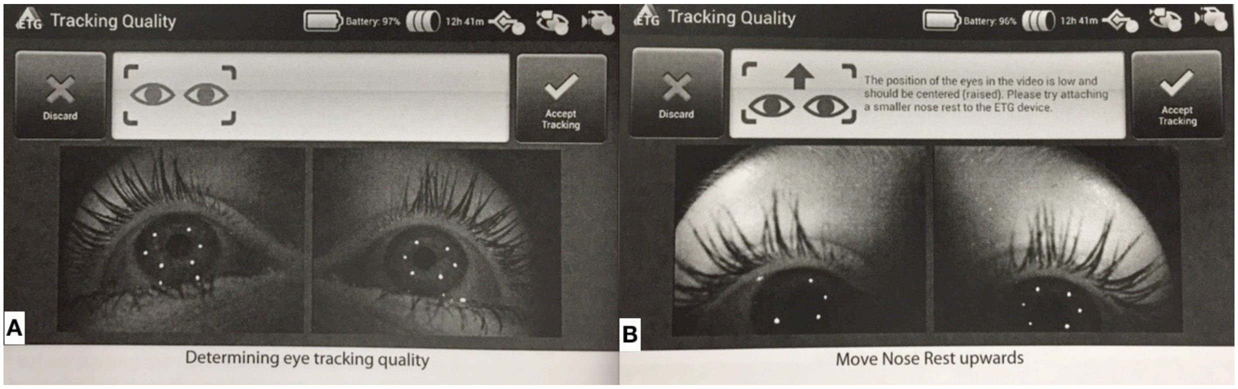


Figure 2-10 SMI Eye Glasses.

2.3.8.2.1 Calibration

As mentioned before, this device differentiated by having an easy calibration mode. It comes with three-calibration modes (0, 1, and 3 point) calibration, a three point calibration mode was used in study (3 & 4), which can result in a more accurate data, however, it takes a bit longer before the experiment task can be started. To perform calibration, three (X) marks were display in a will at a distance of 2.5 m; Participants were asked to focus on one of them (no order is required, however the objects should display as a triangle shape, no matter which direction is the head of triangle). However, before starting the calibration and to achieve good eye-tracking quality, the SMI-ETG should sitting correctly on participants nose as a Nose Rest Indicator (Figure 2-10 A), If an arrow appear, the direction of the arrow indicates which direction the nose rest should be adjusted (Figure 2-10 B). The crosshair cursor will have a small number between (1-3) next to the cursor indicating the current calibration point, the mouse cursor is swiped to the dedicated target point participant is looking at and then click on it, the same process is repeated for point (2 & 3), and the calibration is accepted by clicking on accept calibration point. Before recording, subject was asked to look at a live target to validate the calibration and test the accuracy. The calibration was resetted and performed again when researcher was not satisfied with the calibration out-come. The calibration was performed in the lab in study 3, however, this process was performed on the wall out-side the laboratory in study 4 to make sure that the same weather condition was applied.



The position of the eyes in the video is low and should be centered (raised). Please try attaching a smaller nose rest to the ETG device.

Figure 2-11 Eye-tracking quality, A show's centred eye and nose position, B incorrect eye and nose position.

Moreover, the calibrations, in study (1,2 &3) was checked at the beginning of the time trial, at the middle and at the end of the task by either asking participants to look at one of the calibration point, or to follow a laser pointer pen. In the study four, due to difficulty chasing the calibration since the SMI was connected to a customized Samsung Galaxy S4 Smart recorder which was carried by the participant, the calibration was checked at the beginning and the end of the time-trial.

2.3.9 Video simulation

Participants were positioned in front of a large screen on which the RealVideo simulated cycling course was projected onto a wall and slightly offset to the right of the cycling. The projected video footage was coupled in a multiplicative way to the cyclists' actual power output such that any alteration in speed was instantly represented on the screen. Notwithstanding minor projector repositioning variances, the projected screen size was 2.1 m wide by 1.5 m high with the bottom border of the projection running 1 m above and parallel to the floor. Incorporated into the projection beneath the simulated time-trial video, were five fields of real-time feedback information which, presented from left to right, were speed (km.hr^{-1}), elapsed distance (km), power output (W), pedalling cadence (r.min^{-1}) and heart rate (b.min^{-1}). The size and separation of the projected information blocks facilitated clear differentiation in eye-tracker measurements. An A0 sized RPE scale was also displayed to the left of the projector screen.

2.3.10 Video analysis

A DivX converter program was used in study (1 & 2) to convert the videos so it can be viewable by video-coder program, while BeGaze program was used to convert recorded video in study (3 & 4), which required a special dongle-key. The eye-tracking videos for study (1,2,3 and 4) were subsequently reviewed and manually coded using Video-Coder2 program. Manual coding of eye-tracking data remains the state-of-the-art in active tasks (Vansteenkiste, Cardon, Philippaerts, *et* *al.*, 2015), and within-coder comparisons indicated that gaze location could be determined unambiguously. Reliability of similar methods have shown very good inter-rater reliability (Foulsham *et al.*, 2011). Due to the relatively low sampling rate of the eye-tracker, saccades could not be automatically detected, but fixations were only coded when data was within the same region for at least (≅ 100 ms). Eye gaze was coded by recording the start and end point of each entry into a new region of interest. This allowed us to determine the periods of time spent inspecting each region of interest; eye fixation times were manually recorded in milliseconds against predetermined categories. A different template was created depending on the study design and conditions to determine the number of categories, which vary between experimental studies and also within the same study, for example, between TT, this is well explained in each chapter. However, a category was created to capture all other objects of regard not corresponding to the presented information, for example, when participants looked at the laboratory floor or at laboratory equipment. Fixations of less than (≅ 100 ms), blinks and other periods of data loss (e.g. when participants looked at extreme angles) were also included in the 'other' coding category. This procedure allowed detailed coding of point of regard for the whole length of the time trial. Total gaze time and gaze frequency for each category was calculated on a participant-by-participant basis for the whole time-trial. Gaze frequency was defined as the number of separate eye fixations for each category, and total gaze time was defined as the accumulated time of all eye fixations for each category.

3 Chapter 3. Information Acquisition Differences of Experienced and Novice Time Trial Cyclists

3.1 Introduction

It is important for athletes to employ their available energy effectively to perform optimally and avoid fatigue during exercise, so that “all energy stores are used before finishing a race, but not so much that a meaningful slowdown occurs” (Foster *et al.*, 2003; DeKoning *et al.*, 1999; Hettinga *et al.*, 2007). Pacing strategy is an essential aspect of competitive prolonged athletic performance and refers to the variation of speed during an event by regulating the rate of energy expenditure (Foster *et al.*, 2003; Foster *et al.*, 1994; Foster *et al.*, 1993; Hettinga *et al.*, 2006). Where completion time is the measure of success, pacing strategy has an influence over success in events lasting longer than 60 seconds (Foster *et al.*, 1994).

Several factors are known to influence the particular pacing strategy that an athlete adopts including the duration of the event (Albertus *et al.*, 2005), presence of a competitor (Corbett *et al.*, 2012; Emily L Williams *et al.*, 2015), environmental conditions (Racinais *et al.*, 2015), previous experience (Mauger *et al.*, 2009a), perceptions of exertion (Ulmer, 1986), and the availability and veracity of performance feedback information (Mauger *et al.*, 2009b; Faulkner *et al.*, 2011). Previous models of pacing place a lot of emphasis on an athlete’s awareness of changes to the internal physiological state of their body, experienced as perceived exertion, in relation to their progress towards the endpoint as informed through various forms of feedback. According to Teleoanticipation Theory (Ulmer, 1996) and later on the Central Governor Model (Noakes *et al.*, 2006), a ‘central governor’ anticipates exercise and presents a pacing strategy based on the end-point or duration of exercise. In a more recent manifestation of Central Governor Model, more complex information-processing mechanisms have been proposed in which rate of change of perceived exertion is evaluated in the light of expected duration or distance of an event and modified through appropriate alternations in pace (Tucker, 2009). The Psychobiological Model similarly supports the notion of effort-related decisions about pace in the context of event duration, but argues that such decisions are entirely conscious and that subconscious processes, such as those proposed by the Central Governor Model, are inapposite (Marcora, 2008). The linear relationships found between RPE and the proportion of completed event, are such that the RPE gradient was found to peak in coincidence with the expected endpoint (Joseph *et al.*, 2008; Foster *et al.*, 2009; Faulkner *et al.*, 2008).

In an attempt to factor for varying uncertainty about pace during endurance events, a model has been specified whereby risk is expressed as the proportion of the remaining task multiplied by their momentary RPE, a variable the authors refer to as hazard score (DeKoning *et al.*, 2011). An appealing feature of the hazard score model is that the further an athlete progresses, the lower hazard score becomes, thus explaining how athletes are sometimes able to risk performing very intense spurts of energy towards the end of an event when the risk of not-completing as a consequence of doing so is relatively low. An alternative model proposed that pacing decisions are made based upon the estimated time that present power output can be maintained, as judged against the duration or length of the task (Garcin *et al.*, 2012). More recent suggestions of how pace is regulated have drawn on the decision-making literature (Renfree *et al.*, 2014) and the interdependence of perception and action in attempting to account for pacing behaviour in environmentally complex situations (Smits *et al.*, 2014).

Whatever model of pacing is subscribed to, all involve the athlete monitoring external feedback about their progress and performance during an event. However, the importance placed on knowledge of the endpoint in pacing models has mainly been derived from studies where participants have either been deceived about, or deprived of, progression or performance feedback information (Jones *et al.*, 2013). A number of studies have used false feedback about distance or time to understand the importance of feedback and the use of knowledge during exercise. Studies have found that deceiving athletes about the duration of exercise, by providing false or no knowledge about the exercise endpoint, leads to increased RPE and a different pacing strategy caused by incorrectly allocated of physiological resources (Eston *et al.*, 2012; Billaut *et al.*, 2011). Experience of using blind, true and false performance feedback has also been found to provoke different types of learnt pacing strategies (Micklewright *et al.*, 2010).

Feedback deception and blinding experimental methods have been the dominant approaches used to understand how athletes use information to pace themselves. Deductions about the significance and role of particular types of performance information are made based upon what happens to pace if that information is altered or removed. The underlying logic is that if, after altering or removing a particular source of information pacing or performance worsens, then it can be inferred that that information source has an important contributory role. This approach has led to emphasis in the endpoint in different pacing models.

There are several limitations to this information-knockout approach. The first is the focus on singular sources of information and the lack of investigative sophistication in understanding how athletes interpret various sources of information in conjunction with each other. For example, the importance athletes place on speed or power information to make pacing decisions could potentially vary according to how much time or distance has elapsed, or according to environmental conditions or competitor behaviour. A further, but related, limitation is that knockout and deception studies have not investigated within-trial changes in the emphasis placed on certain types of feedback. For example, potentially an athlete may be more concerned with average speed in the first half of a race and then become more interested in elapsed time or distance towards the end of an event. The final limitation is the inability to understand individual differences in feedback preferences, which could vary according to past experience or the outcome measure by which they appraise their achievement success. A threat to the validity of previous pacing models is the reliance on limited deception and blinding methods, which necessitated indirect interpretation regarding the importance of endpoint awareness as a determinant of athletic pace. It is this point that the present study intended to redress.

A more direct method of measuring what information athletes seek and use during self-paced exercise will greatly improve our understanding of pacing decisions and, to our knowledge, this have never been achieved. In one study the frequency with which children looked at elapsed time during a time-limited run was measured from a video recording and it was found that they looked at the watch more often towards the end of the run (Chinnasamy *et al.*, 2013). While the methods of measuring information-seeking behaviour in this study were quite basic, eye-tracking technology does provide a more sophisticated method of directly measuring what information athletes look at during self-paced exercise. Unlike previous deception and information-knockout studies, the precision with which information-seeking behaviour can be measured using eye-tracking technology is able to overcome the limitations of deception studies discussed earlier. Importantly, eye-tracking enables detailed information to be gathered about how athletes use information in a dynamic and conjunctive ways during an exercise trial, as well as how they learn to use information differently with experience to pace themselves.

The use of eye-tracking technology in sport is a powerful method (Discombe & Cotterill, 2015) that has enabled researchers to develop better insights about perceptual-cognitive mechanisms of sport performance (Gegenfurtner *et al.*, 2011; DTY Mann *et al.*, 2007). In the context of cycling, eye-tracking has provided useful insights about the role of visual behaviour in balance and steering (Vansteenkiste *et al.*, 2014; P Vansteenkiste *et al.*, 2013) but has not been used to understand information pick-up as part of the perceptual-action processes in regulating pace (Smits *et al.*, 2014).

3.1.1 Differences between Novices and Experienced

During the last few decades experts and novices performance has been studied in many different fields such as music, math and problem solving (Ericsson, 2006), business (Dew *et al.*, 2009) and in sports. Several studies have analysed experts and novices performance in baseball (Garland & Barry, 1990; Mcpherson, 1993) soccer (Williams & Davids, 1995) and basketball (Cleary & Zimmerman, 2001), the studies showed that experts have more thoughtful and sophisticated knowledge enable them to recognise and recall specific information in a more effectual way than novices. Cleary & Zimmerman (2001) studied self-regulation forethought and self-reflection processes during free throw shooting in basketball experts, non-experts, and novices players. The study showed that experts were more selective and choose specific technique-related strategies to realise their goals, had better levels of self-efficacy and more strategy attributions than non-experience. Differences in anticipating opponents' action between novices and experts have also been studied in the last few decades, researches showed that experts outperform novices, indicating that experts depends on visually observing opponents' action more than relying on ball-racket or ball- body contact (Williams *et al.*, 2011; Aglioti *et al.*, 2008; A Mark Williams *et al.*, 2002; Cañal-Bruland *et al.*, 2011). In decision-making process when time and accuracy are measured, experts showed more skills than novices (Starkes, 1987). In a study to exam differences in a number of perceptual abilities between novices and experts in basketball, volleyball, and water-polo players, it was found that water-polo experts were better on decision-making and visual reaction, basketball experts had scored better on prediction and selective attention, while volleyball experts were better than novices in perceptual speed, focused attention and direction of moving object (Kioumourtzoglou *et al.*, 1998). The differences between novices and experts in perceptual abilities in different sports seem to be influenced by the nature of the sport. García López *et al.* (2010) examined the differences between novices and exports in procedural knowledge in football players from five different competition level, the study showed high significant rate differences between national and international level than regional, provincial and inexperienced soccer player. Mobile eye-tracking technology has proven especially versatile in allowing researchers to collect data in many different sports domains where performance is dependent upon the ability perceive and process complex information in often fast moving environments**.** Differences between novices and experts in visual behaviour were also investigated. Goulet *et al.* (1989) studied the eye movements and fixations time between expert and novice tennis players. It was concluded that experts had significantly higher level of eye fixations than novices and focused the majority of their attention on the server's racquet and arm holding the racquet. More recently, Wu *et al.* (2013) investigated the differences between experience and novice basketball player in gaze behaviour and anticipation; the study showed that experts had more stable and reliable gaze fixation and a higher accurate rate of anticipation than novices. Indicating that differences in visual perception lead to a differences in action anticipation. Eye-tracking technology has also provided considerable insights about differences in perceptual-cognitive mechanisms between expert and novice performers (Williams *et al.*, 2011; Gegenfurtner *et al.*, 2011), and this approach has great potential in developing a better understanding of information acquisition and decision-making during self-paced cycling**.**

The main finding from the exist researches is that experts pay more attention to relevant source, and have the ability to search and recall more appropriate information than novices. This has a relevance to pacing theory because it raises the question of whether differences exist between expert and novice cyclists in the information feedback they consider to be task relevant, and how frequently they refer to such information and for how long. Therefore, we attend to study the differences in visual search behaviour between experts and novices' cyclists using an eye-tracking system to better understand what do cyclist look at and whether the visual search behaviour change between groups or in a subsequent time trial.

This study adopted a creative and highly original design using eye-tracking technology to better understand perception and pacing mechanisms in cyclists. The purpose was, to 1) to measure TT performance and pacing between, to 2) directly measure what information cyclists look at while performing a time-trial, to 3) compare the information-seeking strategies of novice and experienced cyclists, and to 4) examine whether information-seeking behaviour changed during a subsequent time-trail performance. We hypothesized that 1) experienced cyclists would use fewer sources of information, and 2) they will seek out information less frequently. We also hypothesized that 3) the information-seeking learning effect would be greater among novice cyclists compared to experienced cyclists.

3.2 Methods

3.2.1 Participants

Twenty-nine participants (15 experienced, and 14 novices) were recruited for this study from the University of Essex and local cycling clubs. However, Experienced (n=10) and novice (n=10) cyclists were included in the analysis for this study. Nine participants (5 experienced & 4 novices) were excluded from the analysis due to losing eye-tracking calibration, unclear video, or any other technical problem. Mean ± 1SD age, stature and body mass for the experienced cyclists was 38.6 ± 11.3 years, 176.6 ± 6.9 cm and 74 ± 9.4 kg, and for the novice cyclists was 36.1 ± 9.9 years, 178.5 ± 6.7 cm and 80.2 ± 8.7 kg. The experienced cyclists had participated in competitive 10-mile time-trials for an average of 14.1 ± 13 years. Experienced cyclists had on average trained each week on 4.7 ± 1.1 occasions for a total of 8.5 ± 2.1 hours. The novice cyclists had on average trained each week on 2.8 ± 0.8 occasions for a total of 4.6 ± 1.1 hours across a range of different sports that did not involve cycling.

3.2.2 Design

A three-way mixed experimental design (experience-by-trial-by-segment) was used in which we compared pace, performance and visual behaviour between novice and experienced cyclists (between-subjects experience factor), across two 10 mile (16.1 km) cycling time-trials (within-subjects learning factor) at every 2.5 miles (4 km) within each time-trial (within-subjects segment factor). All participants had a recovery period of 5 to 10 days in between time-trials. During each cycling time-trial completion time (s), speed ($km.hr^{-1}$), power output (W), distance (km), pedalling cadence ($r.min^{-1}$) and heart rate ($b.min^{-1}$) was measured. RPE was recorded every 4 km. During each time-trial, participants wore, previously mentioned in chapter 2, monocular eye-tracking device to measure the type of information they looked at, and the frequency and duration with which they did so. The general experimental procedures for this study are given in Chapter 2 (2.3.7)

3.2.3 Cycling Ergometry

All cycling tests were performed on a Velotron (3D) Racer Mate ergometer (previously explained in chapter two) with RealVideo simulation software (Racermate, Seattle). Participants completed two 10-mile (16.1 km) cycling time-trials on two occasions separated by 5-10 days. The 10 mile time-trial duration was selected as this is a common format used in the UK and one which the experienced cyclists used in this study were most accustomed to. All cycling tests were performed at the same time of day ± one hour. Prior to each time-trial, participants performed a 5-minute self-paced warm-up. Participants were instructed to complete the time-trial in the fastest possible time. They were not provided with any information acquisition or pacing guidance.

3.2.4 Video Simulation

During each time-trial participants were positioned in front a large screen on which the RealVideo simulated cycling course was projected. Various types of real-time feedback information including speed ($km.hr^{-1}$), power output (W), elapsed time (min: sec), elapsed distance (km), pedalling cadence ($r.min^{-1}$) and heart rate ($b.min^{-1}$) were displayed on the screen. An A0 sized RPE scale was also displayed to the left of the projector screen for more details (see section 2.3.9).

3.2.5 Psychophysiological Measures

Heart rate (HR) was recorded during both cycling TT. Average HR was calculated every 4 km and for overall performance. Participants were asked to provide an overall rating of perceived exertion every 4 km using the Borg 6-10 RPE scale (Borg, 1970). For more information see section (2.3.6.1& 2.3.6.2).

3.2.6 Eye-Tracking and Video Analysis

Participants were fitted with the, previously mentioned in chapter two, SensoMotoric Instruments SMI iViewX head-mounted monocular eye-tracking device (HED). Participants wore the eye-tracker throughout each time-trial. The eye-tracking videos were subsequently reviewed and then visual fixation times were manually recorded in milliseconds against nine predetermined categories. Six of the categories related to information feedback that were speed, elapsed distance, power output, cadence, heart rate and elapsed time. Visual fixation times were also recorded for the rating of perceived exertion and the video simulation of the time-trial course that was projected onto the wall. A final category was created to capture all other objects of visual fixation not corresponding to the other eight categories and/or when the signal was lost, for example, when participants looked at the laboratory floor or at laboratory equipment.

3.2.7 Data Processing and Statistical Analysis

Accumulated fixation time and gaze frequency (previously explained in chapter 2.3.10) for each of the nine categories (speed, elapsed distance, power output, cadence, heart rate, elapsed time, RPE, video simulation and other) was calculated on a participant-by-participant basis for the whole time-trial and for each 4 km segment. Accumulated fixation times were then used to determine what information source that each participant looked at for longest accumulated average time (primary), second longest accumulated average time (secondary), third longest accumulated average time (tertiary) and so on until quaternary (4th), quinary (5th), senary (6th), septenary (7th), octonary (8th) and nonary (9th) had all been established. To normalize absolute visual fixation times for inter-participant differences in time-trial performance, primary to nonary fixation data were all converted from absolute time (ms) to percentage of time-trial completion time.

Time-trial average cycling speed (performance) interactions between experts and novices, and between the first and second time-trials was analysed using two-way mixed ANOVAs. Three-way mixed ANOVAs were used to analyse group-by-trial-by-segment interactions in average cycling speed (pace) as well as relative fixation time and gaze frequency for the primary, secondary and tertiary visual categories.

For both performance, pace and visual data, significant interactions were followed up using planned post-hoc comparisons between segments using paired-samples *t* tests for within-group comparisons and independent sample *t* tests for between-group comparisons. Paired-samples *t* tests were also used to compare within group comparison and RPE values. All results are expressed as mean (SD) and effect sizes as partial eta squared.

3.3 Results

3.3.1 Time-Trial Performance

Two-way mixed ANOVA revealed no group-by-trial interaction for average cycling speed, $F_{1,\,18}$=2.7, P=.082, η_p^2=.16, but there was a group main effect, $F_{1,18}$=6.8, P=.018, η_p^2=.27, and a trial main effect, $F_{1,18}$=11.2, P=.004, η_p^2=.38. Independent samples t-tests revealed that the experts had a faster average cycling speed compared to the novices during both the first time-trial (34.5±1.5 $km.hr^{-1}$ vs. 31.5±2.8 $km.hr^{-1}$, t_{18}=2.7, P=0.007, η^2=0.29) and second time-trial (34.9±1.8 $km.hr^{-1}$ vs. 32.1±2.7 $km.hr^{-1}$, t_{18}=2.4, P=0.013, η^2=0.24). Group and trial differences in average cycling speed are presented in Figure (3-2)

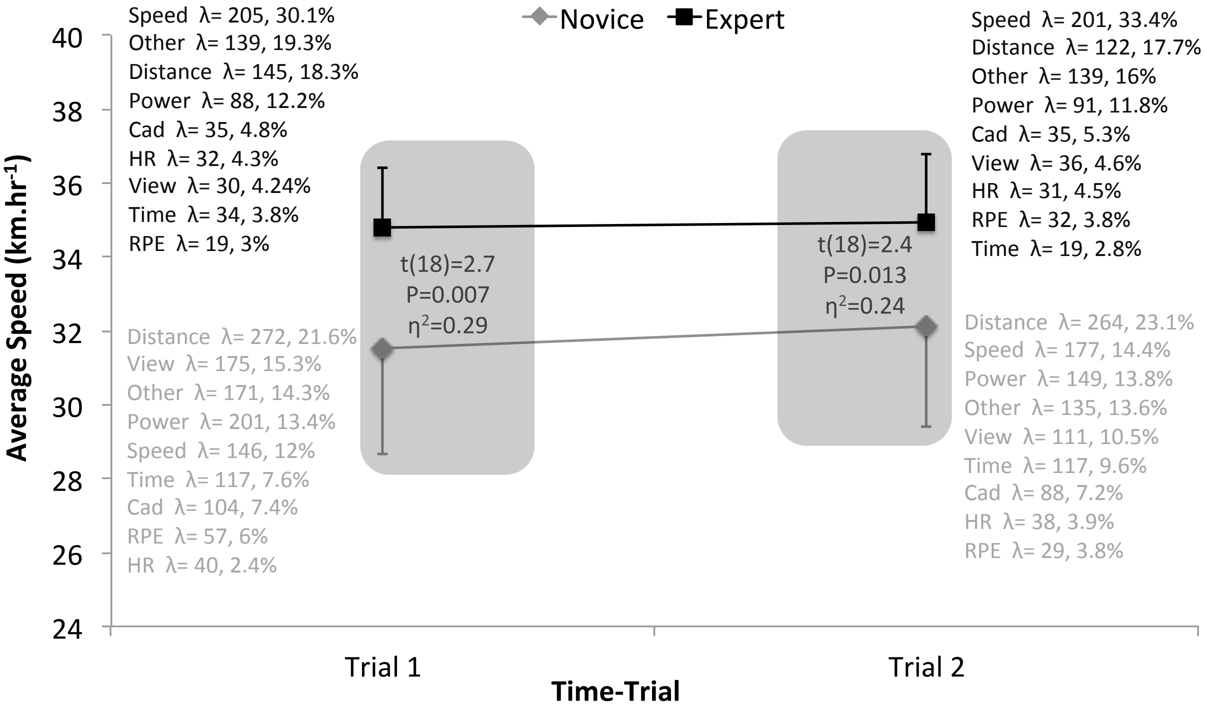


Figure 3-1 Between-trial changes in average cycling speed between novice and expert participants. The average amount of time spent looking at each type of information, relative to time trial completion time (%), is presented alongside each data point along with the average frequency (λ) that each type of information was looked at.

3.3.2 Time-Trial Pace

Three-way mixed ANOVA revealed no group-by-trial-by-segment interaction for cycling pace (km.hr^{-1}), $F_{3,54}$=0.6, P=0.590, η_p^2=.04, no group-by-trial interaction, $F_{1,18}$=0.9, P=0.359, η_p^2=.05, no group-by-segment interaction, $F_{3,54}$=2.3, P=0.086, η_p^2=.11 and no trial-by-segment interaction, $F_{3,54}$=0.3, P=0.809, η_p^2=.02. However there was a group main effect, $F_{1,18}$=7.9, P=0.012, η_p^2=.31, a trial main effect, $F_{1,18}$=12.9, P=0.002, η_p^2=.42 and a segment main effect, $F_{3,54}$=4.3, P=0.009, η_p^2=.19. Post hoc independent samples t-tests found that experts were faster than novices during every time-trial segment, in both time-trials. Group and segment differences in pace with post-hoc outcomes are presented in Figure (3-3) for the first time-trial, and in Figure (3-4) for the second time-trial. Mean and standard deviation data for speed and other time-trial outcomes (completion time, power, cadence, heart rate and RPE) are given in Table (3-1) for each group, time-trial and segment.

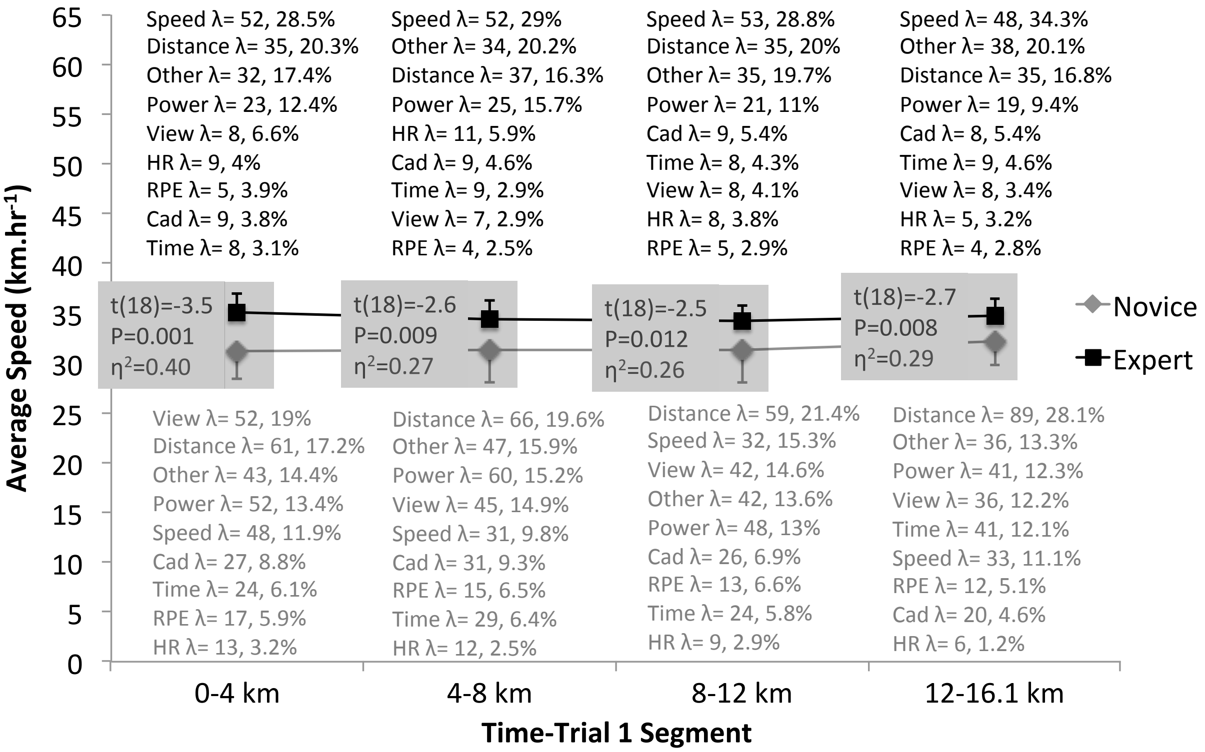


Figure 3-2 First TT, Segment-by-Segment changes in average cycling speed (pace) between novice and expert participants. The average amount of time spent looking at each type of information, relative to segment completion time (%), is presented alongside each data point along with the average frequency (λ) that each type of information was looked at

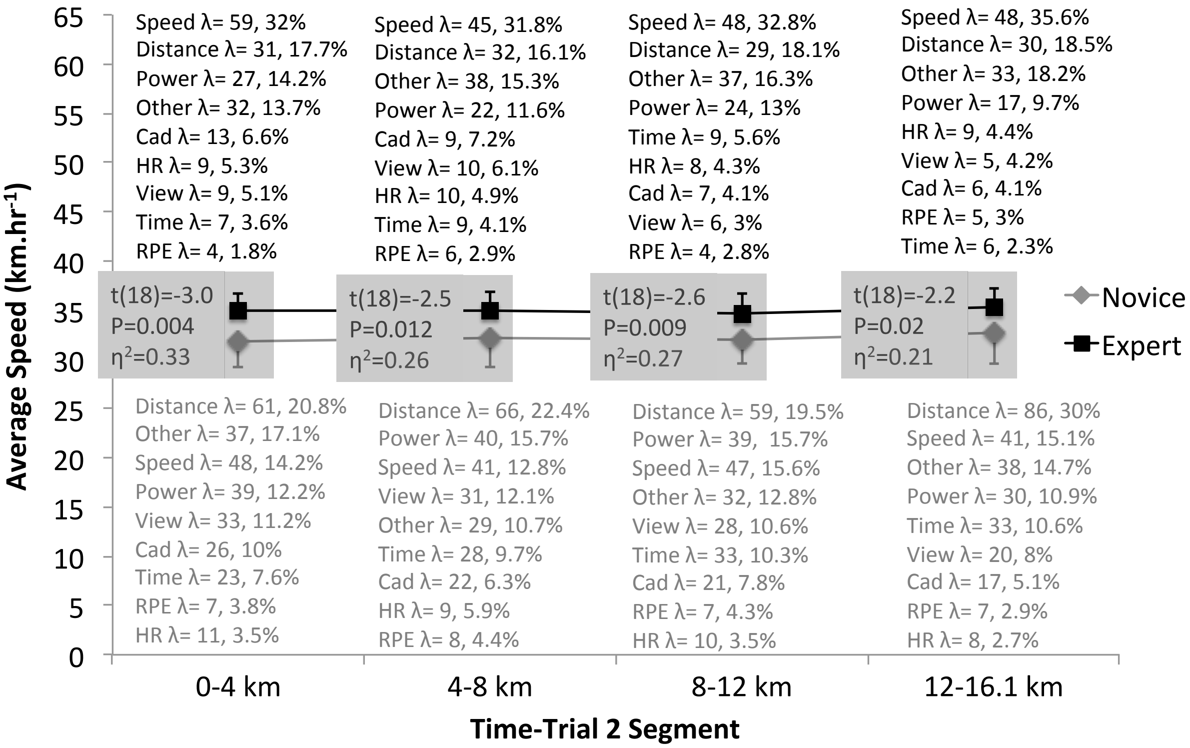


Figure 3-3 Second TT, Segment-by-Segment changes in average cycling speed (pace) between novice and expert participants. The average amount of time spent looking at each type of information, relative to segment completion time (%), is presented alongside each data point along with the average frequency (λ) that each type of information was looked at.

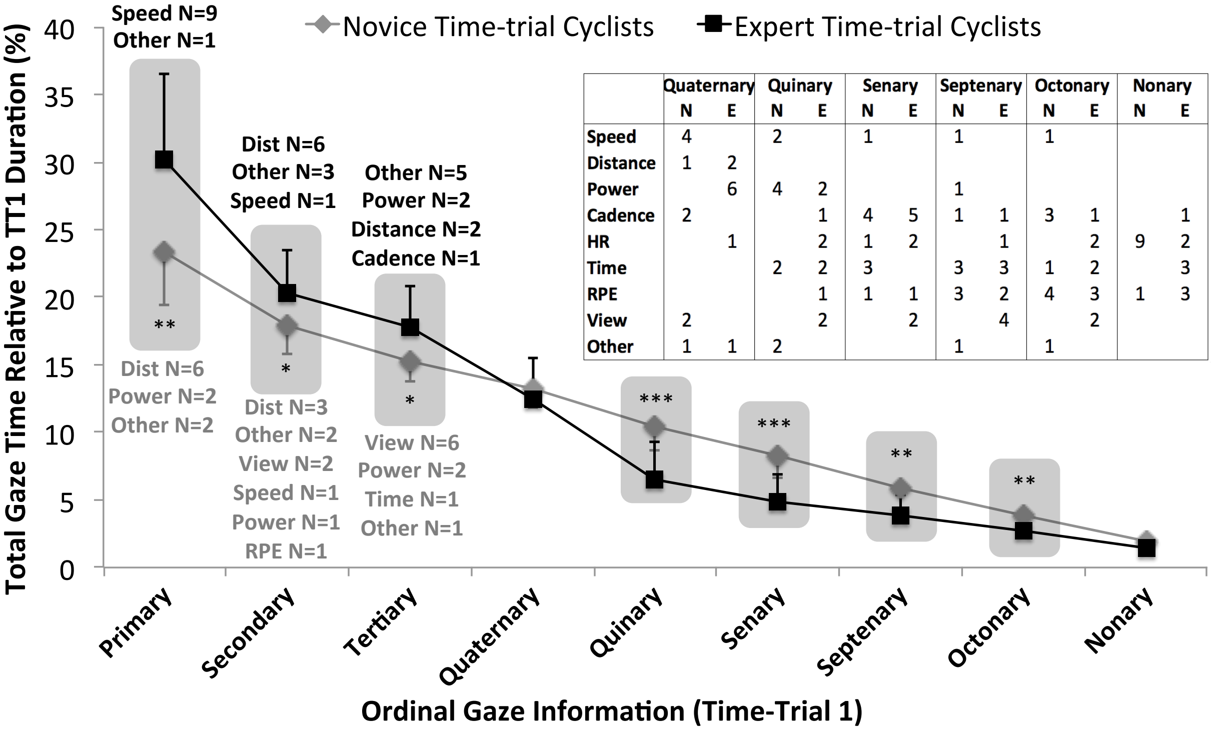
Table 3-1 Mean performance, heart rate and RPE time-trial data for group, trial and segment

		Novice					Expert				
		0-4 km	4-8 km	8-12 km	12-16.1 km	Overall	0-4 km	4-8 km	8-12 km	12-16.1 km	Overall
Speed (km.hr^{-1})	**TT1**	31.2(2.7)	31.3(3.2)	31.3(3.3)	32.2(2.3)	31.5(2.8)	34.9(1.8)	34.4(1.8)	34.2(1.5)	34.5(1.5)	34.5(1.5)
	TT2	31.8(2.6)	32.0(2.8)	32.0(2.4)	32.6(3.1)	32.1(2.7)	34.9(1.8)	34.8(1.9)	34.6(2.0)	35.2(1.9)	34.9(1.8)
Completion Time (s)	**TT1**	465(45)	464(57)	465(59)	459(38)	1854(193)	413(21)	418(22)	421(19)	426(18)	1680(75)
	TT2	455(42)	452(45)	452(37)	455(52)	1816(176)	413(21)	414(23)	416(25)	419(23)	1663(90)
Power (W)	**TT1**	201(42)	200(46)	200(48)	214(38)	204(42)	261(39)	256(38)	257(27)	267(23)	260(30)
	TT2	210(41)	212(44)	210(38)	223(46)	214(42)	272(29)	265(34)	263(28)	272(32)	268(29)
Cadence (r.min^{-1})	**TT1**	85(10)	86(11)	86(12)	89(10)	86(11)	97(5)	98(4)	104(17)	96(2)	99(3)
	TT2	77(17)	85(11)	86(11)	88(11)	84(9)	95(8)	95(7)	96(6)	96(7)	96(7)
Heart Rate (b.min^{-1})	**TT1**	146(19)	160(17)	166(17)	176(13)	162(16)	148(19)	163(15)	166(14)	171(12)	162(15)
	TT2	139(12)	161(11)	169(7)	175(6)	161(7)	145(12)	162(14)	162(26)	172(17)	160(16)
RPE	**TT1**	12.9(0.7)	14.6(0.6)	16.2(0.9)	18.7(0.8)	15.6(0.6)	13.5(1.1)	15.1(1.1)	16.3(1.2)	18.6(0.9)	15.8(1.0)
	TT2	13.0(0.9)	15.0(1.3)	16.2(1.3)	18.9(0.9)	15.7(1.0)	13.3(1.1)	14.8(1.3)	17.1(1.4)	18.9(0.8)	16.0(1.0)

TT1 = First time-trial, TT2 denotes second time-trial. All values presented are group means ± 1SD for each segment (0-4 km, 4-8 km, 8-12 km and 12-16.1 km). Values presented in the overall column are calculated as the mean ± 1SD for the whole time-trial (0-16.1 km).

3.3.3 Whole Time-Trial Eye-Tracking Outcomes: Information Gaze Duration

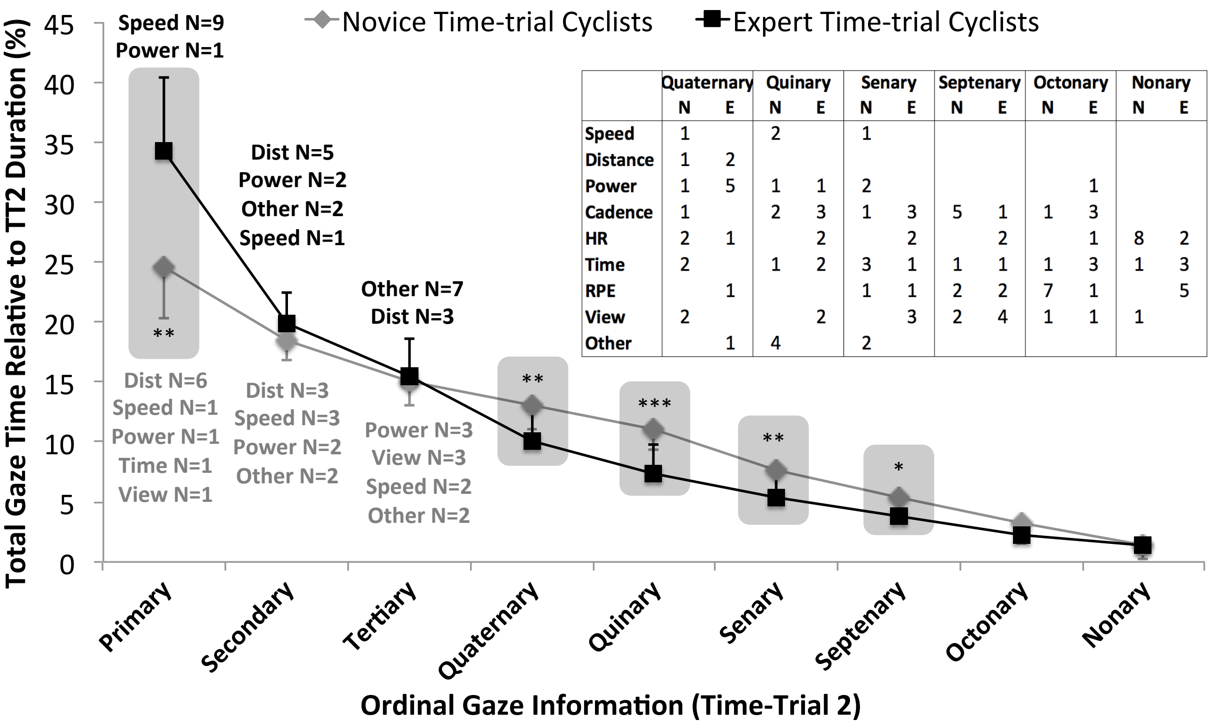
Novice and Expert mean gaze duration data for primary through to nonary information sources calculated over the full 16.1 km time-trials are presented in Figures 3-4 and 3-5. A three-way mixed ANOVA found no trial-by-group-by-information source interaction for relative gaze duration (% time-trial duration), $F_{8,144}$=1.9, P=0.06, η_p^2=.09, and no trial-by-group interaction, $F_{1,18}$<0.1, P=0.89, η_p^2<.01. There was a group-by-information source interaction, $F_{8,144}$=11.5, P<0.001, η_p^2=.39, and a trial-by-information source interaction, $F_{8,144}$=4.2, P<0.001, η_p^2=.19. Independent-samples post-hoc t-tests revealed that experts looked at primary information sources for longer than novices during time-trial 1 (23.3±3.9% vs. 30.2 ± 6.4%, t_{18}=-2.9, P=0.005, η^2=0.32) and time-trial 2 (24.5±4.2% vs. 34.2 ± 6.1%, t_{18}=-4.2, P<0.001, η^2=0.49). Other expert vs. novice post-hoc outcomes are represented in Figures (3-5) and (3-6).



	Quaternary		Quinary		Senary		Septenary		Octonary		Nonary	
	N	E	N	E	N	E	N	E	N	E	N	E
Speed	4		2		1		1		1			
Distance	1	2										
Power		6	4	2			1					
Cadence	2			1	4	5	1	1	3	1		1
HR		1		2	1	2		1		2	9	2
Time			2	2	3		3	3	1	2		3
RPE				1	1	1	3	2	4	3	1	3
View	2			2		2		4		2		
Other	1	1	2				1		1			

Figure 3-4 First TT, Novice and Expert mean relative gaze duration data for primary (most looked at) through to nonary (least looked at) information sources calculated over the full 16.1 km distance. The type of information looked at with the corresponding number of subjects is presented alongside the data points for primary to tertiary sources, and in the embedded tables for quaternary to nonary sources. * Denotes P<0.05; ** denotes P<0.01; * denotes P<0.001.**

Paired-samples post-hoc t-tests showed an increased gaze duration between time-trials among the experts for the primary information source (30.2±6.4% vs. 34.3±6.1%, t_9=-2.8, P=0.01, η^2=0.30) accompanied by decreases in gaze duration for tertiary information (17.8±3.0% vs. 15.5±3.0%, t_9=2.3, P=0.022, η^2=0.23) and quaternary information (12.5±3.1% vs. 10.1±2.5%, t_9=3.3, P=0.005, η^2=0.38). There were no other significant between-trial changes in gaze duration for expert participants, and no between-trials changes at all for novice participants.



	Quaternary		Quinary		Senary		Septenary		Octonary		Nonary	
	N	E	N	E	N	E	N	E	N	E	N	E
Speed	1		2		1							
Distance	1	2										
Power	1	5	1	1	2					1		
Cadence	1		2	3	1	3	5	1	1	3		
HR	2	1		2		2		2		1	8	2
Time	2		1	2	3	1	1	1	1	3	1	3
RPE		1			1	1	2	2	7	1		5
View	2			2		3	2	4	1	1	1	
Other		1	4		2							

Figure 3-5 Second TT, Novice and Expert mean relative gaze duration data for primary (most looked at) through to nonary (least looked at) information sources calculated over the full 16.1 km distance. The type of information looked at with the corresponding number of subjects is presented alongside the data points for primary to tertiary sources, and in the embedded tables for quaternary to nonary sources. * Denotes P<0.05; ** denotes P<0.01; * denotes P<0.001.**

3.3.4 Whole Time-Trial Eye-Tracking Outcomes: Information Gaze Frequency

The frequency of which novice and expert participants looked at primary through to nonary information sources was counted overall for each time-trial and is presented in Figures 3-7 and 3-8. A three-way mixed ANOVA found no trial-by-group-by-information source interaction for gaze frequency, $F_{8,144}$=0.8, P=0.58, η_p^2=.04, no trial-by-group interaction, $F_{1,18}$<2.7, P=0.12, η_p^2=0.13, and no trial-by-information source interaction, $F_{8,144}$=0.3, P=0.97, η_p^2=.01. There was a group-by-information source interaction, $F_{8,144}$=3.6, P=0.001, η_p^2=.17. Independent-samples post-hoc t-tests mostly revealed that experts looked at information sources less frequently than novices. Post-hoc statistical outcomes are presented in Figures 3-7 and 3-8.

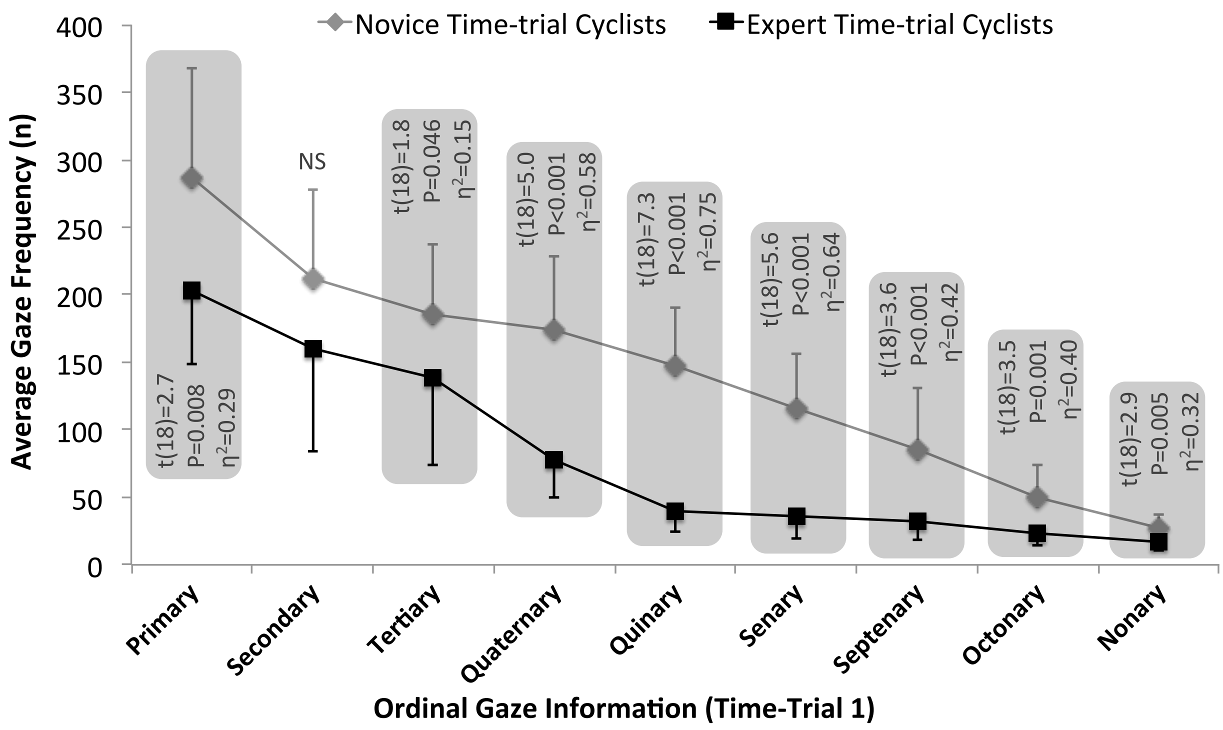


Figure 3-6 First TT, Novice and Expert mean gaze frequency data for primary (most looked at) through to nonary (least looked at) information sources calculated over the full 16.1 km distance. NS denotes not significant.

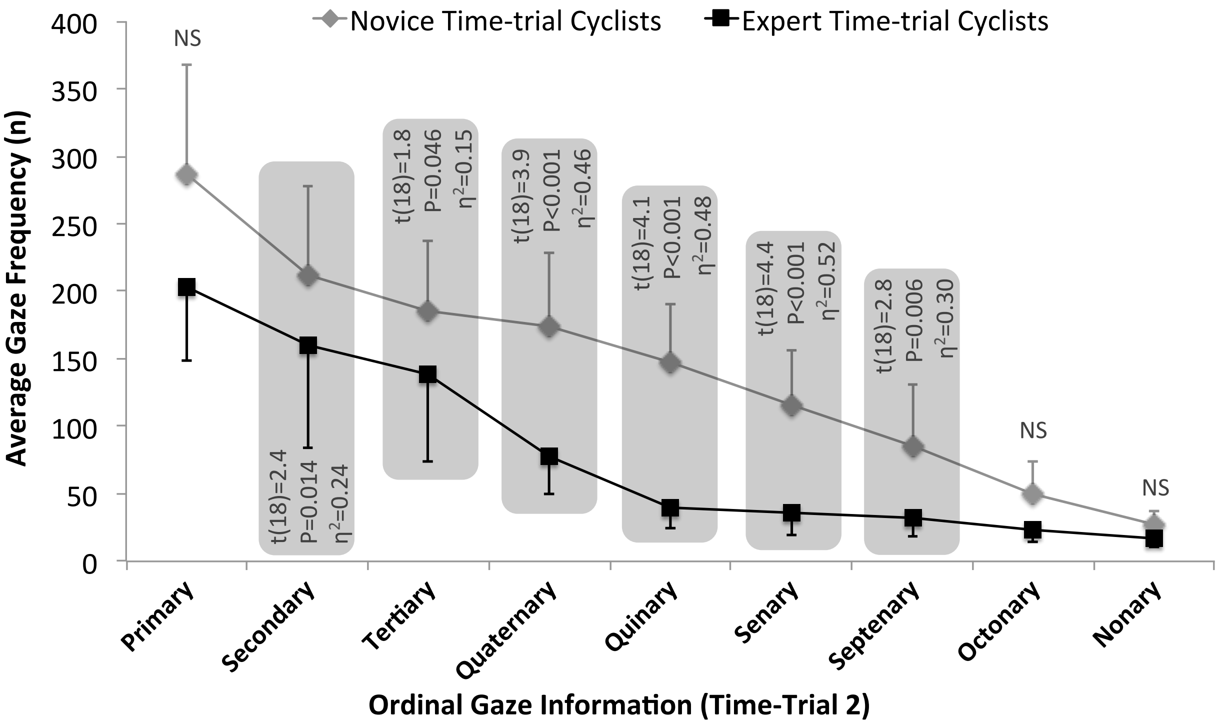


Figure 3-7 Second TT, Novice and Expert mean gaze frequency data for primary (most looked at) through to nonary (least looked at) information sources calculated over the full 16.1 km distance. NS denotes not significant.

3.3.5 Time-Trial Segment Eye-Tracking Outcomes: Gaze Duration and Frequency

Group-by-trial-by-segment analysis of gaze duration and gaze frequency data was carried out using a separate three-way mixed ANOVA for primary, secondary and tertiary information sources. The statistical outcomes are presented in Table (3-2).

Table 3-2 Three-Way Analysis of Variance Outcomes for Eye-tracking Data.

	Primary Information	Secondary Information	Tertiary Information
Relative Gaze Duration			
Trial Main Effect	F(1,18)=7.9, P=0.011, η_P^2=0.31	F(1,18)=7.4, P=0.014, η_P^2=0.30	F(1,18)=6.5, P=0.022, η_P^2=0.26
Segment Main Effect	F(3,54)=6.3, P=0.001, η_P^2=0.26	F(3,54)=0.2, P=0.901, η_P^2=0.01	F(3,54)=0.7, P=0.569, η_P^2=0.04
Group Main Effect	F(1,18)=15.6, P<0.001, η_P^2=0.46	F(1,18)=0.1, P=0.971, η_P^2=0.01	F(1,18)=8.4, P=0.01, η_P^2=0.32
Trial-by-Group Interaction	F(1,18)=1.6, P=0.224, η_P^2=0.08	F(1,18)=36.7, P<0.001, η_P^2=0.67	F(1,18)=3.4, P=0.083, η_P^2=0.16
Segment-by-Group Interaction	F(3,54)=1.3, P=0.281, η_P^2=0.07	F(3,54)=0.4, P=0.733, η_P^2=0.02	F(3,54)=1.2, P=0.309, η_P^2=0.06
Trial-by-Segment Interaction	F(3,54)=1.0, P=0.414, η_P^2=0.05	F(3,54)=0.8, P=0.472, η_P^2=0.05	F(3,54)=1.3, P=0.274, η_P^2=0.07
Trial-by-Segment-by-Group Interaction	F(3,54)=0.2, P=0.879, η_P^2=0.01	F(3,54)=0.2, P=0.864, η_P^2=0.01	F(3,54)=1.1, P=0.354, η_P^2=0.06
Gaze Frequency			
Trial Main Effect	F(1,18)=0.8, P=0.394, η_P^2=0.04	F(1,18)=3.8, P=0.065, η_P^2=0.18	F(1,18)=1.2, P=0.285, η_P^2=0.06
Segment Main Effect	F(3,54)=2.7, P=0.052, η_P^2=0.13	F(3,54)=0.7, P=0.577, η_P^2=0.04	F(3,54)=0.3, P=0.853, η_P^2=0.01
Group Main Effect	F(1,18)=3.4, P=0.081, η_P^2=0.16	F(1,18)=10.6, P=0.004, η_P^2=0.37	F(1,18)=7.7, P=0.012, η_P^2=0.30
Trial-by-Group Interaction	F(1,18)=0.3, P=0.623, η_P^2=0.01	F(1,18)<0.01, P=0.875, η_P^2=0.01	F(1,18)=4, P=0.061, η_P^2=0.18
Segment-by-Group Interaction	F(3,54)=5.9, P=0.001, η_P^2=0.25	F(3,54)=0.4, P=0.744, η_P^2=0.02	F(3,54)=0.7, P=0.535, η_P^2=0.04
Trial-by-Segment Interaction	F(3,54)=2.2, P=0.104, η_P^2=0.11	F(3,54)=0.2, P=0.885, η_P^2=0.01	F(3,54)=0.3, P=0.809, η_P^2=0.02
Trial-by-Segment-by-Group Interaction	F(3,54)=0.7, P=0.535, η_P^2=0.04	F(3,54)=1.1, P=0.367, η_P^2=0.06	F(3,54)=1.5, P=0.223, η_P^2=0.08

Note – Shaded areas indicate statistically significant outcomes

Group-by-trial-by-segment changes in gaze duration are presented in Figure (3-9 – 3-14). Along with post-hoc independent samples t-test outcomes, gaze frequency changes are presented in Figure (3-15 – 3-20).

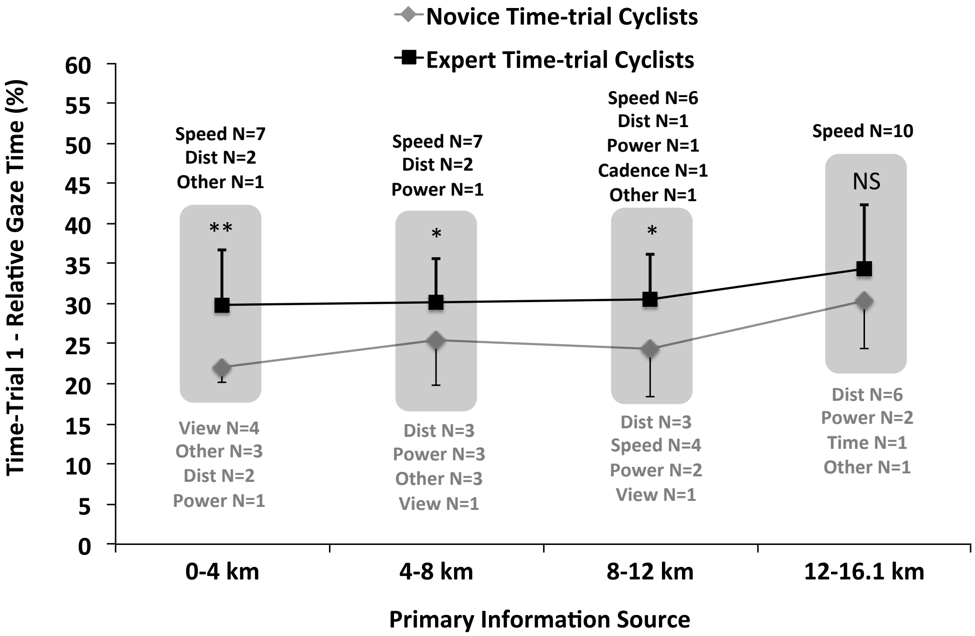


Figure 3-8 Expert versus novice segment-by-segment mean gaze duration data for primary information source in time-trial 1.

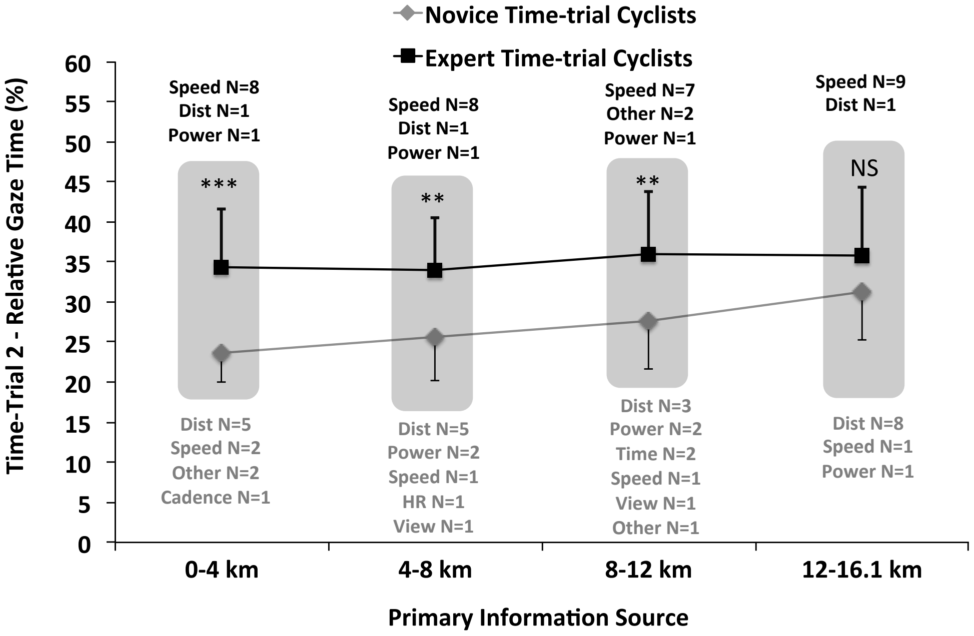


Figure 3-9 Expert versus novice segment-by-segment mean gaze duration data for primary information source in time-trial 2.

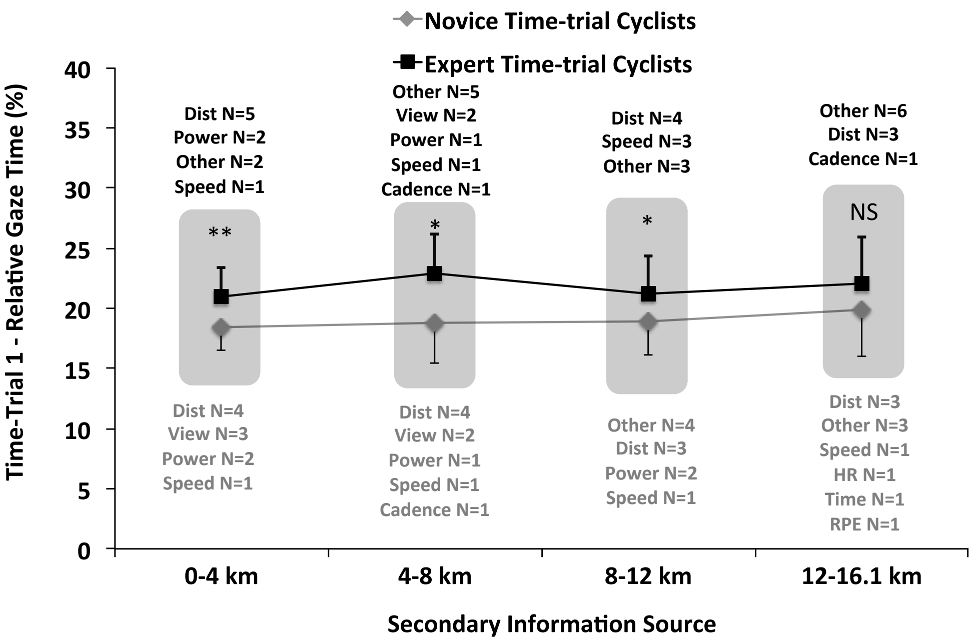


Figure 3-10 Expert versus novice segment-by-segment mean gaze duration data for secondary information source in time-trial 1.

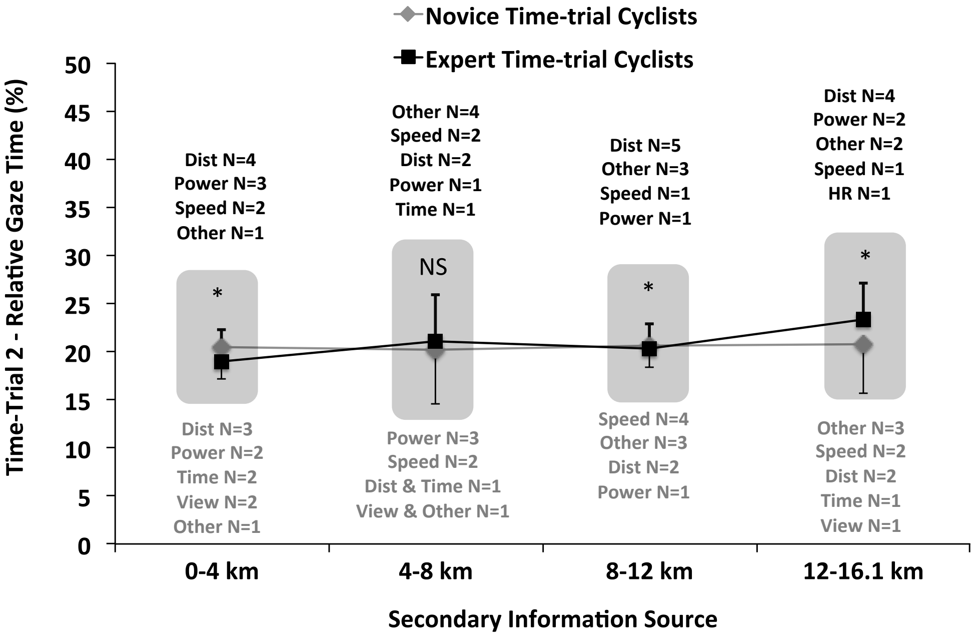


Figure 3-11 Expert versus novice segment-by-segment mean gaze duration data for secondary information source in time-trial 1.

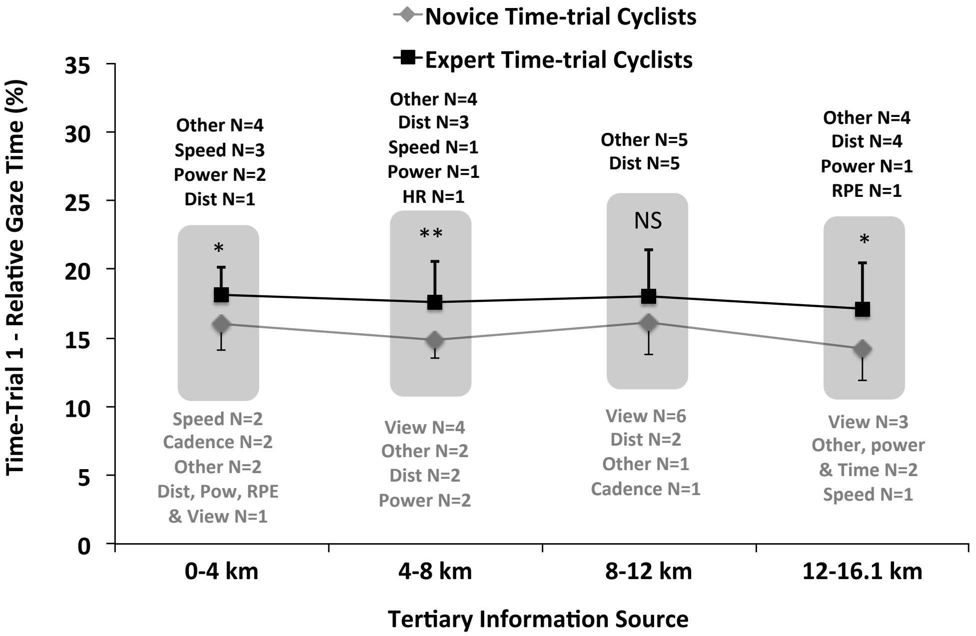


Figure 3-12 Expert versus novice segment-by-segment mean gaze duration data for tertiary information source in time-trial 1.

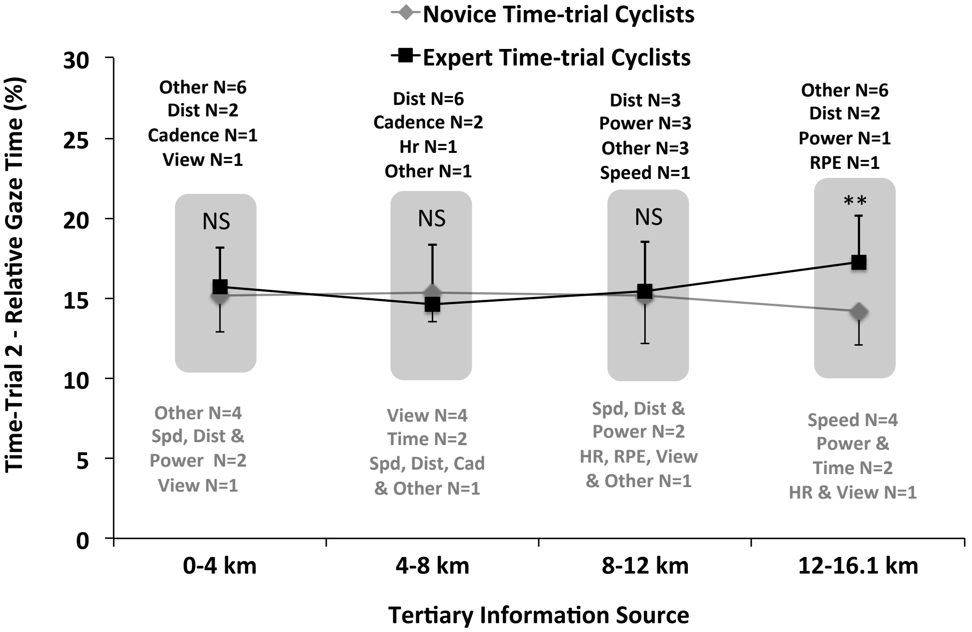


Figure 3-13 Expert versus novice segment-by-segment mean gaze duration data for tertiary information source in time-trial 2.

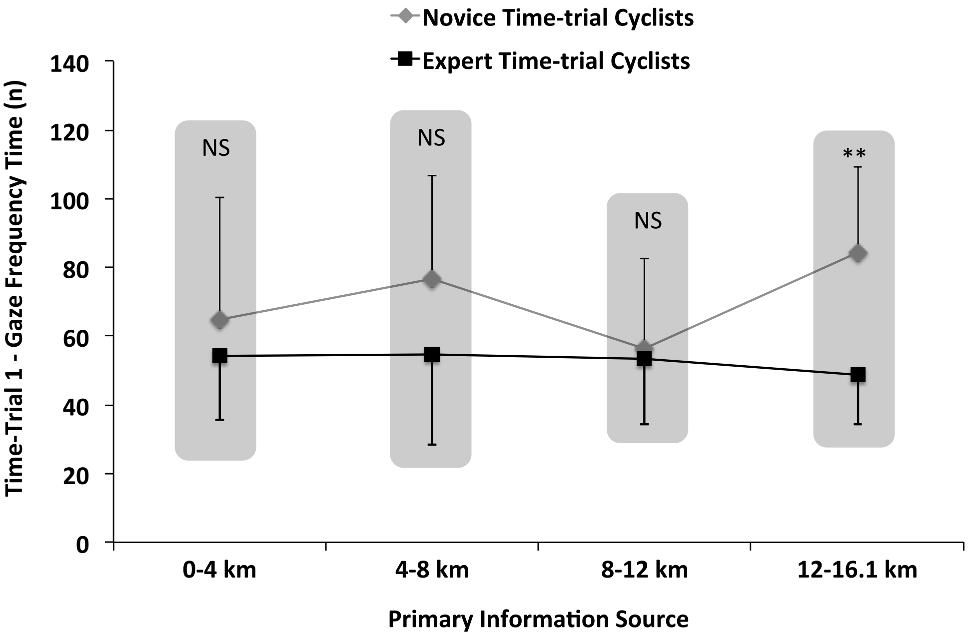


Figure 3-14 Expert versus novice segment-by-segment mean gaze frequency data for primary information source in time-trial 1.

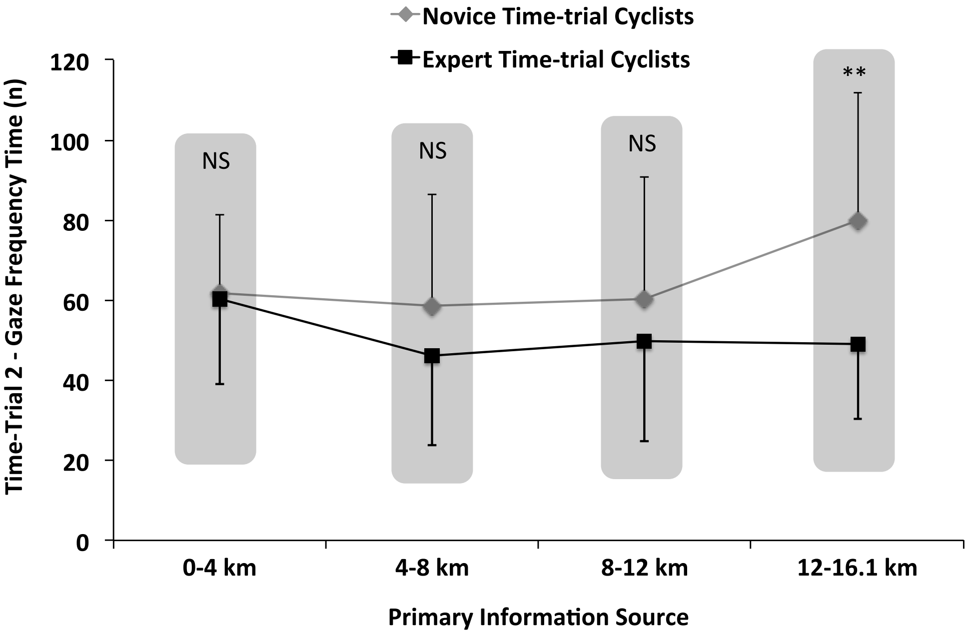


Figure 3-15 Expert versus novice segment-by-segment mean gaze frequency data for primary information source in time-trial 2.

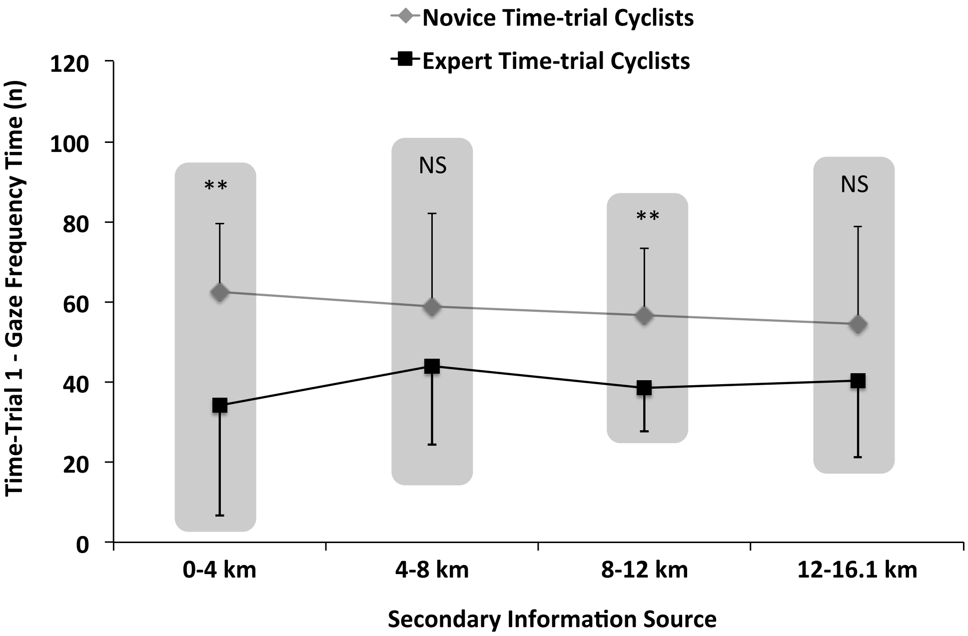


Figure 3-16 Expert versus novice segment-by-segment mean gaze frequency data for secondary information source in time-trial 1.

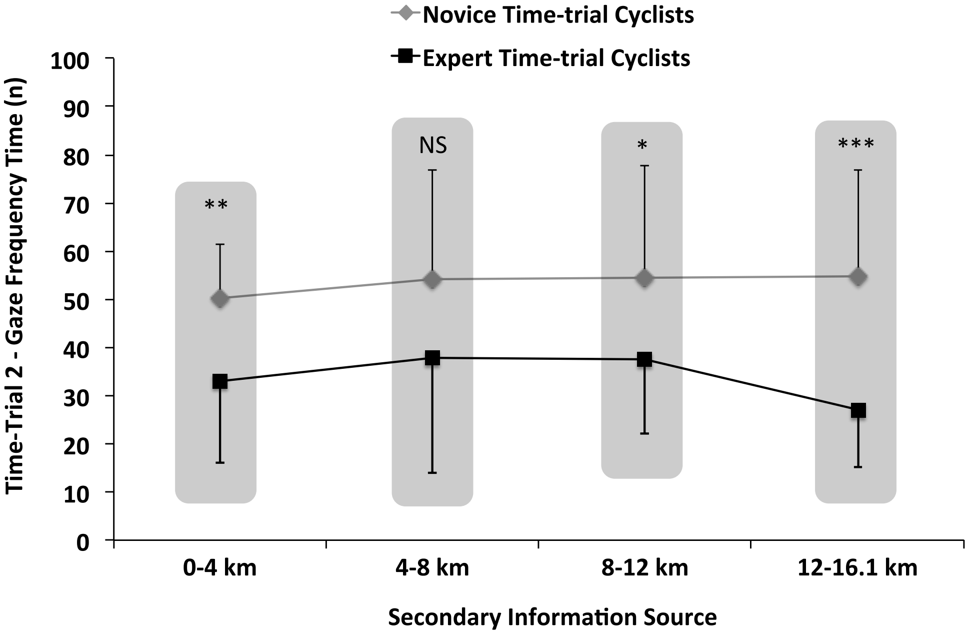


Figure 3-17 Expert versus novice segment-by-segment mean gaze frequency data for secondary information source in time-trial 2.

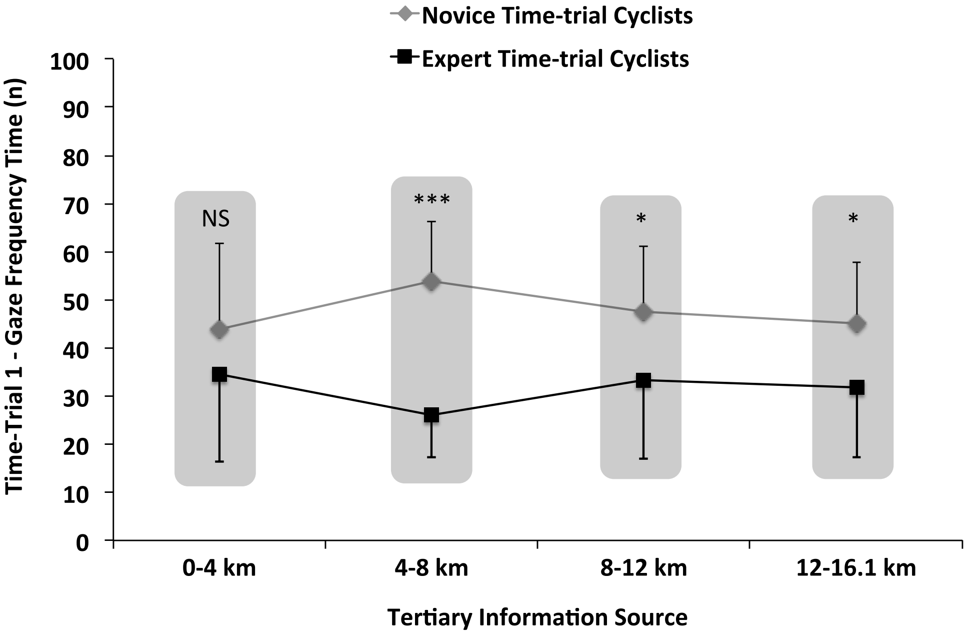


Figure 3-18 Expert versus novice segment-by-segment mean gaze frequency data for tertiary information source in time-trial 1.

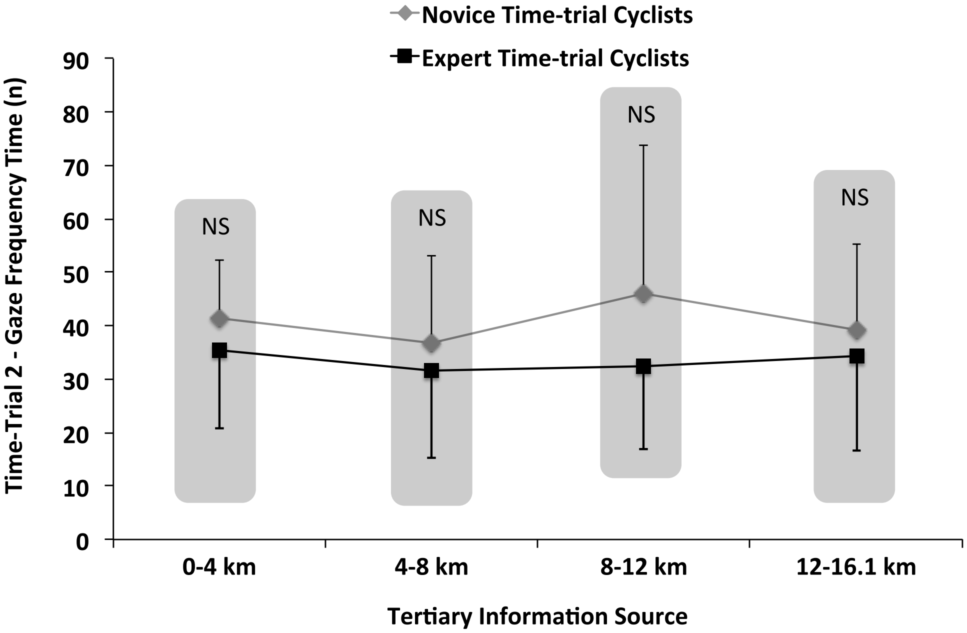


Figure 3-19 Expert versus novice segment-by-segment mean gaze frequency data for tertiary information source in time-trial 2.

Group-by-trial-by-segment analysis for quaternary through to nonary information sources is excluded for the sake of brevity, owing to the large amount of statistical data. We also believe that the analysis of gaze data beyond the three most looked at sources of information is unlikely to yield significant insights about systematic perceptual patterns, pacing and performance. Our rationale is partly supported given the highly variable information gaze patterns evident in the embedded tables of Figures 3-5 and 3-6.

Data is presented in Table 3 showing the combination of primary and secondary information that participants looked as calculated across the entire time-trial durations and on a segment-by-segment basis. Individual participant data is present in an attempt to convey the complex, yet in some instances similar, patterns of information that participants looked at during the time-trials. Seven primary-secondary information combinations were observed for the novice group in both time-trials 1 and 2, whereas the experts exhibited only three primary-secondary information gaze combinations in the first time-trial and four in the second time-trial. There was only one instance where the novices had the same primary-secondary combination as the experts, which was the speed-duration combination by S9 in the second time-trial.

For both time-trials, Mann-Whitney non-parametric comparisons were made between novices and experts in the number of primary sources they looked at in each segment and the number of times they switched what they primarily looked at between segments. Results showed a lower number of different primary sources looked at by experts compared to novices in the first time-trial (1.7±0.8 vs. 2.8±0.9, U=19.5, Z=-2.41, P=0.008) but no difference in the second time-trial (1.5±0.5 vs. 2.3±1.2, U=30, Z=-1.62, P=0.053). From segment to segment, the number of times participants switched to different primary information sources was lower among the experts compared to novices in both the first (1.3±1.4 vs. 2.3±0.9, U=31, Z=-1.53, P=0.064) and second time-trial (0.7±0.8 vs. 1.7±1.3, U=26.5, Z=-1.87, P=0.031). Primary source and primary source switch data is given in Table 3-3.

Table 3-3 Individual gaze combinations of primary and secondary information sources

Time Trial 1							Time Trial 2						
ID	**Primary-Secondary Combination for the Whole Time-Trial**	***Group Code**	**Primary-Secondary Combination Change by Segment (4-8-12-16 km)**	****Primary Dominance by Segment (%)**	**Different Primary Sources Used per Segment (N)**	**Primary Source Switches Between Segments (N)**	**ID**	**Primary-Secondary Combination for the Whole Time-Trial**	***Group Code**	**Primary-Secondary Combination Change by Segment (4-8-12-16 km)**	****Primary Dominance by Segment (%)**	**Different Primary Sources Used per Segment (N)**	**Primary Source Switches Between Segments (N)**
Novices													
S11	DO	1	OV-DP-VO-DO	53-59-52-61	3	3	S13	DS	4	SD-DS-DS-PD	52-59-55-62	3	2
S13	DO		VD-OD-DO-PD	55-60-67-54	4	3	S3	DS		DT-DP-DS-DS	50-56-57-54	1	0
S3	DV	2	DS-VD-DP-TD	53-66-53-57	3	3	S8	DS		OV-DS-TS-DT	58-53-51-65	3	3
S8	DV		VD-DV-SO-DT	55-51-53-74	3	3	S10	DO	1	CD-HD-OD-DO	50-51-51-51	4	3
S12	DP	3	VP-PD-DP-DO	54-53-63-70	3	2	S11	DO		DO-DP-DO-DO	51-65-64-61	1	0
S10	DS	4	DV-DS-DS-DS	53-53-55-55	1	0	S12	DP	3	DP-DP-PD-DT	58-53-56-78	2	2
S1	PD	5	OP-PD-PD-HD	57-66-52-54	3	2	S7	PD	5	DV-PT-PS-DS	55-60-60-60	2	2
S9	PD		PD-PC-PD-DV	60-56-58-68	2	2	S9	SD	8	SD-SD-SO-SD	56-52-55-52	1	0
S7	OD	6	VD-OV-SD-DO	54-58-55-51	4	3	S6	VD	9	DP-VO-VO-DO	55-57-66-56	2	2
S6	OR	7	OV-OR-SO-OR	52-52-52-56	2	2	S1	TP	10	OT-PV-TP-DV	51-56-51-62	4	3
Mean				**55-57-56-60**	**2.8**	**2.3**					**54-56-57-60**	**2.3**	**1.7**
S.D.				2-5-5-8	**0.9**	**0.9**					3-4-5-8	**1.2**	**1.3**
Mode	**##**		**VD-PD-##-DO**		**3**	**3**		**DS**		**##-##-##-DO**		**1**	**2**
Experts													
S21	SD	8	SO-SP-SD-SD	50-50-61-51	1	0	S24	SD	8	SD-SD-SD-SD	61-62-64-64	1	0
S23	SD		DP-SP-PO-SD	50-52-51-65	3	3	S25	SD		SP-SD-OD-SH	50-50-52-52	2	2
S24	SD		SD-SO-SD-SD	65-59-69-68	1	0	S26	SD		DS-DS-SD-SD	54-52-62-71	2	1
S26	SD		SD-SO-DS-SO	56-63-52-70	2	2	S30	SD		SO-SO-SD-SO	66-62-58-61	1	0
S27	SD		SD-SD-SD-SO	66-56-64-58	1	0	S32	SD		SD-SO-SO-SD	64-64-70-66	1	0
S30	SD		SO-DS-SD-SO	59-57-58-57	2	2	S22	SO	11	SD-ST-OS-SO	78-79-59-53	2	2
S25	SO	11	DV-SO-CS-SC	63-51-60-50	3	3	S27	SO		SD-SO-SO-SD	69-57-70-59	1	0
S28	SO		SP-SP-SO-SO	51-54-67-65	1	0	S21	SP	12	SP-SO-SP-DS	65-65-72-51	2	1
S32	SO		SD-SO-SO-SO	69-65-62-63	1	0	S28	SP		SP-SP-SO-SP	68-61-68-69	1	0
S22	OS	12	OD-SO-OS-SO	53-60-54-55	2	3	S23	PS	13	PS-PS-PD-SH	63-65-59-52	2	1
Mean				**58-57-60-60**	**1.7**	**1.3**					**64-62-63-60**	**1.5**	**0.7**
S.D.				7-5-6-7	**0.8**	**1.4**					8-8-7-8	**0.5**	**0.8**
Mode	**SD**		**SD-SO-SD-SO**		**1**	**0**		**SD**		**##-SO-SO-SD**		**1**	**0**

Note - *Group code represents a specific primary-secondary information source combination; **Dominance of the primary information is expressed as a percentage of the combined gaze time for both primary and secondary sources. Primary-secondary information source combinations are represented by two letters, with each single letter being coded as follows: S=Speed; D-Elapsed DIstance; P=Power; C=Cadence; H=Heart Rate; T=Elapsed Time; R=Ratings of Perceived Exertion; V=Projector Simulation View and O=Other. ## Indicating mode shared by more than one category

A three-way mixed ANOVA found no Group-by-trial-by-segment interaction for the percent dominance of the primary source in the primary-secondary combination, $F_{3,54}$=1.0, P=0.42, η_p^2=.05, no trial-by-group interaction, $F_{1,18}$=3.1, P=0.10, η_p^2=.15, no group-by-segment interaction, $F_{3,54}$=2.4, P=0.08, η_p^2=.12, and no trial-by-segment interaction, $F_{3,54}$=0.5, P=0.72, η_p^2=.03. There was no trial main effect $F_{1,18}=2.0$, $P=0.18$, $\eta_p^2=.10$ or segment main effect, $F_{3,54}=1.2$, $P=0.31$, $\eta_p^2=.06$ but there was a strong group main effect, $F_{1,18}=8.1$, $P=0.01$, $\eta_p^2=.31$. Independent-samples post-hoc t-tests, pooled for both trials and all four segments, revealed that dominance of the primary information source in the primary-secondary combination was greater for the experts compared to the novices (06.5±7.0% vs. 56.8 ± 5.7%, $t_{158}=-3.6$, $P<0.001$, $\eta^2=0.01$). Group-by-trial-by-segment primary dominance values are given in Table 3-3.

3.4 Discussion

This study was the first to make direct measurements of information-acquisition behaviour among time-trial cyclists and constitutes a significant step forward in our understanding of endurance exercise pacing among time-trial cyclists. It seems that patterns of information acquisition during a self-paced cycling time trials are very complex and that pacing behaviour is not necessarily universally informed by the integration of endpoint awareness and perceived exertion, as previous models have argued (DeKoning *et al.*, 2011; Faulkner *et al.*, 2008; Foster *et al.*, 1994; Noakes *et al.*, 2006; Garcin *et al.*, 2012; Tucker, 2009; Ulmer, 1996; St Clair Gibson *et al.*, 2006). This is because we observed that, firstly, cyclists refer to different types of information according to their experience, with experts primarily looking at speed and novices primarily looking at distance (Figures 3-2, 3-5, & 3-6). Secondly, experts are more selective in their information acquisition behaviour compared to novices, referring to fewer sources of information (Figures 3-5 & 3-6), which they look at less frequently (Figures 3-7 & 3-8) and for longer (Figures 3-5 & 3-6). Thirdly, novices increased the duration (Figures 3-9 – 3-14) and frequency (Figures 3-15 – 4-120) of looking at their primary information source during the final segment of the time-trial but experts were more constant throughout the trials. Finally, with only four different combinations of primary and secondary information used by the experts, there was better commonality in what information they looked at compared to the novices who used ten primary-secondary information combinations (Table 3-3). Our finding that experienced cyclists refer to task-relevant information less often is consistent with a meta-analysis of eye-tracking studies of expert performers(Gegenfurtner *et al.*, 2011), yet our findings that experienced cyclists fixate for longer than novices is not consistent with the meta-analysis. This maybe because, as acknowledged by the authors of the meta-analysis, the type of sport task may moderate expert-novice differences in visual behaviour compared to other domains (Gegenfurtner *et al.*, 2011). Experts also tended to stick to a primary information source throughout the time-trial, whereas novices switched the type of information they primarily looked at between segments much more often (Table 3-3). Overall the evidence strongly suggests that feedback about distance to the endpoint is not universally the most important influence on pacing decisions and that cyclists may instead differ in the types of information they refer to and use, and that such preferences may differ between the various segments of an event. We are not suggesting that endpoint awareness is not important in pacing regulation, clearly it is given how often it featured as either a primary or secondary point of regard in our findings (Table 3-3). Our argument is that previous pacing models are deficient in accounting for variations in information acquisition that we have found attributable to individual preference, expertise or event segment. It seems that in simulated time-trial cycling experts primarily look at speed in combination with distance, whereas distance feedback appears to be the more dominant feedback reference for novices.

An important finding of this study was that experts and novices differed in the types of information they looked at in both time-trials. Speed was what the majority of experts (9/10) looked at most across the whole time-trial. In contrast, distance was looked at by most novices (6/10), noting that in both time-trials a significant number of novices (4/10) chose to primarily look at other information too. In addition to experienced cyclists being more consistent in what information they look at, of note is that they looked at primary information for longer and less frequently.

While the eye-tracking data we have collected reveals a lot about how time-trial cyclists acquire information, it does not tell us anything about how the information is integrated and processed, or the decisions they have made. For this, other process-tracing methods such as think aloud protocols, may usefully compliment eye-tracking in the study of decision-making and pacing. This is because that, while eye-tracking technology provides a powerful method for measure information acquisition processes, it reveals nothing about how that information is subsequently processed. Although longer eye fixation times have been linked to greater depth of processing(Fiedler & Glöckner, 2012; Glaholt & Reingold, 2009; Shi *et al.*, 2013)rather than assuming this to be the case in future pacing studies, it would be preferable to use eye-tracking in conjunction with think aloud protocols to directly capture information processes. Nevertheless, the results of the present study highlight differences in information acquisition between novice and experienced time-trial cyclists that bring to question the common information-processing mechanisms put forward by previous pacing models (DeKoning et al., 2011; Faulkner et al., 2008; Foster et al., 2003; Garcin et al., 2012; Joseph et al., 2008; Marcora, 2008; Noakes et al., 2004; Ulmer et al., 1996). In particular, the assumption in previous pacing models that the integration of endpoint awareness with perceived exertion is the primary and universal driver of pacing decisions, regardless of athletic experience or individual feedback preferences. It may be that decision-making among experienced cyclists was different to novices and indeed different between individuals which resulted in a need to seek out more varied sources of information. This is consistent with the idea that individuals use information in an adaptive way according to the perceived demands of a situation or problem (Hutchinson & Gigerenzer, 2005). Thus, it could be that distance information is still important to experienced cyclists but, owing to their previous experience, they are able to process and integrate such information much more quickly and thus do not need to look at it quite so often or for so long. Since the experienced participants were experienced at performing the 16.1 km time-trial format, it is also quite likely that their need to refer to distance information was less than novices unaccustomed to cycling such a distance. The extent to which information acquisition differences between experienced and novice cyclists are attributable to distance familiarity, is something that could be tested by using the same experimental protocol but with an unfamiliar time trial distance**.** While it is well established that experience influences pacing strategy (Foster *et al.*, 2009; Mauger *et al.*, 2009a; Micklewright *et al.*, 2010), our findings further show that information-seeking strategies accompanying pacing behaviour are also dependent upon previous experience.

As expected the expert cyclists completed both time-trials faster than the novices (Figure 3-2), with both groups exhibiting a mostly constant pace throughout (Figures 3-3 & 3-4). Owing to imperfect fitness matching between the novice and experienced cyclists, we cannot conclude that that time-trial performance differences between the groups was exclusively due to experience differences. While in future studies greater effort should be made to measure associations between moment-by-moment change in gaze and pacing time-series data (Micklewright *et al.*, 2016), in this study we have limited our analysis to detecting concomitant changes in gaze and pace at a segment-by-segment level. What our data clearly shows is that, whatever type of information is preferred as the primary reference, the experts look at it for longer than the novices (Figures 3-5 & 3-6) but less frequently (Figure 3-7 & 3-8). As previously discussed, this is broadly consistent with previous expertise literature (Gegenfurtner *et al.*, 2011). During the second time-trial the experts increased the relative amount of time they spent looking at the primary information source from 30 to 35% showing that they became more selective in what information they referred to. The shallower curves presented in (Figure 3-5 & 3-6) also shows that novices tended to distribute their attention across a number of different information sources. In both time-trials novices spent more time looking at quaternary to octonary sources of information. The notion that experienced cyclists are more selective in what feedback they look at is also consistent with previous expertise literature (Gegenfurtner *et al.*, 2011; Derek T Y Mann *et al.*, 2007) and is supported in a number of ways. In the first three segments, the experts on average spent between 5-10% longer than novices looking at the primary information source in time-trial 1 (Figure 3-9) and time-trial 2 (Figure 3-10). It is only in the last segment of the time-trials from 12-16.1 km, that the novices increase both the amount of time (Figures 3-9 & 3-10) and the frequency (Figures 3-15 & 3-16) with which they look at the primary information source close to that of the experts. The increased acquisition behaviour towards the end of the time-trial is consistent with the behaviour observed in children during a self-paced running task (Chinnasamy *et al.*, 2013), further supporting the idea that feedback-dependency is more strongly associated with proximity to the end-point among inexperienced athletes compared to experienced athletes.

The data from our study indicates greater consistency in experts' approach to information acquisition both in terms in inter- and intra-participant behaviour. Inter-participant consistency is evident in the data showing that 9 of 10 experts chose to primarily look at speed. Even when combinations of information sources are considered, experts consistency chose either speed-distance (6/10) or speed-other (3/10) as the primary and secondary information sources they refer to. In fact, across both time-trials the experts only exhibited four different primary-secondary information combinations, whereas ten different primary-secondary combinations were observed among the novices (Table 3-3).

Greater intra-participant consistency among the experts is apparent owing to the fact that on a segment-by-segment basis, the modal primary-secondary combinations were speed-distance and speed other, but for the novices it was often not possible to specify a modal combination because the primary-secondary permutations were so varied. On average novices used 2.3 different primary information sources across the four segments compared to 1.5 for the experts. Novices also tended to switch primary information sources between segments more frequently than the experts as indicated in (Table 3-3).

The primary-secondary combination data presented in Table 3-3 is also interesting because it highlights that distance is still an important reference source to expert, but only secondary to and in combination with speed. In contrast, distance feedback appears to be the most dominant type of information they refer to in combination with many other types of secondary information. A lot of emphasis has been placed on the role of the endpoint in influencing pacing (Les Ansley *et al.*, 2004; Billaut *et al.*, 2011; DeKoning *et al.*, 2011; Faulkner *et al.*, 2008; Foster *et al.*, 2009; Joseph *et al.*, 2008; Noakes *et al.*, 2006; Ulmer, 1996; St Clair Gibson *et al.*, 2006; Marcora, 2008) support for which being found in a number of studies where deception or blinding methods have been used (Billaut *et al.*, 2011; Eston *et al.*, 2012; Jones *et al.*, 2013; Micklewright *et al.*, 2010). However, our study shows that the importance placed on knowledge of the end-point may be overstated in most pacing models and that, knowledge of the endpoint may in fact be a secondary to information about speed in informing the actions of expert cyclists**.** Another interesting outcome of this study is that perceived exertion did not feature in the primary-secondary information acquisition combinations for any of the participants (Table 3-3), and that, whether experienced or novice cyclists, all looked at least three other sources of information in preference to the 6-20 RPE scale. That does not mean perceived exertion is not an important factor in pacing decisions as predicted by many of the previous models. It does however, highlight to methodological complexities of investigating pacing decisions in terms of the acquisition and utilization of external referents, which can be easily observed using methods like eye-tracking, and the integration of internal bodily referents such as perceived exertion, which cannot be directly observed. This particular problem warrants innovative research using process-tracing methods of the kind described in much more detail elsewhere (Micklewright *et al.*, 2016)**.**

This eye-tracking study has produced some important new data not entirely consistent with previous models of pacing about the attention to, and use of, feedback information. Nevertheless, there are a number of limitations associated with the laboratory-based nature of this experiment and the eye-tracking technology that was used. Cyclists in our study performed simulated time-trials on a static cycle ergometer under conditions where certain demands on the visual system were absent, for example those associated with balancing, navigating, negotiating hazards and avoiding collisions as reported elsewhere (P Vansteenkiste *et al.*, 2013; Vansteenkiste *et al.*, 2014). Furthermore, differences between laboratory and real-world visual behaviour have been reported in several studies, the most notable findings being more centralized fixations in the real world, a tendency to fixate on closer objects in the laboratory (Foulsham *et al.*, 2011), and earlier longer object fixations in the real-world (Dicks *et al.*, 2010)**.** Therefore it cannot be assumed that, during road-based time-trials, the capacity to attend to performance information will be the same as reported in this experiment since it will compete with, or be interrupted by, other demands placed on the visual system. In the future, with careful configuration of mobile eye-tracking technology, it may be possible to measure the attention to performance information in field-based studies with associated improvements in ecological validity.

Another limitation of this study relates to the link between visual information, decision-making processes and pacing behaviour. While there is some evidence that what individuals look at is associated with their choices (Fiedler & Glöckner, 2012; Glaholt & Reingold, 2009; Shi *et al.*, 2013; Shimojo *et al.*, 2003), it is unclear whether visual attention influences choice or simply reflects a choice that has been made (Shimojo *et al.*, 2003). In our study the issue is further complicated by the difficulties of quantifying a pacing choice, since the method of detecting a meaningful change in pace from either speed or power time-series data is mathematically complex (Passfield *et al.*, 2013). Even if it were possible to precisely identify moments where a decision had been made to increase or decrease pace, decisions to maintain pace would clearly be impossible to detect, as they would not be indirectly reflected in time-series data. In this study, conclusions about the link between visual attention and pacing decisions are deduced from the associated changes in vision and pace observed at a segment-by-segment level (Figures 3-2, 3-9 – 3-14 and 6; Table 3-3). In future, greater precision about the association between visual attention to performance information and pace could be investigated by setting up experiments were cyclists are presented with pacing dilemma where their decision to act can be pinpointed in time.

Finally, with regards to information acquisition and decision-making during endurance sport, further consideration is needed regarding fatigue related constraints on visual behaviour because they are often overlooked (Williams *et al.*, 2004). A relationship between fatigue and declining visual attention was found in one interesting study where increased levels of exertion among athletes was associated with reduced visual behaviour before making a rifle shot (Williams *et al.*, 2015). Saccadic eye-movements are so fast and energetically efficient (Thiele *et al.*, 2002) that they are less likely to be responsible for such effects compared to high-order cognitive processes such as attention allocation mechanisms which have themselves been found to become fatigued as characterized by reduced capability to suppress irrelevant external cues (Faber *et al.*, 2012). Such factors are likely to impact information acquisition and decision-making during endurance sport and warrant further investigation.

3.5 Conclusions

Although perhaps counterintuitive, this study challenges the degree of importance placed on knowledge of the endpoint to pacing in previous models. This is especially true for experienced cyclists for whom distance feedback was looked at secondary to but in conjunction with information about speed. Novice cyclists appear to have a greater dependence upon distance feedback, which they look at for shorter and more frequent periods of time than the experts. Experts are more selective in the information they refer to during a time-trial and they are also more consistent in the combination of primary and secondary information they use, and more consistent between various phases of a time-trial. The difference in information acquisition behaviour observed in this study may reflect differences in motivational regulators, with experts perhaps focusing more strongly on performing at the fastest speed and novices focusing on completion of the distance.

This study is the first to directly measure cyclists information-seeking behaviour during a time-trial and the data shows that the information athletes attend to and use during self-paced endurance tasks is much more complex than previously assumed and not necessarily dominated by knowledge of the endpoint. Nevertheless, there are a number of limitations associated with this study such that it cannot be assumed that information-seeking behaviour would be the same during a road-based time-trial. There are also improvements to the analysis of time-series data about speed that might reveal hidden moments where a decision to alter pace has been made so that corresponding gaze behaviour can be interrogated with greater precision. Nevertheless, this study has produced some exciting new insights about the information-seeking strategies of expert and novice cyclists, as well as a new method for investigating visual attention and decision-making during paced exercise.

4 Chapter Four: The Effect of Depriving Cyclists from Preferred Feedback Information on Pacing and Performance

4.1 Introduction

It is known that appropriate regulation of energy expenditure reduces the rate of fatigue development and thus enhances performance. To achieve such a regulation, athletes are continually required to make decisions. The decision whether to continue the current strategy or to switch to a different one is based on the most available relevant information (Renfree *et al.*, 2014). However, what is still ambiguous is to what extend different type of available information affects pacing decision, and whether athletes require a specific piece of performance information to make pacing decision and perform optimally. According to the recent model of decision-making, it has been suggested that heuristic principle may be the most appropriate method in such complex situations, when the result is unknown; this is known as a strategy to make a quick and accurate decision by selecting a few but relevant information from the available information (Gigerenzer & Gaissmaier, 2011). Individuals may react differently to the type of information provided, based on the previous experience; participants may interpret the type of information contradictory to make pacing-related decision. Therefore, the deductions regarding the significance and role of particular types of performance information depends on the effects on pace of information alteration or removal.

There is a general assumption that information feedback enhances pacing and performance. Mauger *et al.* (2009b) found that performance feedback is advantageous during exercise and enhance performance and pacing strategy especially at the start and end of the event. A recent study conducted by Smits *et al.* (2016) examined the importance of available performance feedback on performance and pacing, two group of 10 participants were asked to perform 20 km cycling TT either with full performance feedback or no feedback at all. The study found between groups differences in PO profile, especially at the end of the race, concluding that the availability of performance feedback effect pacing strategy. However, a number of performance information source was available during this study, and it is difficult to determine if such differences are due knowledge of the endpoint, as it has been emphasised by previous studies (Les Ansley *et al.*, 2004; Albertus *et al.*, 2005; Baden *et al.*, 2005; Billaut *et al.*, 2011; Eston *et al.*, 2012; Faulkner *et al.*, 2011; Mauger *et al.*, 2009b; Nikolopoulos *et al.*, 2001), or because of other performance related information, If this is the case, then why do cyclists need other performance related information such as PO, speed and cadence?. In the first study Boya *et al.* (2017) studied differences in information acquisition between novices and expert cyclists during a 10 mile cycling TT. The study found that experts were more selective in information seeking behaviour than novices; furthermore, they found that both groups mostly look at one piece of feedback information as the primary source of information, in which speed was the primary source of information for the majority of experienced cyclist while distance was for novices. This indicates that the priority of available performance information differs between participants; it could be interpreted differently according to participants' previous experience. A further interesting point to explore is whether all cyclists need distance knowledge to effectively pace themselves, as has been previously known.

Current pacing literature is limited with regard to the interactions between information acquisition, decision-making, and performance. Micklewright *et al.* (2016) proposed a multidimensional process to enhance our understanding of the pacing decision that involves number of processes including the information acquisition**.** Eye-tracking technology, as it has been previously mentioned in chapter two, provides a more sophisticated method to directly measure what information athletes look at, by calculating average fixation time, during self-paced exercise. Eye fixation is a useful measure of information acquisition, it can provide the total of processing time being applied at the point of interest (Poole & Ball, 2005) that could be useful in understanding the way in which athletes select signals in a complex situation during self-pace exercise.

According to the researcher’s knowledge, no previous study has investigated the process of information acquisition during self-pace exercise, and the way in which different types of performance information could affect athlete performance and pacing decision. By providing cyclists with performance feedback, we wish to determine the alteration in performance and pacing strategy during cycling TT that could be achieved be locate the preferred type of information, using eye-tracker. Therefore, the purpose of this study was to 1) determine cyclists preferred performance feedback information, and 2) whether depriving cyclists from preferred feedback information affect TT pacing and performance. We hypothesised that 1) cyclists differ in the preferred type of performance information, and that 2) isolation cyclist from preferred feedback information affect cyclists’ pacing and performance.

4.2 Methods

4.2.1 Participants

Nineteen experienced cyclists were recruited for this study, however; five subjects were excluded from the data analysis due to calibration issue, unclear video, or any other technical problem. Fourteen cyclists were included in the analysis, whose mean ± 1SD age, stature and body mass was (31.8 ± 3.8 years, 177.8 ± 5.1 cm and 77.6 ± 8.7 kg). Participants had cycling time-trial experience for an average of 5.6 ± 4.2 years, training on average for 4.1 ± 1.7 sessions per week for a total of 5:54 ± 00:42 hours per week.

4.2.2 Design:

A two-way repeated-measures experimental design was used in which participants performed four 5 km cycling time trials on separate occasions. In the first visit, after a 5 minute warm-up, participants performed a familiarization 5 km self-pace cycling time trial (TT_{FAM}) during which several types of performance feedback information (power output, speed, distance, cadence, heart rate and performance time) was projected, for them to see and an A0 sized RPE scale (see chapter two section 2.2.4). The same method was used during the second time trial (TT_{ALL}), but participants wore a (previously explained in chapter two) calibrated SMI iViewX head-mounted monocular eye-tracking device that measured the time spent looking at each type of feedback. The eye-tracking data was used to identify the most looked at information by each participant; during the time trial (ALL). Participants performed two further randomly counterbalanced time trials in which either just primary feedback was presented (TT_{PRIME}), or all feedback information except primary was presented ($TT_{ALL-PRIME}$). Time-trial performance was measured as average speed and pace was every 1 km. The general experimental procedures for this study are given in Chapter 2 (2.3.7).

4.2.3 Cycling Ergometry (Velotron 3D)

All cycling tests were performed on a Velotron (3D) Racer Mate ergometer with RealVideo simulation software (previously mentioned in chapter two). Participants completed 5 km self pace cycling time-trials at the same time of day ± one hour on four occasions separated by (3-7) days.

4.2.4 Visual simulation and eye-tracking analysis

During each time-trial participants were positioned in front a large screen on which the RealVideo simulated cycling course was projected, see chapter two section (2. 3.9). The eye-tracking videos were subsequently reviewed and then visual fixation times were manually recoded using a Video-Coder2 program in milliseconds against nine predetermined categories in TT_{ALL} see chapter two section (2.3.10), chapter three section (2.3.7), In TT_{PRIME}, a video simulation of just the preferred feedback information was projected. Therefore video footages in TT_{PRIME}, was coded against two categories ‘PRIME’ and ‘OTHER’ (figure 5-1A) in which a designed box was used to cover the cycling path and the rest of information that participant was only able to see the previously identified preferred information. While, $TT_{ALL-PRIME}$, the video footage was manually coded against 8 previously mentioned, in chapter two, categories except previously identified preferred information on participant-by-participant basis. While, video footages in TT_{PRIME}, was coded against two categories ‘PRIME’ and ‘OTHER’.

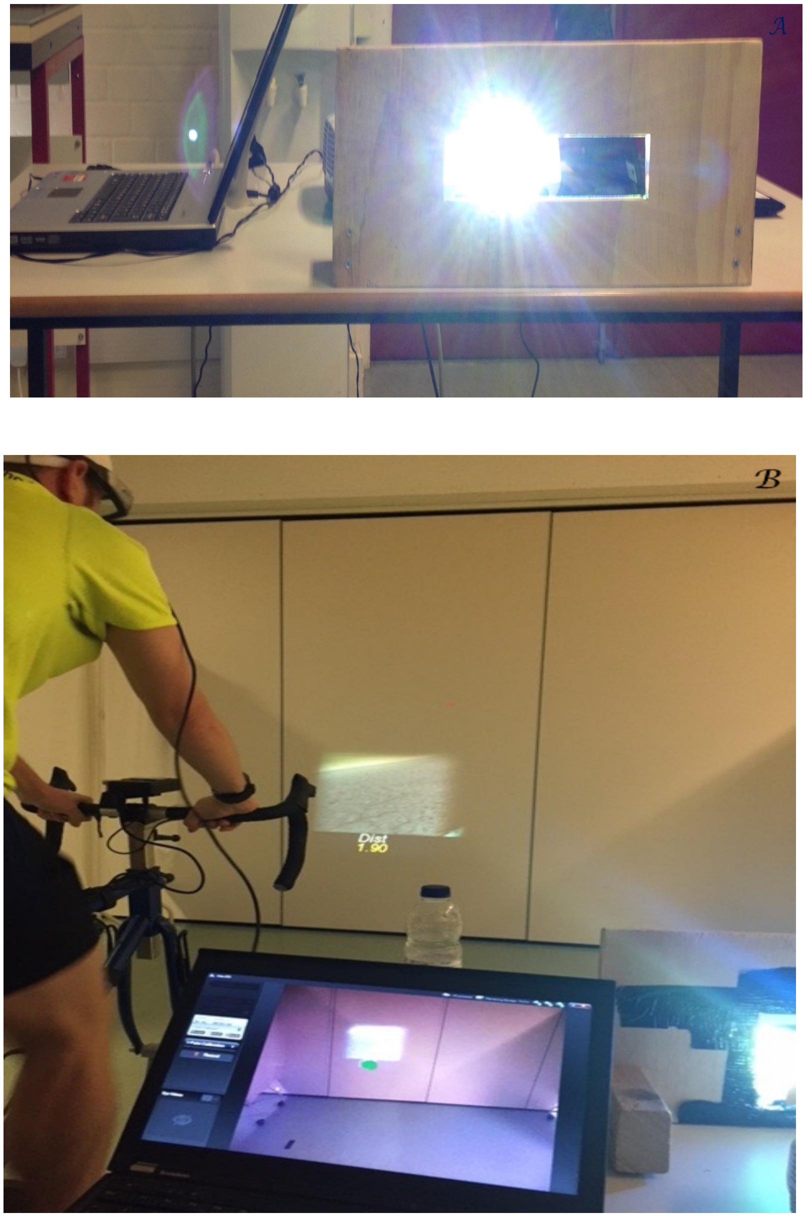


Figure 4-1 A) Represent the designed box to cover different type of performance information and present only the preferred sort of information, B) represent participant seeking the primary information during TT, while the computer is recording participants eye-movement, the green circle on the computer screen represent participants point of interest.

4.2.5 Psychophysiological measures

Heart rate (HR) was recorded during all cycling time trials, in which average HR was calculated every 1 km segment. Participants were asked to provide an overall rating of perceived exertion (RPE) every 1 km using the Borg 6-10 RPE scale (Borg, 1970). See chapter two section (2.3.6.1 and 2.3.6.2).

4.2.6 Data Processing and Statistical Analysis

In the second time-trial (TT_{ALL}), accumulated fixation time and gaze frequency for each of the nine categories see chapter three section (3.2.7) was calculated on a participant-by-participant basis for the whole time-trial and for each 1 km segment. Accumulated fixation times were then used to determine what information source each participant looked at for the longest accumulated average time. The same process was used in the third time-trial ($TT_{ALL-PRIME}$) but for 8 categories, since participants were not provide with their preferred source of information. However, in the fourth time-trial (TT_{PRIME}) accumulated fixation and gaze frequency was calculated for two categories, primary and other. To normalize absolute visual fixation times for inter-participant differences in time-trial performance, fixation data were all converted from absolute time (ms) to percentage of time-trial completion time.

Time-trial average cycling performance (speed, power, cadence, HR, and RPE), fixation time and frequency for secondary source of information interactions between trials were analysed using one-way repeated-measures ANOVAs. Two-way mixed ANOVAs were also used to analyse condition-by-distance interactions in cycling pace (speed, power, cadence and HR), RPE as well as relative fixation time and gaze frequency for the primary, secondary visual categories. A paired-sample t-test was used to measure the differences in average relative fixation time and gaze frequency for primary, secondary through to nonary sources of information).

For both performance, pace and visual data, significant interactions were followed up using planned post-hoc comparisons for overall performance and between segments using paired-samples *t* tests for within-group comparisons. All results are expressed as mean (SD) and effect sizes as partial eta squared.

4.3 Results

4.3.1 Time-Trial Performance

One-way repeated-measure ANOVA revealed differences between trial in overall speed $F_{2,26}$=10.3, P=0.002, η_p^2=.442. Bonferroni-corrected post hoc paired samples t-tests revealed that compared to $TT_{ALL\text{-}PRIME}$ participants were faster in both TT_{PRIME} (t_{13}=3.6, P=0.0015, η^2=0.493), and TT_{ALL} (t_{13}=3.3, P=0.0025, η^2=0.459) (Figure 4-2). Overall power $F_{2,26}$=8.4, P=0.005, η_p^2=.391. Bonferroni-corrected post hoc paired samples t-tests revealed that overall power was higher in TT_{PRIME} (t_{13}=21.3, P=0.000, η^2=0.95) compare with $TT_{ALL\text{-}PRIME}$ (Figure 4-3). A significant difference in overall cadence was also found, $F_{2,26}$=4.5, P=0.021, η_p^2=.259. Bonferroni-corrected post hoc paired samples t-test revealed significant differences between TT_{PRIME} and $TT_{ALL\text{-}PRIME}$ (t_{13}=2.7, P=0.008, η^2=0.36) (Figure 4-4). Mean and standard deviation data for performance time-trial outcomes (speed, completion time, power, and cadence) are given in Table 4-1 for both overall time-trial and segment.

Table 4-1 Mean and (1SD) for performance, heart rate and RPE time-trial data for trial and segment

		1 km	2 km	3 km	4 km	5 km	Overall
Speed (km/hr^{-1})	**TT$_{ALL}$**	37.9(2)	37.4(2.2)	37.4(2.2)	37.3(2.4)	38.8(2.1)	37.8(2.1)
	TT$_{PRIME}$	37.9(2)	37.9(2.1)	37.7(2)	37.7(2.2)	39.2(1.8)	38.1(1.9)
	TT$_{ALL-PRIME}$	36.6(2.3)	37.3(2.1)	37.2(1.9)	37.1(2.1)	37.8(2.1)	37.2(1.9)
Completion Time (s)	**TT$_{ALL}$**	95.3(5.2)	96.6(5.7)	96.4(6.2)	96(6.4)	93(5.1)	478.3(26.1)
	TT$_{PRIME}$	95.2(5.1)	95.1(5.2)	95.7(5.1)	95.9(5.7)	92(4.4)	473.9(23.7)
	TT$_{ALL-PRIME}$	98.9(6.4)	96.9(6.1)	96.9(5)	97.4(5.7)	95.5(5.2)	485.6(25.3)
Power (W)	**TT$_{ALL}$**	307.4(45.9)	273(37)	270.7(37.4)	265.5(38)	296.5(40.2)	282.6(36.5)
	TT$_{PRIME}$	307.8(41.2)	287.7(38)	275(35.8)	274.4(32.6)	308.0(36.7)	290.6(30.9)
	TT$_{ALL-PRIME}$	286.5(45.8)	270.6(37.3)	268.5(30.9)	262.9(32.2)	276.4(37)	273(32.2)
Cadence (r.min^{-1})	**TT$_{ALL}$**	102.8(8.2)	104.0(7.8)	103.47.9)	104.1(7.4)	104.1(8.7)	103.7(7.6)
	TT$_{PRIME}$	99.9(11)	99.4(12.4)	98.9(12.2)	98.4(12)	98.1(12.3)	98.9(11.7)
	TT$_{ALL-PRIME}$	108.2(9)	106.9(10.4)	104.8(11.4)	103.9(10.8)	103.9(11.3)	105.5(10.2)
Heart Rate (b.min^{-1})	**TT$_{ALL}$**	142.8(11.9)	165.1(11.8)	169.2(9.5)	172.4(8.4)	175.9(10)	165.1(8.6)
	TT$_{PRIME}$	142.3(8.7)	163.6(9)	168(9.3)	172.7(9.5)	176.8(10)	164.7(8.8)
	TT$_{ALL-PRIME}$	142.2(11)	160.7(10)	168.9(9.1)	173.3(8.8)	178.1(8.8)	164.4(8.2)
RPE	**TT$_{ALL}$**	12.4(1.1)	13.7(1.4)	15.1(1.2)	16(1.3)	18(1.9)	15(1.1)
	TT$_{PRIME}$	12.2(1.7)	14.2(1.6)	15.1(1.6)	16.2(1.6)	17.5(1.2)	15(1.4)
	TT$_{ALL-PRIME}$	12.6(1)	14.3(1)	15.4(1.3)	16.5(1.3)	17.8(1.9)	15.4(1)

All values presented are trials means ± (1SD) for each segments (1 km, 2 km, 3 km, 4 km, 5 km). Valuespresented in overall column are calculated as the mean ± (1SD) for the whole TT (0-5)km.

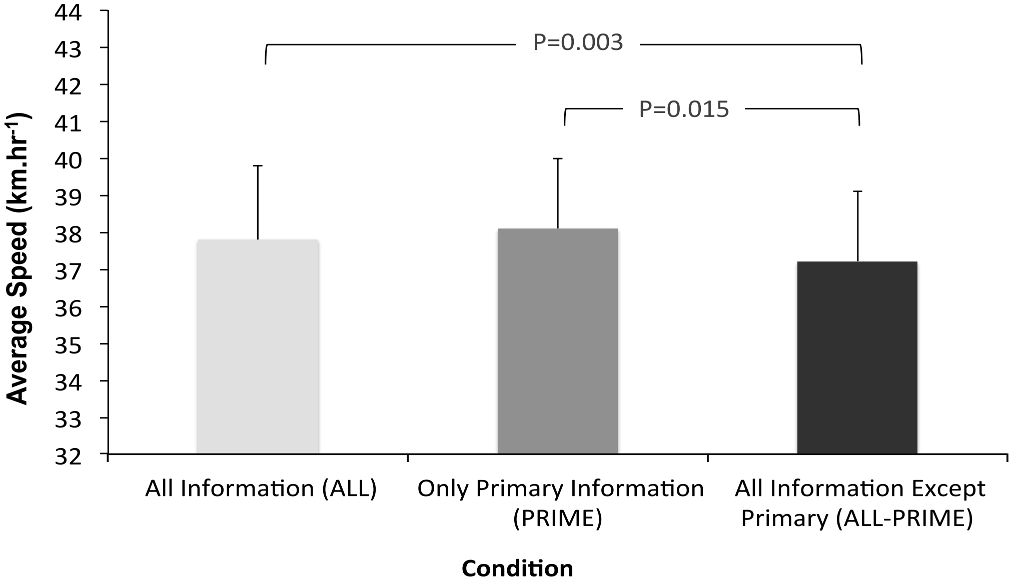


Figure 4-2 Average cycling performance between trials for speed.

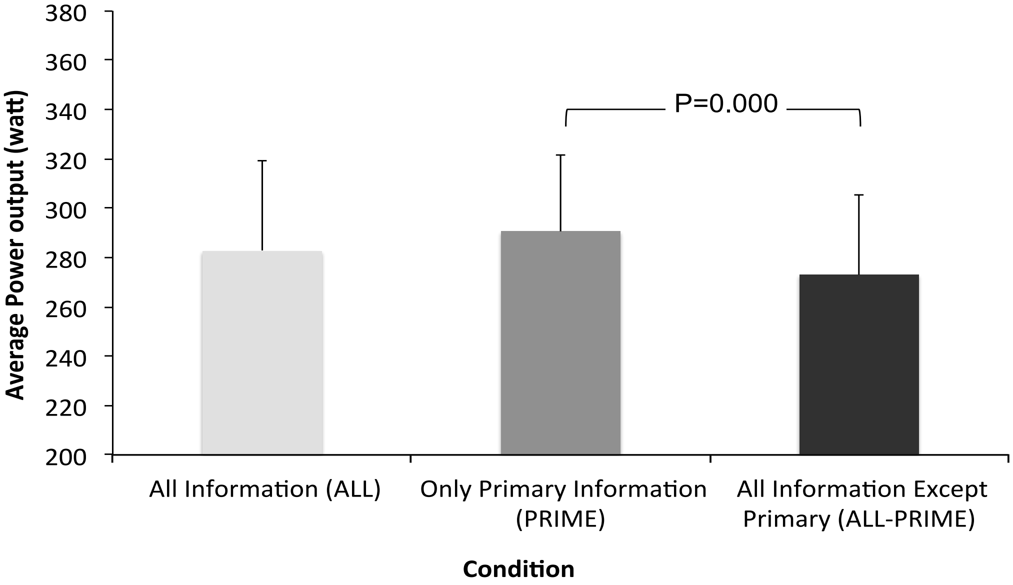


Figure 4-3 Average cycling performance between trials for power output.

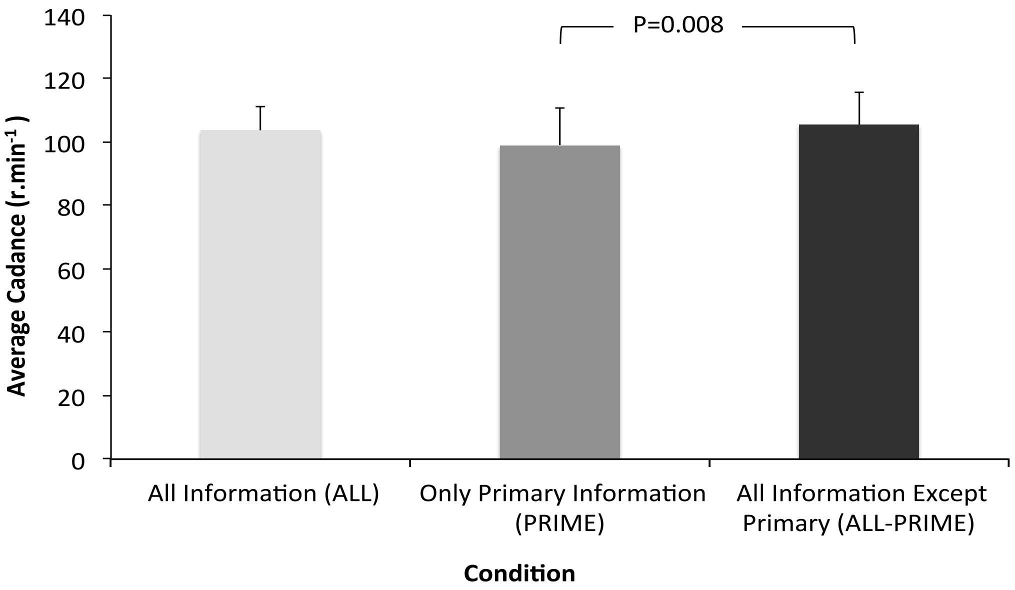


Figure 4-4 Average cycling performance between trials for cadence.

4.3.2 Time-Trial Pace

Two-way repeated-measure ANOVA revealed no trial-by-segment interaction for cycling pace (km.hr^{-1}) $F_{8,104}$=1.9, P=0.15, η_p^2=.126, power (w) $F_{8,104}$=1.7, P=0.19, η_p^2=.116, and cadence $F_{8,104}$=2.3, P=0.077, η_p^2=.151. A segment mean effect was detected for both speed $F_{4,52}$=5.9, P=0.004, η_p^2=.313, and power $F_{8,104}$=14.5, P=0.000, η_p^2=.528. Post hoc paired samples t-test outcome between TTs for each 1 km segment for speed showed a significant difference between TT_{ALL} and TT_{PRIME} in the second km segment t_{13}=-2.9, P=0.007, η^2=0.39, no farther significant differences were found (Figure 4-5). A significant difference between TT_{ALL} and $TT_{ALL\text{-}PRIME}$ in the first and last km segment were found t_{13}=3.6, P=0.002, η^2=0.5, and t_{13}=2.3, P=0.02, η^2=0.28 respectively, no farther differences were found (Figure 4-6). In addition, a significant difference between TT_{PRIME} and $TT_{ALL\text{-}PRIME}$ in the first, fourth and last km segment were found t_{13}=2.6, P=0.01, η^2=0.34, t_{13}=2.3, P=0.019, η^2=0.29, and t_{13}=2.5, P=0.015, η^2=0.31, no farther differences were found (figure 4-7).

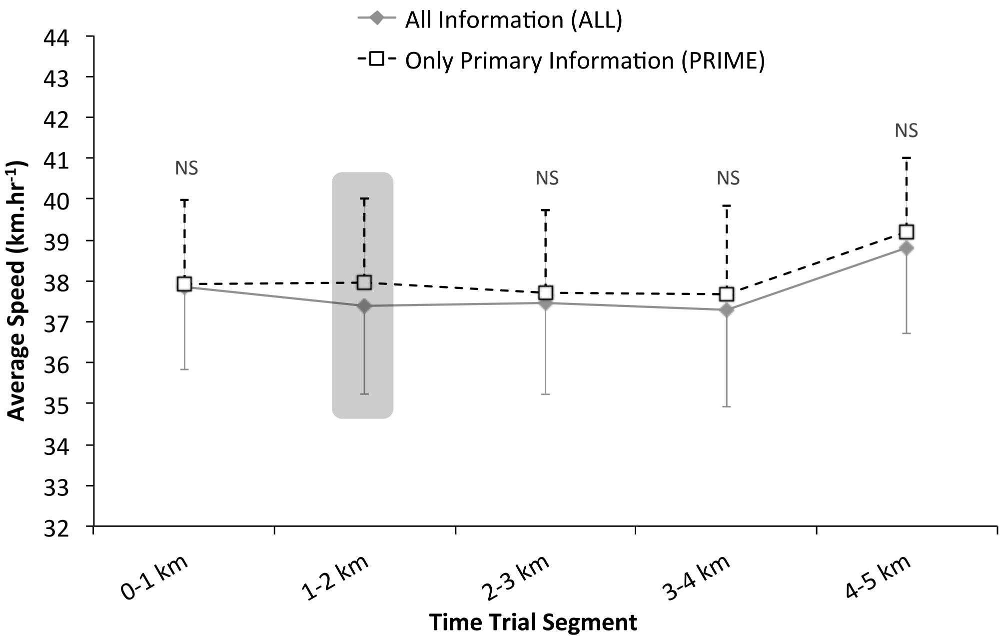


Figure 4-5 Speed pacing profile between TT $_{(ALL)}$ and TT $_{(PRIME)}$.

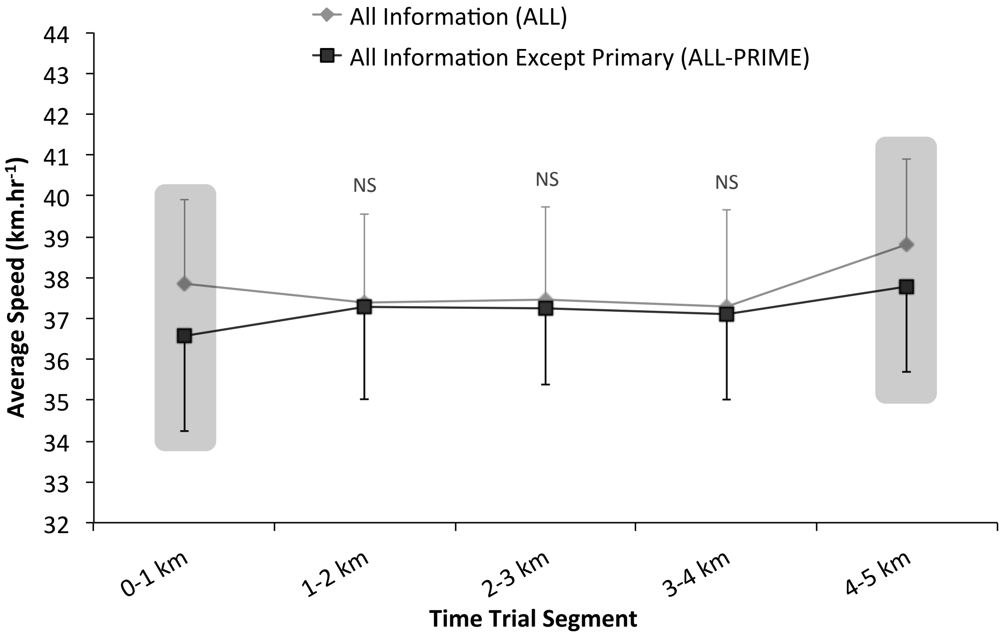


Figure 4-6 Speed pacing profile between (TT $_{(ALL)}$ and TT $_{(ALL-PRIEM)}$).

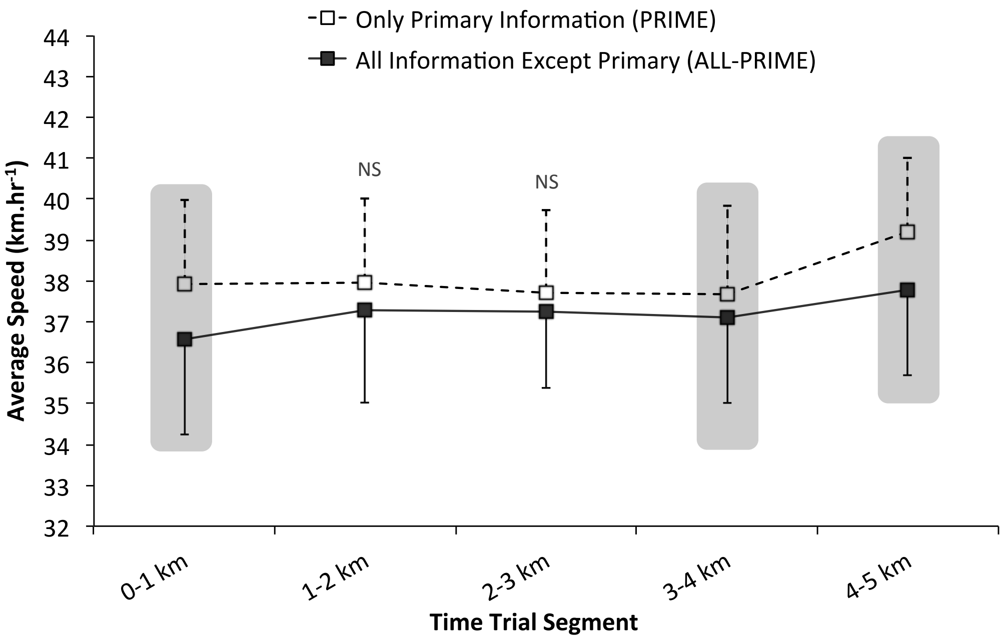


Figure 4-7 Speed pacing profile between TT $_{(PRIME)}$ and TT $_{(ALL\text{-}PRIEM)}$.

Post hoc paired samples t-test outcome between TTs for every 1 km segment for power output showed a significant difference between TT_{ALL} and TT_{PRIME} in the second km segment t_{13}=-3.2, P=0.004, η^2=0.43, no farther significant differences were found (Figure 4-8). A significant difference between TT_{ALL} and $TT_{ALL\text{-}PRIME}$ in the first and last km segment were found t_{13}=2.8, P=0.008, η^2=0.37, and t_{13}=2.3, P=0.02, η^2=0.28 respectively, no farther differences were found (Figure 4-9). In addition, a significant difference between TT_{PRIME} and $TT_{ALL\text{-}PRIME}$ in the second, fourth and last km segment were found t_{13}=2.4, P=0.017, η^2=0.30, t_{13}=1.9, P=0.036, η^2=0.22, and t_{13}=2.5, P=0.013, η^2=0.33, no farther differences were found (figure 4-10).

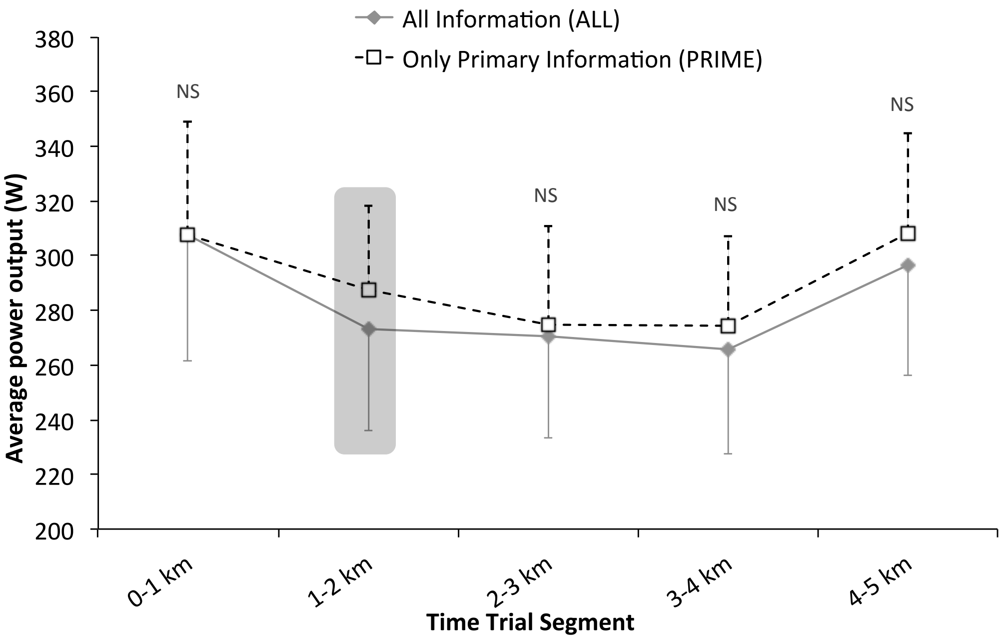


Figure 4-8 Power pacing profile between TT (ALL) and TT (PRIME).

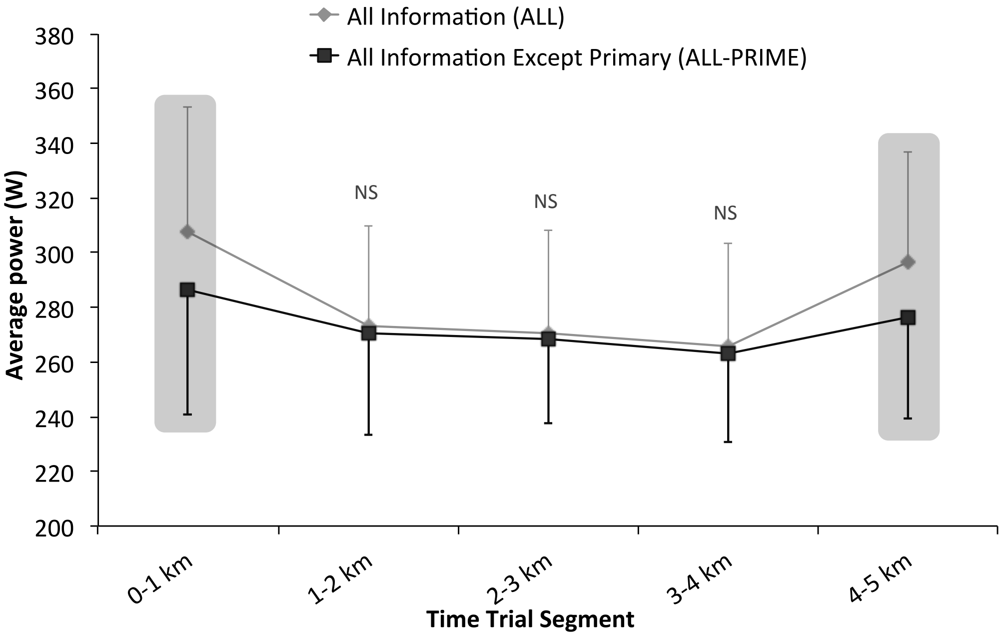


Figure 4-9 Power pacing profile between TT (ALL) and TT (ALL-PRIEM).

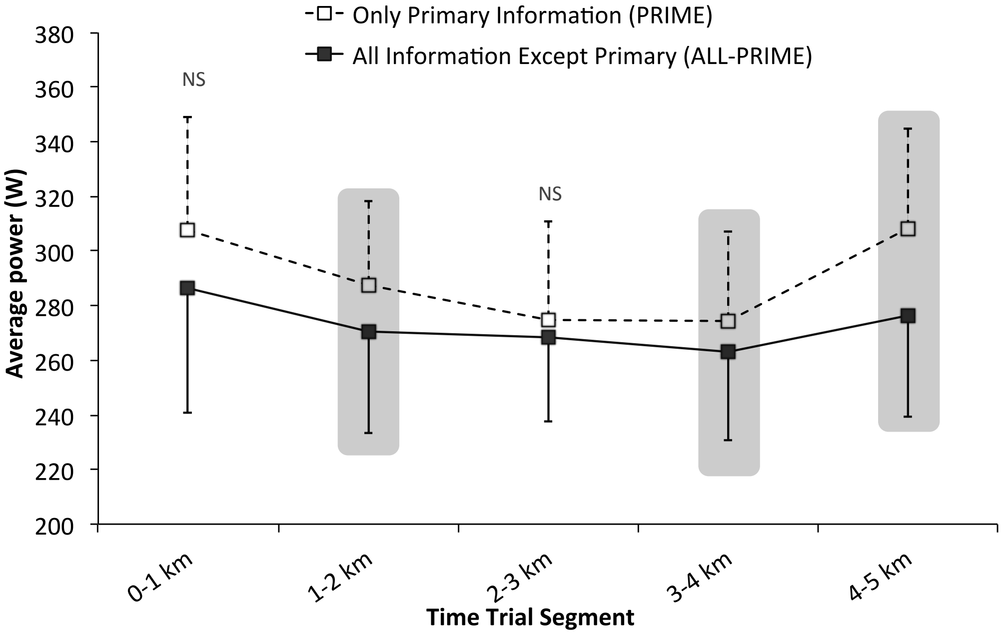


Figure 4-10 Power pacing profile between TT $_{(PRIME)}$ and TT $_{(ALL-PRIEM)}$.

4.3.3 Heart Rate and RPE Data

Two-way repeated-measure ANOVA revealed no trial-by-segment interaction for HR (b.min^{-1}) $F_{8,104}$=1.4, P=0.203, η_p^2=.114, and overall differences $F_{8,104}$=1.9, P=0.3, η_p^2=.150. The test also showed no trial-by-segment differences in RPE $F_{8,104}$=1.4, P=0.492, η_p^2=.06. Mean and standard deviation data for heart rate and RPE are given in Table 4-1 for both overall time-trial and distance segments.

4.3.4 Whole Time-Trial Eye-Tracking Outcomes: Information Gaze Duration

Paired samples t-test for overall relative gaze fixation (% time-trial duration) for primary source of information revealed that compared to TT_{ALL}, participants increased gaze fixation in TT_{PRIME} (33.1±8.6% vs. 60.5±8.1%, t_{13}=-10.2, P=0.000, η^2=0.88). A two-way repeated measure ANOVA for primary source of information between segment in TT_{ALL} and TT_{PRIME}, since participants were not provided with their primary information in $TT_{ALL-PRIME,}$ revealed no Trial-by-segment interaction for relative gaze fixation, $F_{4,\ 52}$=0.5, P=0.637, η_p^2=.03, and no between segments interaction $F_{4,52}$=2.2, P=0.109, η_p^2=.146.

One-way repeated measure ANOVA for overall relative gaze fixation revealed differences in the secondary source of information $F_{2, 26}$=25.2, P=0.000, η_p^2=0.66. Bonferroni-corrected post hoc paired samples t-test revealed differences between TT_{ALL} and TT_{PRIME} t_{13}=-6.5, P=0.000, η^2=0.76, and between TT_{ALL} and $TT_{ALL\text{-}PRIME}$ t_{13}=9.1, P=0.000, η^2=0.86. Two-way repeated measure ANOVA for secondary source of information between segment revealed no trial-by-segment interaction between TTs $F_{8,104}$=1.0, P=0.391, η_p^2=.07, and no between segment interactions $F_{8,104}$=0.3, P=0.739, η_p^2=.024. A post hoc paired samples t-test was executed for the average relative gaze fixation from tertiary through to nonary information source between TT_{ALL} and $TT_{ALL\text{-}PRIME}$. Gaze duration data for primary through to nonary information sources calculated over the full 5 km time-trials are presented in (Figures 4-11).

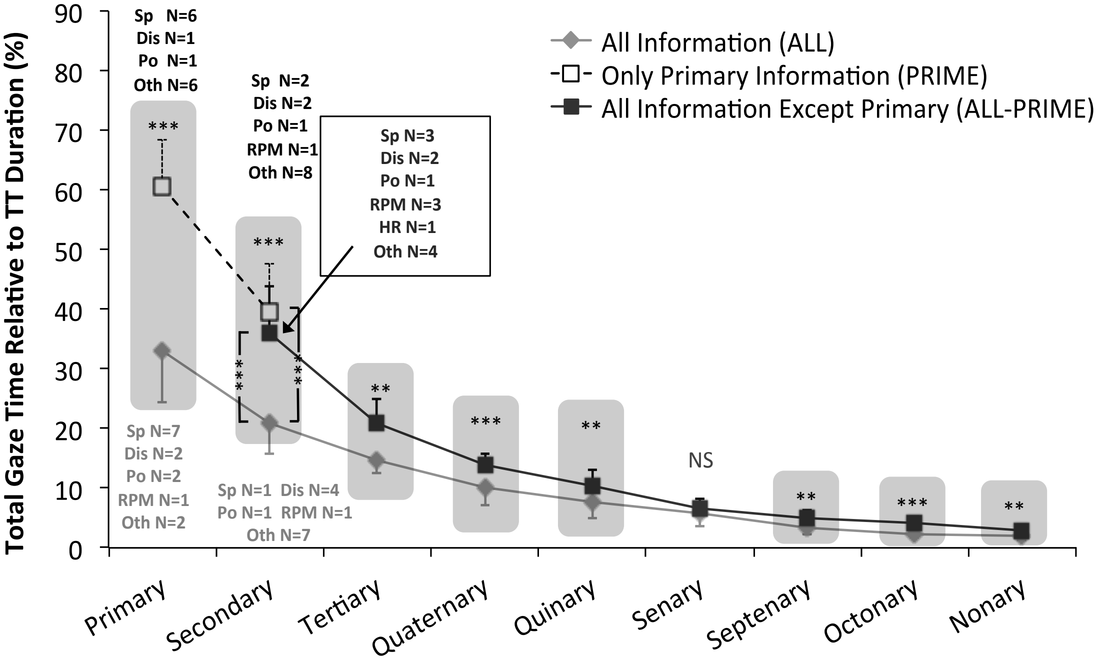


Figure 4-11 TTs eye-tracking outcome for primary (most looked at) through to nonary (least looked at) information sources calculated over the full 5 km distance for relative gaze duration and. * denotes P<0.05; ** denotes P<0.01; * denotes P<0.001, NS denotes not significant.**

4.3.5 Whole Time-Trial Eye-Tracking Outcomes: Information Gaze Frequency

Paired sample t-test for overall gaze frequency for primary source of information revealed no significant differences between TT_{ALL} and TT_{PRIME} (107 ±31.9 vs. 109±26.2, t_{13}=0.2, P=0.838). Two-way repeated measure ANOVA for primary gaze frequency between TT_{ALL} and TT_{PRIME}, since participants were not provided with their primary information in $TT_{ALL\text{-}PRIME,}$ revealed no Trial-by-segment interaction $F_{4,52}$=0.7, P=0.568, η_p^2=.05, and no between segment interaction $F_{4,52}$=2.1, P=0.114, η_p^2=.0.142.

One-way repeated measure ANOVA for overall gaze frequency revealed differences in the secondary source of information $F_{2,\ 26}$=9.5, P=0.001, η_p^2=0.424. Bonferroni-corrected post hoc paired samples t-tests revealed differences between TT_{ALL} and TT_{PRIME} t_{13}=-3.7, P=0.0015, η^2=.570, and between TT_{ALL} and $TT_{ALL\text{-}PRIME}$ t_{13}=-3.7, P=0.0015, η^2=.509. Two-way repeated measure ANOVA showed no trial-by-segment interaction for gaze frequency between TTs for the secondary source of information $F_{8,104}$=0.8, P=0.500, η_p^2=.06, and no between segment interactions $F_{8,104}$=2.5, P=0.086, η_p^2=.161. A post hoc paired samples t-test was executed in total gaze frequency from tertiary through to nonary information source between TT_{ALL} and $TT_{ALL\text{-}PRIME}$. Gaze frequency data for primary through to nonary information sources calculated over the full 5 km time-trials are presented in (Figures 4-12).

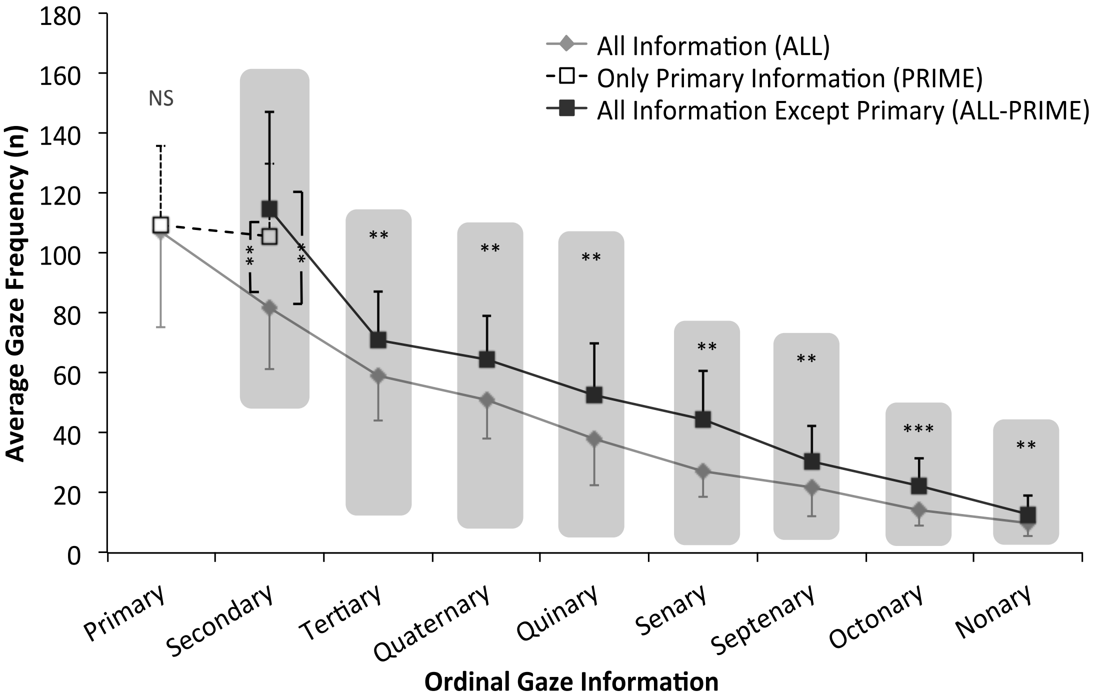


Figure 4-12 TTs eye-tracking outcome for primary (most looked at) through to nonary (least looked at) information sources calculated over the full 5 km distance for Gaze frequency. * Denotes P<0.05; ** denotes P<0.01; * denotes P<0.001, NS denotes not significant.**

4.4 Discussion

The principal findings of this study indicate that participants perform slower when isolated from the preferred feedback information. Participants produced a higher speed and PO when they had either all performance related feedback provided or only the preferred feedback, this was apparent in TT_{ALL} and TT_{PRIME} (Figures 4-2& 4-3). In previous studies (Albertus *et al.*, 2005; Les. Ansley *et al.*, 2004; Micklewright *et al.*, 2010), it was found that cyclists produced similar performance even when they received false feedback, suggesting that varying the type of feedback is insufficient to influence performance. In addition, Mauger *et al.* (2009a) found that distance feedback has no influence on performance, and athlete can perform similarly based on the prior experience. This indicates that relative distance can be created within the brain making prior knowledge of task demands sufficient for experienced athletes to produce a comparable completion time to that when receiving full feedback. This was recently supported by Smits *et al.* (2016); they found no difference between groups in overall performance during 20 km cycling TT, whether participants had full performance related feedback or no feedback. Despite the previous studies above, in general, there is an assumption that feedback enhances performance, Mauger *et al.*, (2009) found that the provision of accurate performance feedback improves performance suggesting that performance feedback motivation can optimise the regulation of exercise intensity. The differences in overall performance in this study were perhaps because of the cautiousness that was acquired in isolation preferred performance feedback. No differences in completion time and produced power between TT_{ALL} and TT_{PRIME} indicate that participants can perform well with access to only a single preferred source of information.

Albertus et al. (2005) found that during a 20 km TT, no change in pacing strategy were observed when participants were provided with incorrect distance feedback. In contrast, other studies Mauger *et al.* (2009b) Micklewright *et al.* (2010) and Smits *et al.* (2016) found that the availability of correct performance related information influence pacing strategy. Interestingly, our finding adds that deprived cyclists from their preferred performance information lead to develop a different pacing strategy. This was most apparent in the first and last km segments between TTs (Figures 4-6, 4-7, 4-9 & 4-10), indicating that the sort of available information determine pacing strategy. Suggesting that the way cyclists select information differ according to their behaviour and expertise level, a piece of information could be of more interest to a cyclist and of less importance to other. In the first study (chapter three) Boya *et al.* (2017) found that experienced cyclists who were provided with performance related feedback including (speed, distance, PO, cadence, HR, and time) were mainly directed their gaze to speed information during their trials. Moreover, Micklewright *et al.* (2010) stated that experienced cyclists may successfully pace themselves according to speed and PO feedback that might indicates that a single preferred performance feedback could lead to a successful pacing. The result showed that the availability of unnecessary to many types of performance feedback might distract attention and therefore the performance and pacing decision. Gigerenzer (2008) state that in complex situations, human decision makers often use simple rules that neither require all available relevant information nor integrate the information that is used but that however allows them to accomplish their aims quickly and effectively.

A further important finding of the current study was that participants differed in information-seeking behaviour and the types of information they looked at. During TT_{ALL}, when participants information acquisition was measured to identify the primary source of information, distance were looked at by just (2/14, ‘3/14 ignoring other’) as a primary source of information, while interestingly, speed was the primary source of information for (7/14, ‘8/14 ignoring other’) (Figure 4-11). This is notable to be an important finding, most of the previous pacing models (Les. Ansley *et al.*, 2004; Billaut *et al.*, 2011; DeKoning *et al.*, 2011; Faulkner *et al.*, 2011; Foster *et al.*, 2009; Marcora, 2008; Noakes *et al.*, 2006; St Clair Gibson *et al.*, 2003), were proposed to evaluate the importance of certain type of information in effort regulation, and placed a lot of emphasis on the role of knowledge of endpoint on pacing strategies, suggesting that different pacing strategies could be developed when participants are incorrectly informed or blinded from the TT endpoint. Despite the useful direction of investigation, the role of certain information on pacing behaviour provided by such methods, a few limitations have been pointed out (previously mentioned in Chapter 1 section 1.6.3).

Further evidence for the role of the endpoint in effort regulation can be find in In $TT_{ALL\text{-}PRIME}$, despite (11/14) participants being provided with distance information and deprived from preferred information, participants performed slower and produce different pacing strategy, indicating that the availability of distance feedback is not essential in effort regulation. Evidence to support this can be found in a study by Ansley et al. (2004); the study showed that distance feedback is inessential in producing an optimal pacing in a successive 4 km TT. However, (3/14) participants were seeking distance that may suggest that pacing-decision is based on individual behaviour in term of selecting feedback information. Therefore, measuring eye movement and eye fixation provide a more sophisticated method to determine the information acquisition and the important placed upon certain type of feedback provided using eye-tracker. However, we mainly acknowledge that eye-tracker helps collecting information about what participants mostly look at during a specific event, and it does not reveal information about what athletes think and how they make decision.

To my knowledge, this study is the first to measure the influence of preferred performance-related feedback information on overall performance and pacing decision using eye-tracker. Most of previous study determine changing in pace by providing participant with correct, incorrect, or blind distance feedback or/and applied similar experimental condition to all participants, apart from Smits *et al.* (2016) study which provided the participants with either six different types of task-related information feedback or no feedback. However, the study was unable to show whether the change in pace was due to distance knowledge or other task related information. Knowledge of distance might be important at the end of race to show the end spurt, for some participants, or during the whole event for others, but it is not necessary to be the only and most important performance information that effect pace and performance, especially during a flat course TT. Future studies should focus on differences between participants preferring different type of performance feedback.

During TT_{PRIME} participants increased the relative amount of time they spent looking at the primary information source, regardless of the type of information they were selected, from 33% to 60% showing that they became more focused, despite no significant differences in performance were found between TT_{ALL} and TT_{PRIME}, participants were four second faster in TT_{PRIME}; this might indicate a relation between what the individual looks at is associated with performance, suggesting that subjects might use fixation time for physiological and psychological regulation (Williams *et al.*, 2002; DeOliveira *et al.*, 2008). However, participants performed slower and developed a different pacing strategy when they were isolated from their preferred feedback information. This might be because participants developed performance expectations from their experience of relying on a certain types of performance information that, when not available to them, lead to a different pacing strategy.

4.5 Conclusion

The current study provides a first indication that deprived cyclist from preferred feedback information influence pacing and performance, and that a single preferred source of information is enough to pace perfectly and perform similarly. It seems that pacing is based more on fewer but preferred performance information feedback rather than providing a lot, but not useful or needed information. Furthermore, it indicates that the availability of too many sources of feedback information may have distracting or confusing effects compared to condition when preferred information is available. Another important finding in this study is that participants differ in the sort of preferred information, in which knowledge about the endpoint ‘distance’ is not important to be the only source of information that athlete can rely on to perform well. But there is other performance related information such as speed and power output that are important and such a priority might rely on the individual behaviour or previous experience.

5 Chapter Five - The Effect of Continuous, Intermittent and Blind Preferable Performance Information Feedback on Pacing and Performance

5.1 Introduction

Adopting a successful strategy by an athlete has a significant impact on performance. It is crucial for athletes to know how and when to invest their energy to regulate the exercise intensity (Smits *et al.*, 2014). Recent frameworks Smits *et al.* (2014) and Renfree *et al.* (2014) suggest that pacing is a decision-making process depends on number of (previously mentioned) factors. Variation in pace through the race might reflect the behaviour respond to the available internal and external information. One of the most common questions in pacing area is what influences the selection of an optimal pacing.

In previous pacing model such as, the teleoanticipation theory (Ulmer *et al.*, 1996) and the CGM (Noakes *et al.*, 2005), distance knowledge as performance feedback has been emphasised to determine the pace and pacing strategy, suggesting that pacing and intensity is predetermined in a feedforward manner before the onset of the exercise. Performance feedback has been found to influence pacing and performance, such contribution has been examined in the area of deception in an existing review (Jones *et al.*, 2013), however, most of the deceptive feedback intervention researches have focused on the knowledge of the remaining exercise bout ‘endpoint’. Previous experience has also been found to influence pacing strategy (Micklewright et al., 2010; Edwards and Polman, 2013; Smits et al., 2014). Micklewright *et al.*, (2016) however, state that pacing decision is a multidimensional process, proposing a framework based on the ecological psychology and the interdependence of perception and action. The review suggested that limiting our understanding of pacing decision to one conscious/subconscious dimension would leave other athletic behaviour unexplored. Such multidimensional process will enhance our understanding of athletic behaviour in complex situation; however; to do so, a special research technique known as process tracing is needed.

Visual search strategy is the way that performers move their eyes to focus on selected area of environment (Moreno *et al.*, 2002). The visual search literature suggests that eye movement, which is the result of an interaction between cognitive and perceptual process (Richardson & Johnson, 2008), could be a useful way to investigate psychological process such as cognitive and decision-making (Mele & Federici, 2012). The fixation duration of the selective point is indicative of perceptual strategy and decision-making. It has been assumed that visual orientation is related to information extraction and visual attention (Williams & Davids, 1998). Visual information is required in almost all the decision-making processes, but differs according to task or individuals goals; it is valued very differently in each case. Eye movement and eye fixation measurement is on way of investigation information acquisition processes, which provide an alternative to deception and blinding studies (Micklewright *et al.*, 2016). In a more recent study (Boya *et al.*, 2017), using eye-tracking, found differences in information acquisition between novices and experienced cyclists. The study shows that distance is not the only performance feedback information do cyclists prefer during TT, as it was previously known, but also other performance information. The majority of experienced cyclists preferred other type of performance information ‘speed’ as a primary source of information, indicating that cyclists might rely on other sources, rather than distance, to regulate themselves, and that information acquisition differ according to the level of experience.

In study two, a published conference paper, Boya & Micklewright (2016) examined the role of performance feedback information in pacing and performance; the study found that participants differ in the way they select their performance feedback information and a piece of information might be important for one and of a less interest for other. More interestingly, the result showed that performing a 5 km cycling TT without the preferred feedback information effect cyclists overall performance and pacing strategy. The study suggests that participants perform similar when the preferred information was available. However, they were provided with preferred performance information throughout the whole TT. The aspect that still needs to be investigated is whether cyclists continually need the preferred information, or having it in intermittent time period will be enough to perform comparable and produce a similar pacing strategy. Thus, the aim of this study was to examine the influence of preferable feedback information on effort distribution and performance by identifying how performance and pacing respond when the frequency of exposure to preferred information is reduced. It was hypothesised that cyclists would distribute the exercise intensity and performer similar TT time as far as they have received the preferred information feedback, whereas blind feedback would negatively effect performance time and pacing decision.

5.2 Method

5.2.1 Participants

Fifteen experienced cyclists were recruited for this study, however three participants were excluded due to unclear eye-tracking video ‘ loss of calibrations’. The twelve remaining participants had a good pre and post calibration. Mean ± 1SD participant age, stature and body mass was (35.6 ± 7.8 years, 176.1 ± 6.8 cm and 79.3 ± 10.2 kg). Participants had cycling experience for an average of 11.6 ± 10.1 years, training on average 3.2 ± 1.3 sessions per week for a total of 1:42 ± 00:24 hours:mins per session.

5.2.2 Design

A two-way repeated-measures (trial-by-segment) experimental design was used in which participants performed a 5 km cycling time trial TT on six separate occasions, comparing pace, performance and visual behaviour every 500 m. The within-subject trial factor incorporated variations to the type of information presented to participants and how often it was presented. All participants had a recovery period of 5 to 7 days between time-trials. Before each TT, participants performed a

5-minute self-paced warm-up. The first TT was a familiarization self-paced 5 km cycling time trial (TT_{FAM}) during which several types of performance feedback (power output, speed, distance, cadence, heart rate, and performance time) were projected on a wall in front of them (see chapter two section 2.2.4). The second TT was identical (TT_{ALL}) except participants wore a mobile eye-tracker (SMI eye-glasses) to identify the primary (preferred) type of information looked at. Experimental manipulations of information presentation were carried out in the remaining four randomly counter-balanced TT that included continuous presentation of primary (preferred) information (TT_{PRIME}), 15 sec presentation of primary information every 500 m (TT_{500}), 15 sec presentation of primary information every 1000 m (TT_{1000}), and without the presentation of any information (TT_{BLIND}). The general experimental procedures for this study are given in Chapter 2 (2.3.7)

5.2.3 Cycling Ergometer and Video Simulation

All participants performed a 5-minute self-paced warm-up followed by 5 km cycling time trial using Velotron (3D) Racer Mate (previously explained in chapter two) on 6 separate occasions. In TT_{FAM} and TT_{ALL}, a large video simulation was projected onto a wall in front of participants to displayed various types of real time performance feedback information, see chapter two section (2.2.4). In TT_{PRIME}, a video simulation of just the preferred feedback information was projected using a designed box see chapter four section (4.2.4). The same box was used in TT_{500} and TT_{1000}, to present the information for 15 second every 500 m and 1 km sequentially. In TT_{BLIND}, no information was presented in front of cyclists. Cycling performance was continuously measured and calculated as an average every 500m segments. Participants were informed that information would be presented randomly in 5 different occasions in $TT_{1000,}$ and 10 different occasions in TT_{500}, All the TTs were performed at the same time of the day ± one hour in a randomized order.

5.2.4 Psychophysiological measures

Heart rate (HR) was recorded during all cycling time trials. Average HR was calculated every 500 m segment. Participants were also asked about rating of fatigue (ROF) in four different occasions. After the warm-up, before the start of the race, directly after the race, and after 5 minutes from the race. See chapter two section (2.3.6.1 and 2.3.6.3).

5.2.5 Visual behaviour

Participants were fitted with a SensoMotoric Instruments SMI iView ETG eyeglasses eye-tracker device. Eye-movement was continuously recorded during each TT and the footage from the eye tracker was reviewed and manually coded using the previously mentioned video-coder2 program (see section 2.3.9). Eight categories were created to calculate the frequency and the fixation time in TT_{ALL}, in which six categories related to performance information (speed, elapsed distance, power output, cadence, heart rate and elapsed time), one category for the video simulated footage, and a final category to code anything else such as the lab floor, or in case of losing signal (other). Fixation time and frequency looking at each category, or object of regard, was subsequently calculated for each TT segment and across the whole TT.

5.2.6 Data Processing and Statistical Analysis.

Visual data was presented on participant-by-participant basis. In TT_{ALL}, accumulated fixation time and gaze frequency for each of the eight categories (speed, elapsed distance, power output, cadence, heart rate, elapsed time, video simulation and other) was calculated for the whole TT and every 500 m segment. Accumulated fixation times were then used to determine what information source each participant looked at for the longest accumulated average time, see chapter two section (2.3.9) (2.3.10), chapter three section (3.2.7). In TT_{PRIME}, TT_{500} and $TT_{1000,}$ the accumulated fixation time and gaze frequency was calculated for two categories (prime and other) for the whole time-trial on participant-by-participant basis and every 500m segment, however, it was presented as percentage of segment completion time in TT_{PRIME}, while it was presented as a percentage of the presented time in TT_{500} and $TT_{1000.}$

Time-trial average cycling speed, power output, cadence and heart rate between time-trials was analysed using one-way ANOVAs. Two-way repeated measure ANOVAs were used to analyse trial-by-segment interactions in average cycling speed, power output, cadence and heart rate. All the significant interactions were followed up using planned post-hoc comparisons between segments using paired-samples t test comparisons. All results are expressed as mean (SD) and effect sizes as partial eta squared.

5.3 Results

5.3.1 Time-Trial Performance

Performance outcomes (speed, completion time, power, cadence, and heart rate) for each TT segment and the whole TT are given in Table 5-1. Mean finishing times for TTs were 477.9 ± 30.4 sec for TT_{ALL}, 477.3 ± 30.1 sec for TT_{PRIME}, 481.7 ± 33 sec for TT_{500}, 482.8 ± 29.6 sec for TT_{1000} and 489.6 ± 30.6 sec for TT_{BLIND}. One-way repeated-measure ANOVA revealed differences between trials in overall speed $F_{4,44}$=4.8, P=0.003, η_p^2=0.306. Bonferroni-corrected post hoc paired samples t-tests revealed differences in overall speed between TT_{ALL} and TT_{BLIND} (t_{11}=4.5, P=0.001, η^2=0.642), and between TT_{PRIME} and TT_{BLIND} (t_{11}=6.9, P=0.000, η^2=0.81) (Figure 5-1). Overall power $F_{4,44}$=4.2, P=0.005, η_p^2=.278. Bonferroni-corrected post hoc paired samples t-tests revealed differences between TT_{ALL} and TT_{BLIND} (t_{11}=3.9, P=0.002, η_2=0.58), and between TT_{ALL} and TT_{BLIND} (t_{11}=5.8, P=0.002, η^2=0.75) (Figure 5-2).

No significant differences in overall cadence was found between trials, $F_{4,44}$=0.9, P=0.46, η_p^2=0.07. Familiarization TT values are presented in (Table 5-2).

Table 5-1 Mean and (1SD) for performance and heart rate time-trials data for trials and segments.

		0.5 km	1 km	1.5 km	2 km	2.5 km	3 km	3.5 km	4 km	4.5 km	5 km	overall
Speed (km/hr^{-1})	TT_{ALL}	36.9(3.7)	38.4(2.4)	37.5(2.6)	37.7(2.5)	37.7(2.7)	37.8(2.4)	37.4(2.7)	37.4(2.8)	37.9(2.5)	39.9(2.8)	37.9(2.5
	TT_{PRIME}	36.8(3.3)	38.5(2.5)	37.8(2.6)	37.6(2.9)	37.5(2.9)	37.7(2.7)	37.9(2.6(	37.6(2.6)	38.6(2.6)	39(2.1)	37.9(2.5)
	TT_{500}	37.1(4.5))	37.9(3.1)	37.6(2.8)	37.2(2.7)	37.3(3)	37.5(2.8)	37.9(3.1)	37.3(2.8)	37.7(2.7)	38.4(2)	37.6(2.6)
	TT_{1000}	36.3(4.3)	38.1(3.1)	37.8(2.5)	37.5(2.3)	37.4(2.7)	37.2(2.3)	37.5(2.6)	37.3(2.5)	37.8(2.3)	37.9(2.7)	37.5(2.4)
	TT_{BLIND}	37.4(5.2)	38(3.5)	37(2.5)	37(2.2)	37(2.2)	36.7(2.2)	36.8(2.4)	36.4(2)	36.4(2.6)	36.3(2.7)	36.9(2.4)
Completion Time (s)	TT_{ALL}	49.3(4.8)	47.1(2.8)	48.2(3.2)	48(3.2)	48(3.3)	47.8(3)	48.3(3.3)	48.4(3.5)	47.6(3)	45.3(3.1)	477.9(30.4)
	TT_{PRIME}	49.3(4.2)	46.9(2.8)	47.8(3.2)	48.2(3.5)	48.3(3.5)	47.9(3.4)	47.7(3.3)	48.1(3.2)	46.8(3.2)	46.2(2.5)	477.3(30.1)
	TT_{500}	49.2(5.8)	47.8(3.9)	48.1(3.5)	48.6(3.4)	48.5(3.8)	48.2(3.6)	47.8(3.9)	48.5(3.5)	48(3.6)	47(2.5)	481.7(33)
	TT_{1000}	50.1(5.5)	47.6(3.6)	47.8(3.1)	48.2(2.9	48.4(3.3)	48.5(2.9)	48.3(3.3)	48.5(3)	47.8(2.8)	47.7(3.4)	482.8(29.6)
	TT_{BLIND}	49(6.4)	47.7(4.2)	48.8(3.2)	48.8(2.8)	48.8(2.7)	49.2(2.7)	49.1(3)	49.7(2.8)	49.7(3.4)	49.9(3.6)	490.6(30.6)
Power (Watts)	TT_{ALL}	311.6(87.8)	298.9(54.5)	275.6(51.1)	278.2(50)	276.6(54.4)	279(49.8)	272.9(52.9)	271.3(58.4)	282.6(52.2)	327.3(63.6)	287.4(52.9)
	TT_{PRIME}	304.5(75.8)	297.5(56.3)	283.1(52.1)	276.5(57.3)	275.2(61.6)	278.6(55.6)	280.2(54.2)	276.3(51.6)	299.4(55)	303.9(42.6)	287.5(52.4)
	TT_{500}	326.5(109)	285.2(61.5)	277.3(56.4)	270.1(52.7)	270.7(58.4)	274.5(56.2)	282.9(65.1)	270.7(54.9)	278.9(51.5)	291(41.4)	282.8(54.9)
	TT_{1000}	311.7(108)	285.6(67.1)	280.6(53.5)	272(45.4)	271.5(58.2)	268.9(45.6)	274.2(56.1)	268.9(48.7)	278.3(44.7)	282.5(54.8)	279.4(52)
	TT_{BLIND}	336.1(117)	286.8(76.4)	264.4(50.1)	263.1(44.9)	262.6(45)	256.4(45.9)	260.9(50.8)	250.4(39.1)	254.7(51.6)	252.2(51.4)	268.8(52.2)
Cadence (r.min^{-1})	TT_{ALL}	99.8(9.4)	104.6(7.4)	103.4(5.7)	103.4(5.5)	103.2(5.5)	103.1(5.8)	103.4(5.2)	103.1(5.4)	103.3(5.2)	104.6(6.2)	103.2(5.6)
	TT_{PRIME}	99.3(11.1)	104.3(9.9)	102.7(9.6)	102.1(9.2)	102.4(9.5)	102.6(9.3)	102.3(9.6)	101.8(9.8)	102.4(9.3)	102.8(10)	102.3(9.3)
	TT_{500}	103.5(7.7)	108.4(7.8)	107.6(8.5)	107.2(8.5)	107(8.1)	106.6(9.7)	106(9.2)	105.3(9)	105.5(7.7)	106.5(9.4)	106.4(7.9)
	TT_{1000}	100.7(10.9)	106.2(10.7)	104.1(9.1)	103.9(10.1)	104.1(10.6)	104.8(9.8)	104.6(9)	103.4(9.6)	105.1(9.1)	104.8(9.6)	104.2(9.6)
	TT_{BLIND}	102(9.9)	105.8(8.7)	104.5(9.4)	104.7(9.4)	105.1(10.3)	103.6(10.9)	103.9(11)	103.5(10.8)	103.6(9.5)	103.2(10.6)	104(9.7)
Heart Rate (b.min^{-1})	TT_{ALL}	131.5(16)	157.7(10.8)	165.8(13.2)	167.9(13.7)	169.8(13.5)	172.1(13.2)	174.3(13)	175.5(12.5)	177.4(12.5)	181.1(11.1)	167.3(11)
	TT_{PRIME}	134.2(15.8)	155.5(10.2)	164.8(11)	166.8(11.9)	169.2(12.9)	171.8(14)	173.1(13.2)	174.7(13.5)	174.8(10.3)	175.8(9.5)	166.1(9.6)
	TT_{500}	137.9(18.7)	160.9(9.5)	164.8(11)	166.1(12.2)	168.7(12.6)	171.1(13.1)	172.2(13)	174.1(13)	175.4(12.2)	177.4(11.2)	166.9(11)
	TT_{1000}	137.3(24.6)	161.8(11.8)	166.9(12.3)	168.3(12.8)	170.4(12.7)	171.7(12.9)	173.5(12.6)	175.2(11.1)	176.1(10.3)	177(10.7)	167.8(11.3)
	TT_{BLIND}	133.8(15.3)	157(11.2)	163.7(13)	165.5(14)	168(12.8)	168.9(12.9)	169.3(12.4)	170.2(11.2)	171.3(10.8)	174.8(10.9)	164.3(9.8)

All values presented are trials means ± (1SD) for each segments (0.5 km, 1 km, 1.5 km, 2 km, 2.5 km, 3 km, 3.5 km, 4 km, 4.5km, 5 km). Values presented in overall column are calculated as the mean ± (1SD) for the whole TT (0-5) km.

Table 5-2 Mean and (1SD) for Familiarization time trial.

		0.5 km	1 km	1.5 km	2 km	2.5 km	3 km	3.5 km	4 km	4.5 km	5 km	overall
TT$_{FAM}$	**Speed (km/hr-1)**	38.0	38.3	37.6	37.4	37.3	37.2	37.0	36.8	37.7	39.0	37.6
	Completion Time (s)	47.8	47.1	48.0	48.3	48.4	48.5	48.9	49.1	48.0	46.3	480.4
	Power (Watts)	347.8	287.6	273.5	268.9	268.9	265.4	261.7	258.3	281.4	304.0	281.7
	Cadence (r.min-1)	102.0	105.6	103.2	102.2	103.1	102.9	102.2	102.5	102.7	103.8	103.0
	Heart Rate (b.min-1)	139.6	166.3	170.3	173.3	172.1	174.7	176.5	177.4	178.9	182.6	172.0

All values presented are TT$_{FAM}$ means ± (1SD) for each segments (0.5 km, 1 km, 1.5 km, 2 km, 2.5 km, 3 km, 3.5 km, 4 km, 4.5km, 5 km) . Values presented in overall column are calculated as the mean ± (1SD) for the whole TT (0-5) km.

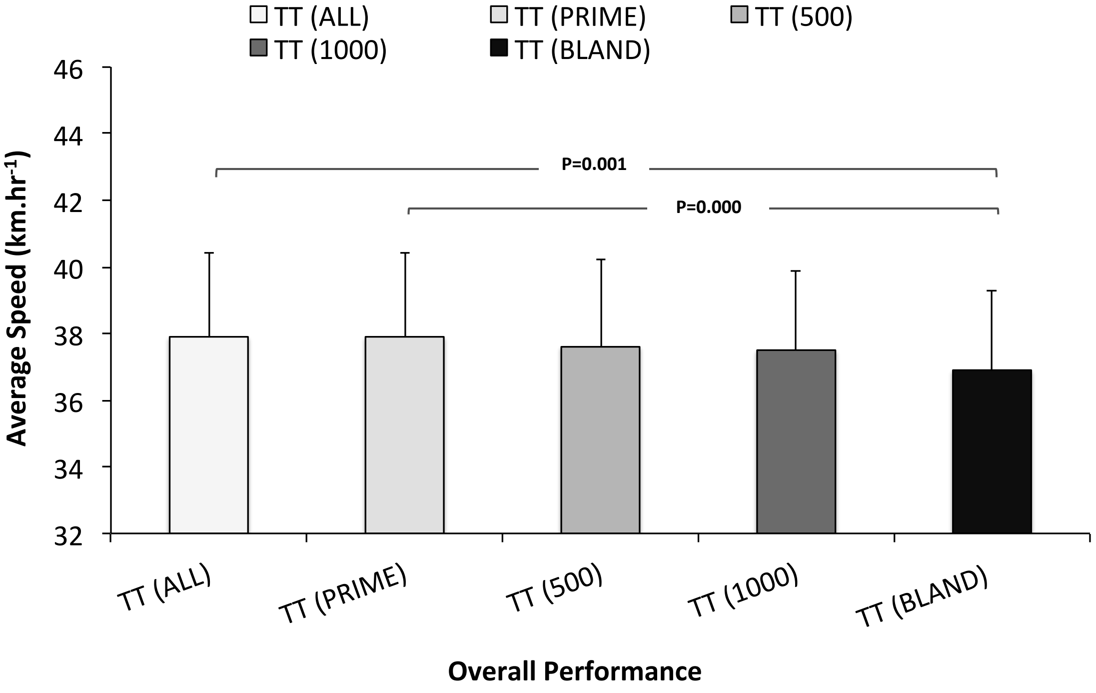


Figure 5-1 Average cycling performances between trials for speed.

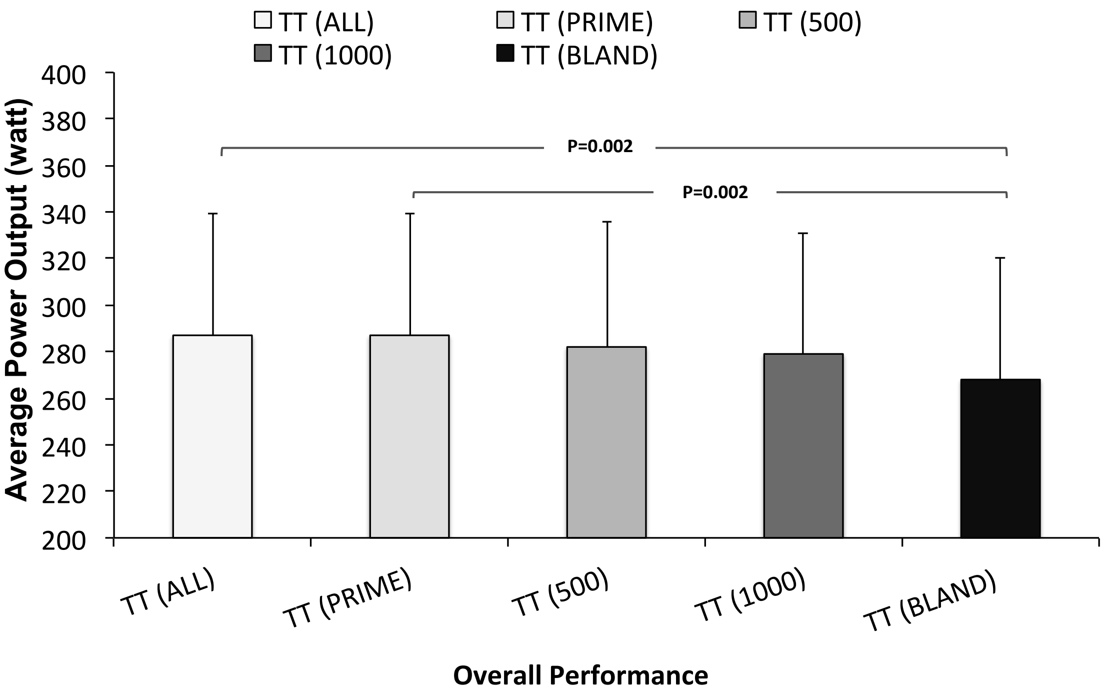


Figure 5-2 Average cycling performances between trials for power output.

5.3.2 Time Trial pace

Two-way repeated-measure ANOVA revealed trial-by-segment interaction for cycling pace ($km.hr^{-1}$) $F_{36,396}$=2.2, P=0.013, η_p^2=.16. Power output (w) $F_{36,396}$=2.5, P=0.04, η_p^2=.17, but no significant differences in trial-by-segment for cadence $F_{36,396}$=0,6, P=0.74, η_p^2=.05 (Figure 5-3& 5-4). A segment effect was detected for power output $F_{9,99}$=4.7, P=0.024 η_p^2=.30, but not for speed $F_{9,99}$=2.1, P=0.135, η_p^2=.15. Post hoc paired samples t-test outcome between TTs for each 500m segment for speed profile showed no significant differences between TT_{ALL} and TT_{PRIME} (Figure 5-5).

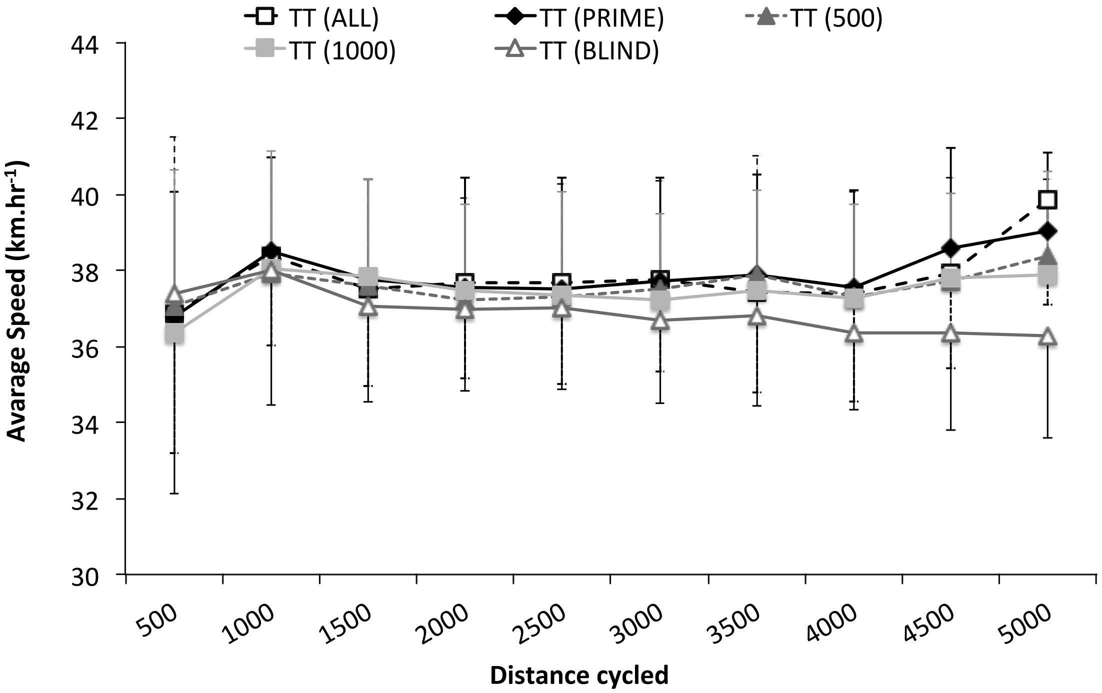


Figure 5-3 Speed pacing profile for all TTs.

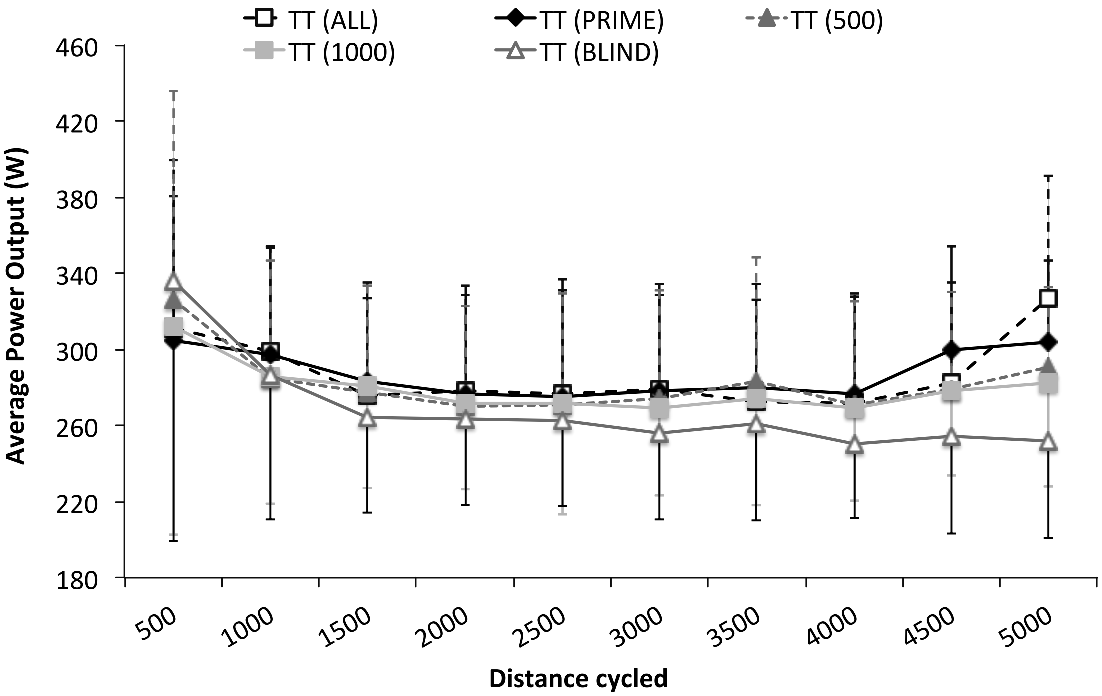


Figure 5-4 Power output pacing profile for all TTs.

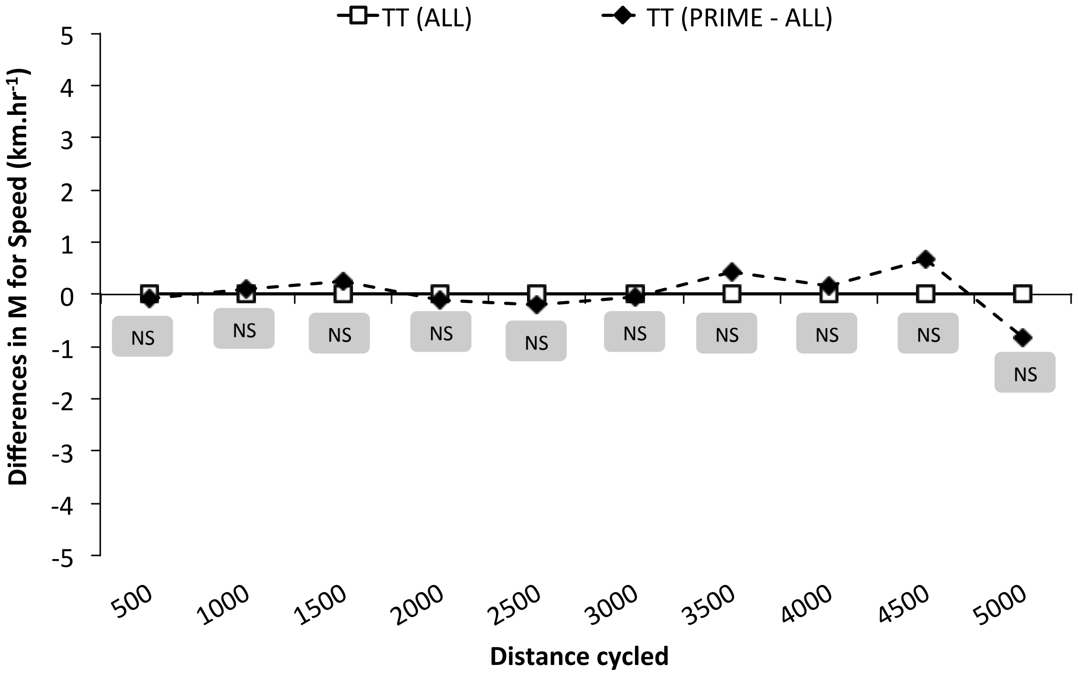


Figure 5-5 Differences in mean speed between TT_{PRIME} and TT_{ALL} compare to TT_{ALL}.

Significant differences between TT_{ALL} and $TT_{500,}$ in 5000m segments t_{11}=2.5, P=0.008, η^2=0.36, no further significant differences between the two Trials were found (Figure 5-6).

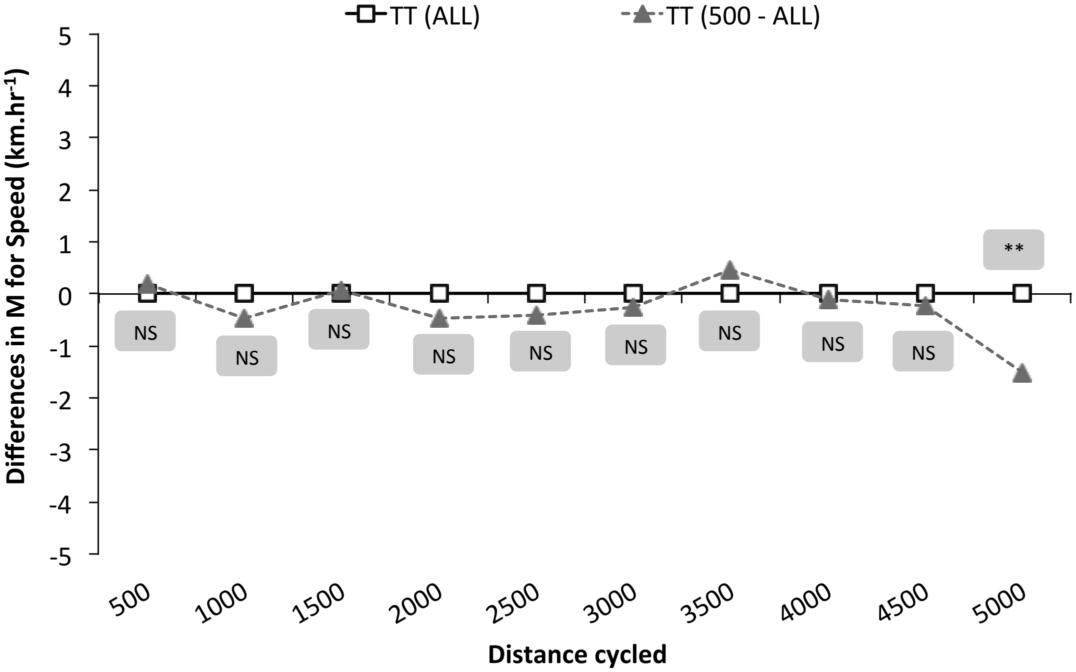


Figure 5-6 Differences in mean speed between TT_{500} and TT_{ALL} compare to TT_{ALL}.

Significant differences between TT_{ALL} and $TT_{1000,}$ in 5000m segments t_{11}=3.1, P=0.005, η^2=0.46, no further significant differences between the two Trials were found (Figure 5-7).

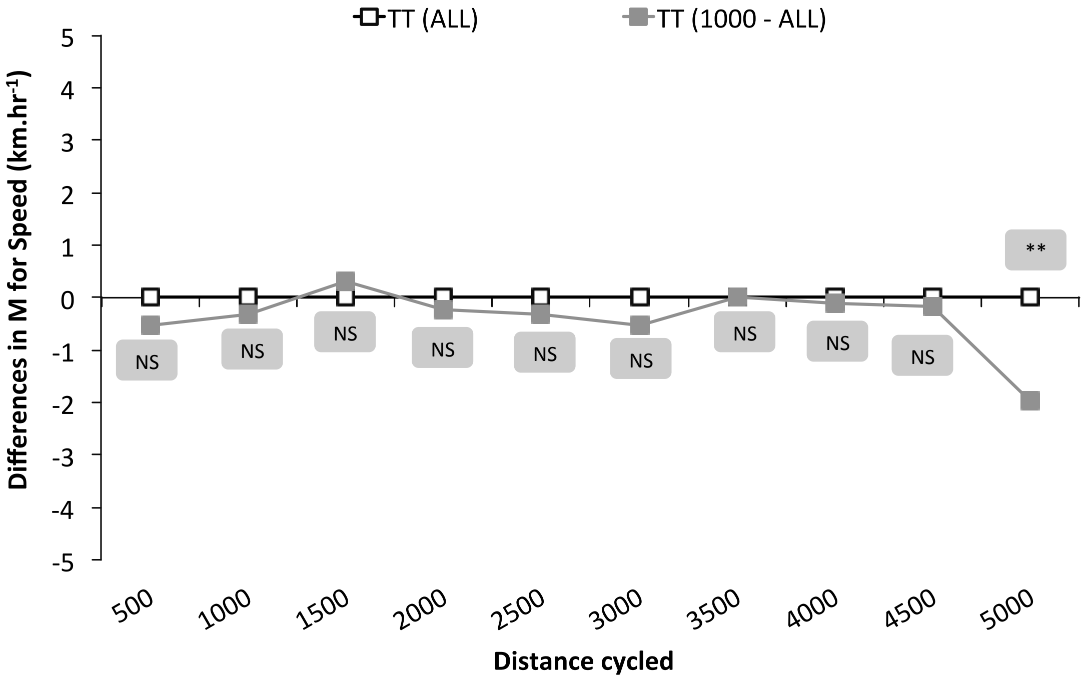


Figure 5-7 Differences in mean speed between TT_{1000} and TT_{ALL} compare to TT_{ALL}.

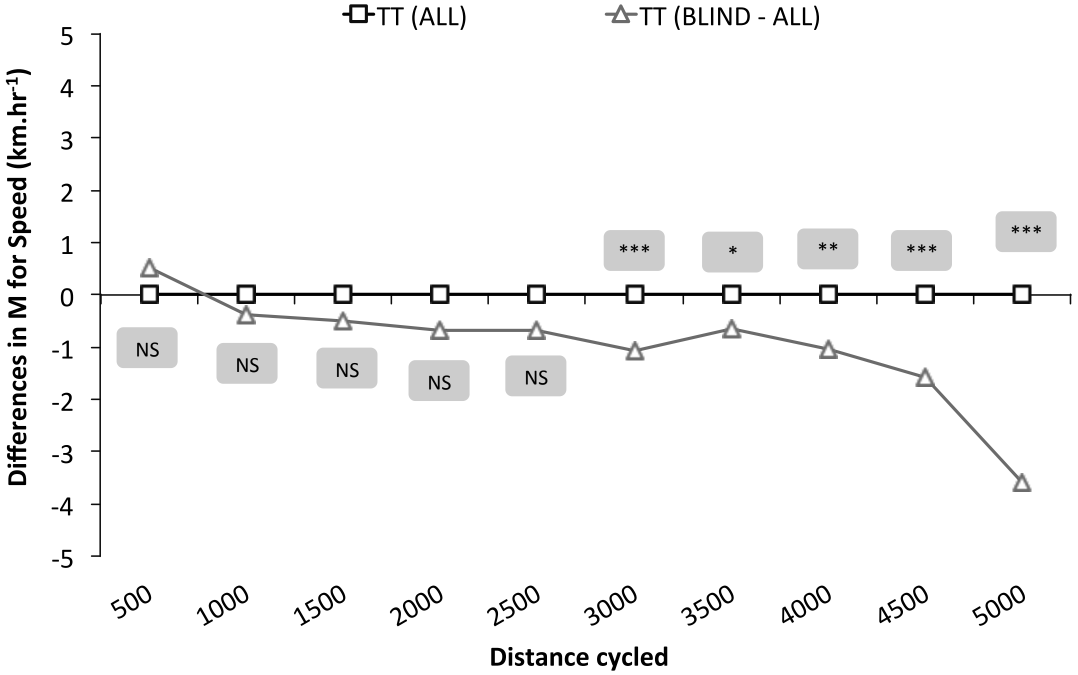


Figure 5-8 Differences in mean speed between TT_{BLIND} and TT_{ALL} compare to TT_{ALL}.

Significant differences between TT_{ALL} and $TT_{BLIND,}$ in 3000m, 3500m, 4000m, 4500m, and 5000m segment, t_{11}=5.6, P=0.000, η^2=0.74, t_{11}=2.06, P=0.016, η^2=0.27, t_{11}=2.9, P=0.004, η^2=0.42, t_{11}=5.2, P=0.000, η^2=0.72, and t_{11}=6.8, P=0.000, η^2=0.8 respectively, no further significant differences were found (Figure 5-8).

The test also showed significant differences between TT_{PRIME} and TT_{BLIND}, in 3000m, 3500m, 4000m, 4500m, and 5000m segments t_{11}=2.70, P=0.006, η^2=0.39, t_{11}=4.2, P=0.000, η^2=0.62, t_{11}=3.8, P=0.000, η^2=0.56, t_{11}=7.8, P=0.000, η^2=0.84, t_{11}=4.2, P=0.000, η^2=0.62, respectively no further significant differences were found (Figure 5-9).

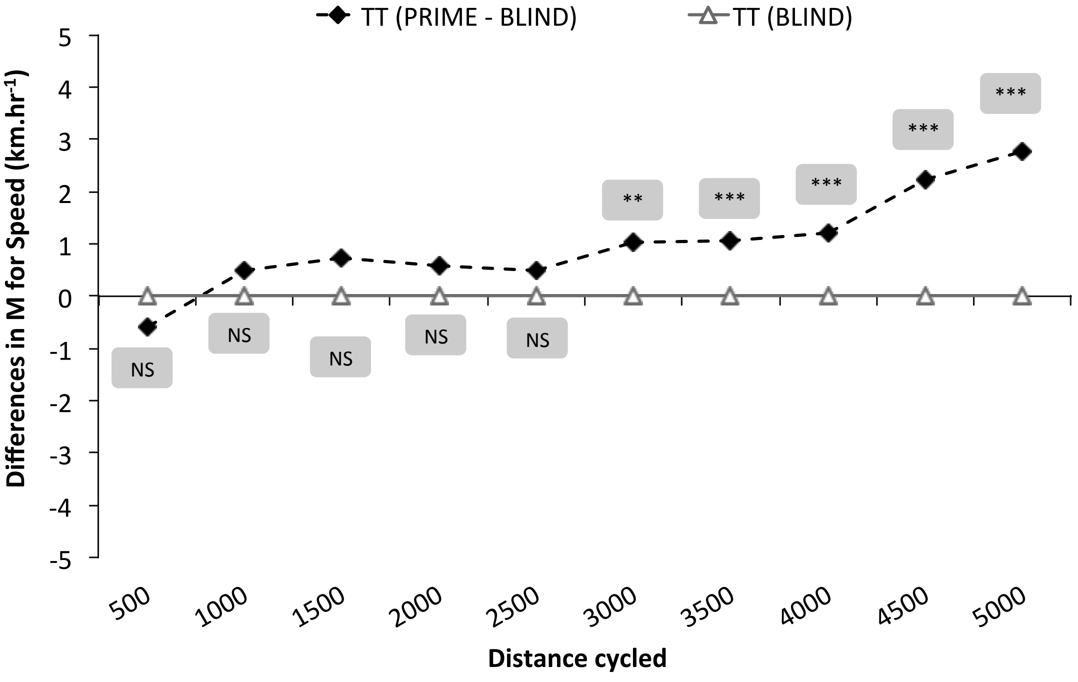


Figure 5-9 Differences in mean speed between TT_{PRIME} and TT_{BLAND} compare to TT_{BLAND}.

Significant differences between TT_{500} and TT_{BLIND}, in 3000m, 3500m, 4000m, 4500m, and 5000m segments t_{11}=2.1, P=0.015, η^2=0.28, t_{11}=2.2, P=0.014, η^2=0.16,

t_{11}=2.6, P=0.006, η^2=0.30, t_{11}=2.8, P=0.005, η^2=0.41, t_{11}=4.2, P=0.000, η^2=0.64, respectively no further significant differences were found (Figure 5-10).

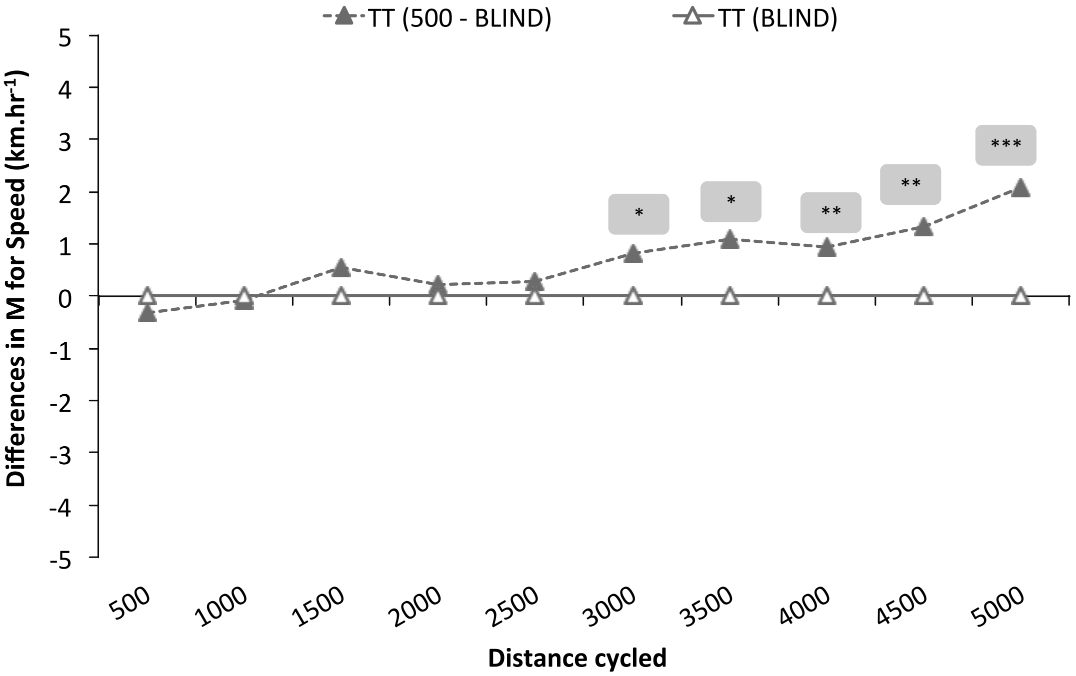


Figure 5-10 Differences in mean speed between TT_{500} and TT_{BLAND} compare to TT_{BLAND}.

Significant differences were also found between TT_{1000} and TT_{BLIND}, in 3000m, 3500m, 4000m, 4500m, and 5000m segments t_{11}=2.2, P=0.014, η^2=0.29, t_{11}=2.1, P=0.014, η^2=0.29, t_{11}=2.8, P=0.005, η^2=0.39, t_{11}=4.5, P=0.000, η^2=0.65, t_{11}=2.6, P=0.007, η^2=0.37, respectively no further significant differences were found (Figure 5-11).

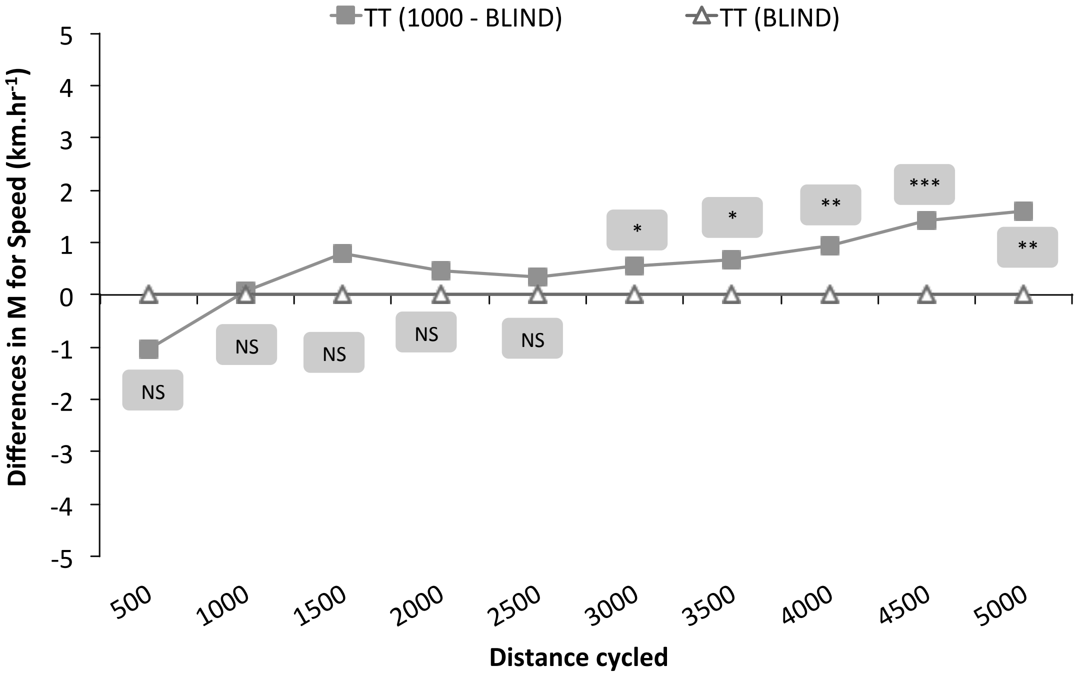


Figure 5-11 Differences in mean speed between TT_{1000} and TT_{BLAND} compare to TT_{BLAND}.

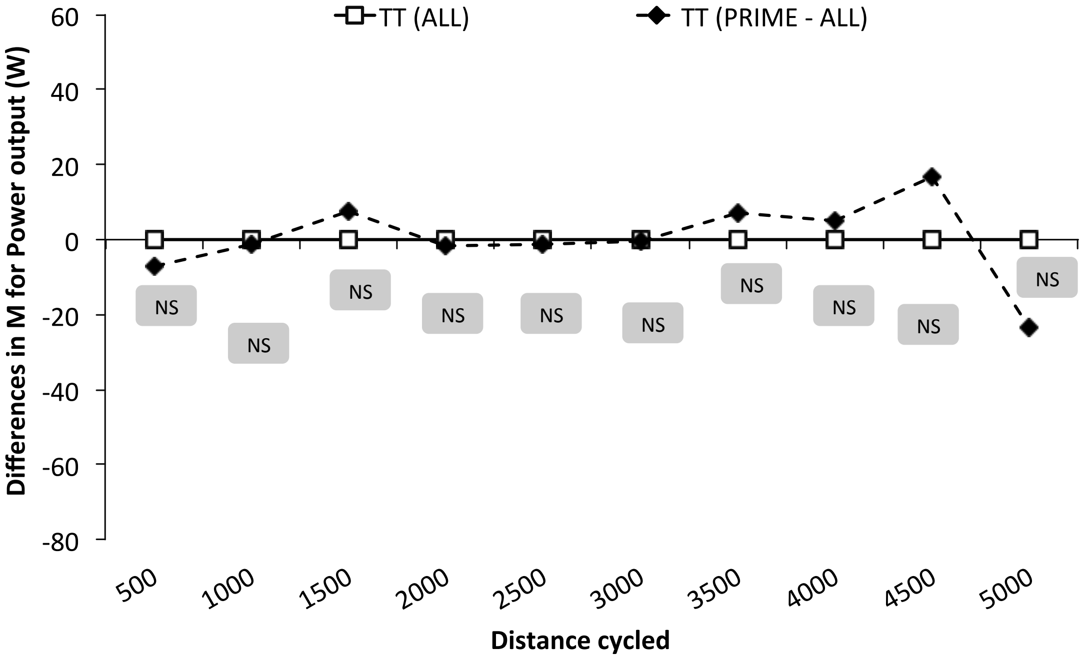


Figure 5-12 Differences in mean power output between TT_{PRIME} and TT_{ALL} compare to TT_{ALL}.

Post hoc paired samples t-test between TTs for each 500m segment for power output showed no significant differences between TT_{ALL} and TT_{PRIME} (Figure 5-12).

Significant differences between TT_{ALL} and $TT_{500,}$ in 5000m segments t_{11}=2.7, P=0.006, η^2=0.37. No, further significant differences between the two trials were found (Figure 5-13).

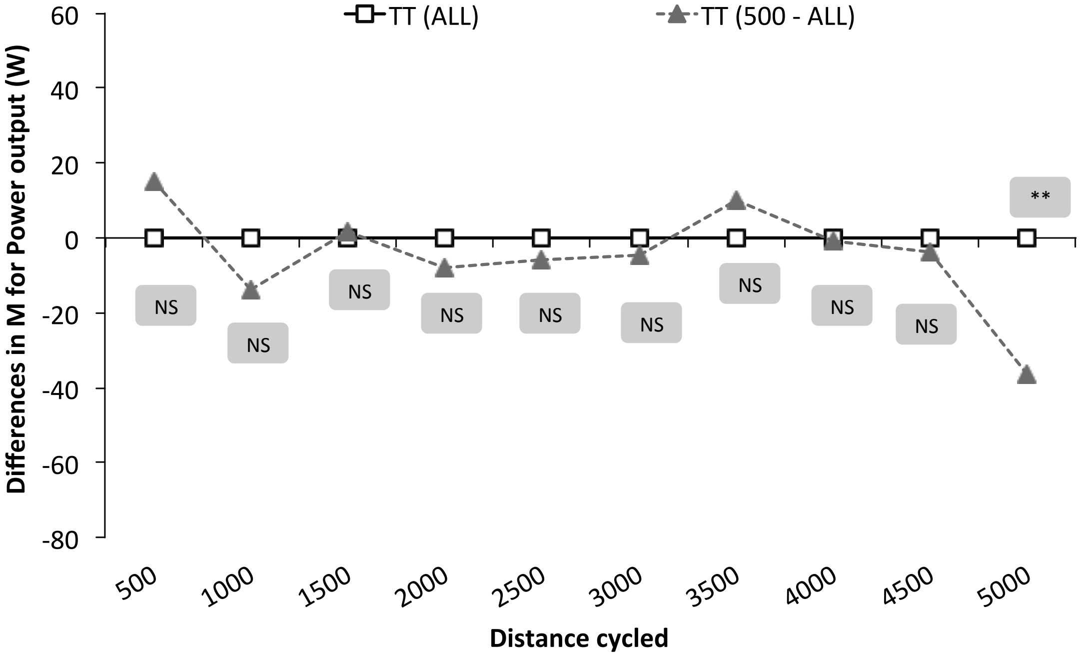


Figure 5-13 Differences in mean power output between TT_{500} and TT_{ALL} compare to TT_{ALL}

Significant differences between TT_{ALL} and $TT_{1000,}$ in 5000m segments t_{11}=3.0, P=0.003, η^2=0.45, no further significant differences between the two trials were found (Figure 5-14).

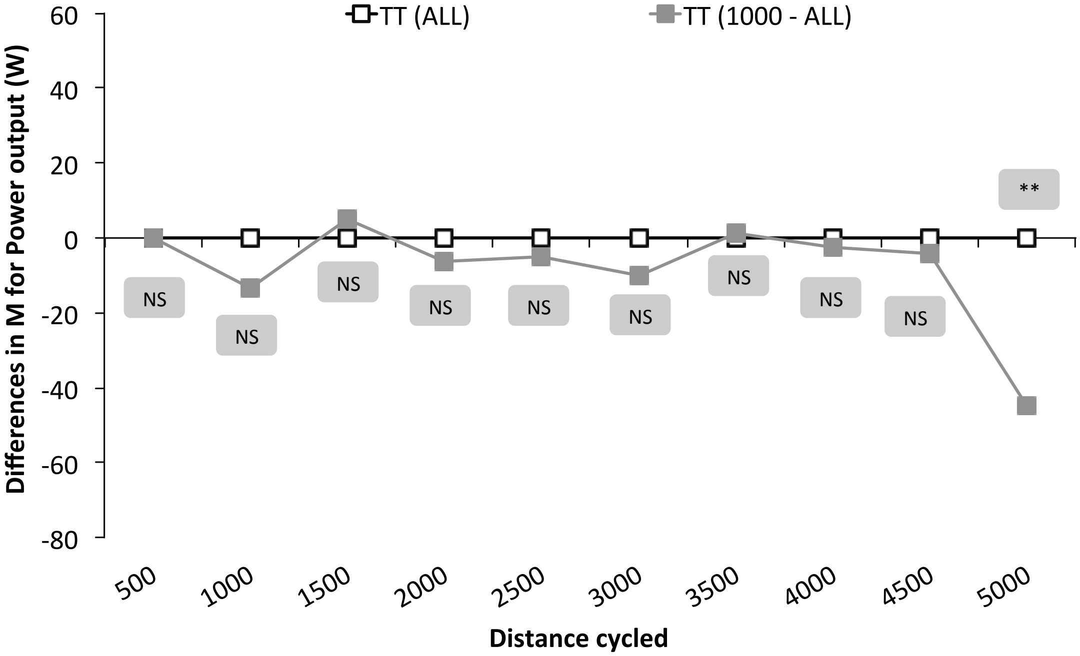


Figure 5-14 Differences in mean power output between TT_{1000} and TT_{ALL} compare to TT_{ALL}.

And significant differences between TT_{ALL} and $TT_{BLIND,}$ 2000m, 2500m, 3000m, 3500m, 4000m, 4500m and 5000m segments t_{11}=1.8, P=0.022, η^2=0.24, t_{11}=1.9, P=0.020, η^2=0.25, t_{11}=5.6, P=0.000, η^2=0.73, t_{11}=1.9, P=0.022, η^2=0.25, t_{11}=2.6, P=0.007, η^2=0.37, t_{11}=5.2, P=0.000, η^2=0.72, and t_{11}=6.9, P=0.000, η^2=0.80 respectively. No, further significant differences between the two trials were found (Figure 5-15).

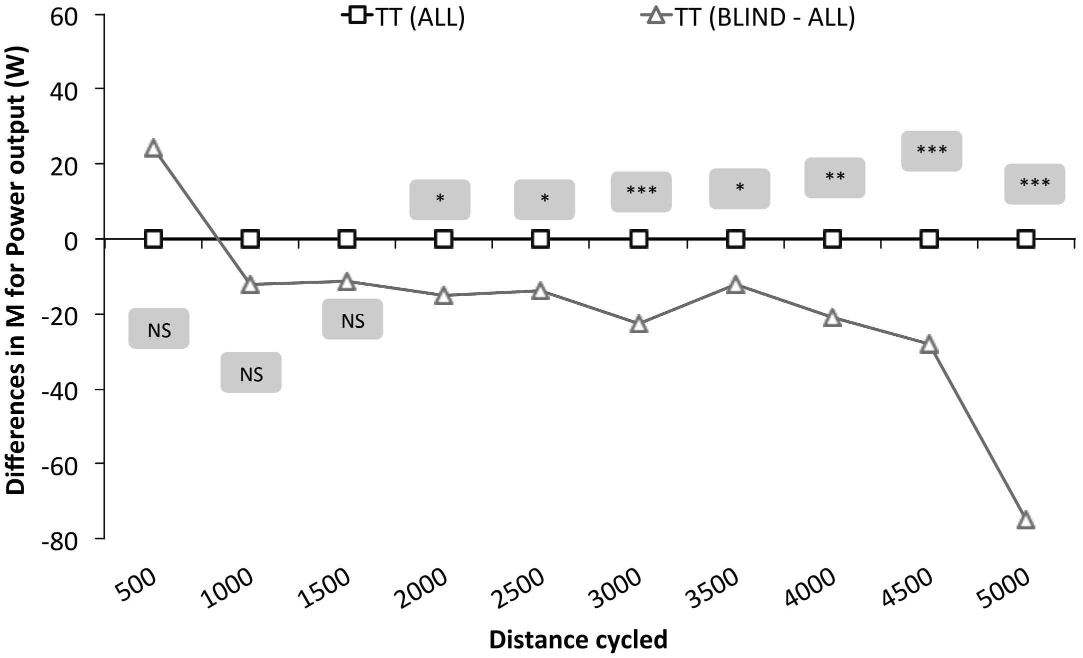


Figure 5-15 Differences in mean power output between TT_{BLAND} and TT_{ALL} compare to TT_{ALL}.

The test also showed significant differences between TT_{PRIME} and TT_{BLIND}, in2000m, 3000m, 3500m, 4000m, 4500m, and 5000m segments t_{11}=1.9, P=0.022, η^2=0.24, t_{11}=2.9, P=0.007, η^2=0.43, t_{11}=3.7, P=0.001, η^2=0.54, t_{11}=3.8, P=0.000, η^2=0.56, t_{11}=5.9, P=0.000, η^2=0.76, and t_{11}=4.5, P=0.000, η^2=0.64, respectively. No, further significant differences were found (Figure 5-16).

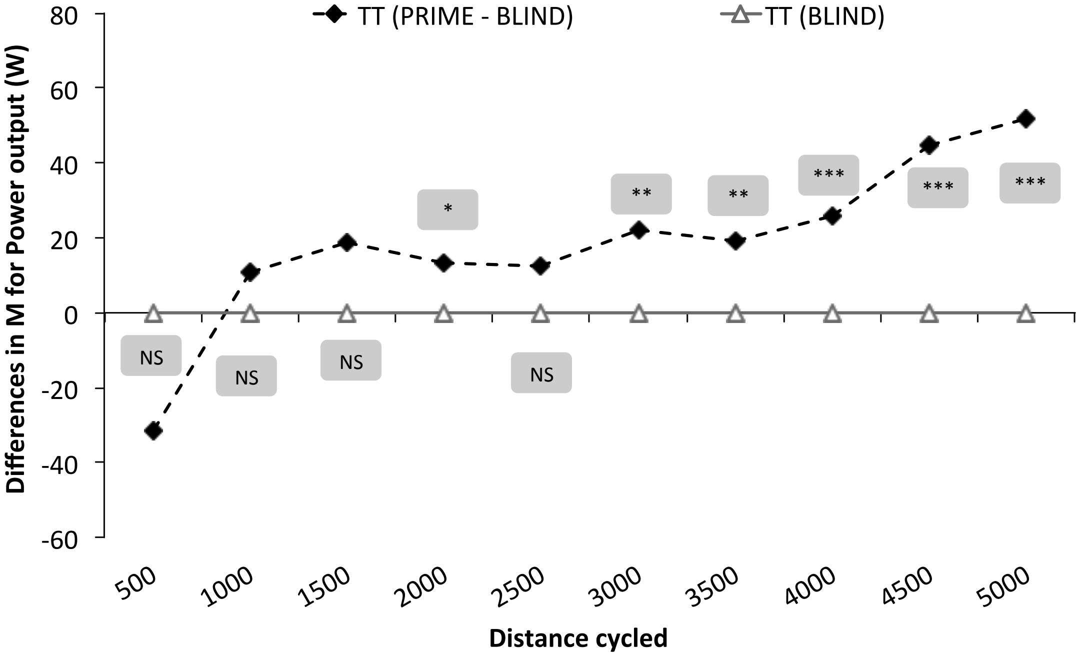


Figure 5-16 Differences in mean power output between TT_{PRIME} and TT_{BLIND} compare to TT_{BLIND}.

Significant differences between TT_{500} and TT_{BLIND}, in 3000m, 3500m, 4000m, 4500m, and 5000m segments t_{11}=2.2, P=0.013, η^2=0.30, t_{11}=1.9, P=0.022, η^2=0.24, t_{11}=2.7, P=0.005, η^2=0.40, t_{11}=2.9, P=0.004, η^2=0.44, t_{11}=3.6, P=0.002, η^2=0.53, respectively. No, further significant differences were found (Figure 5-17).

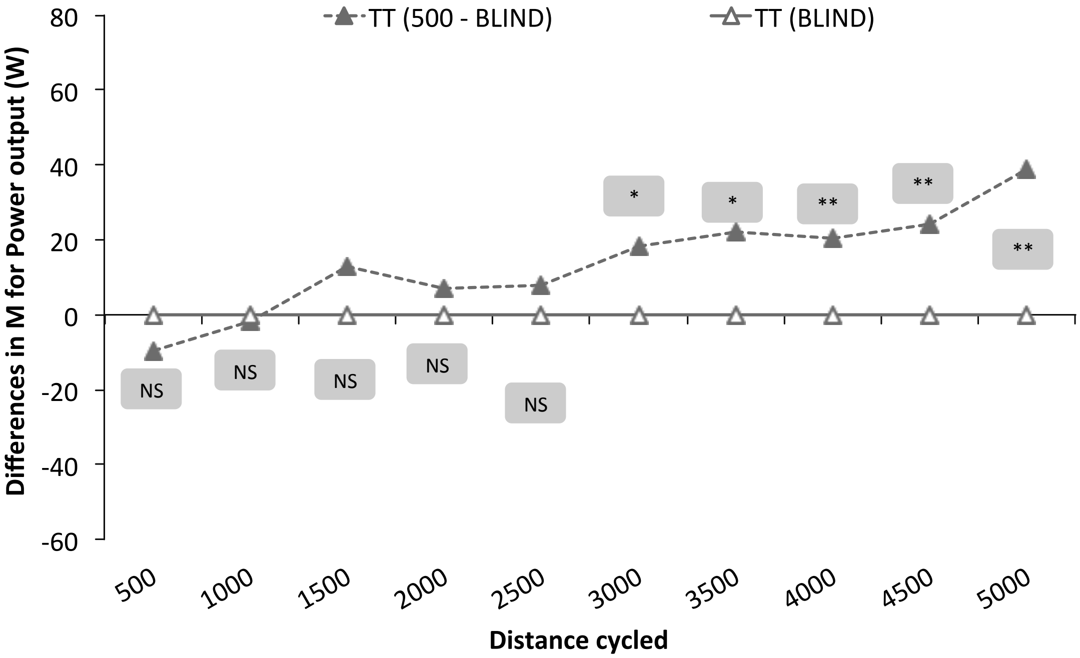


Figure 5-17 Differences in mean power output between TT_{500} and TT_{BLIND} compare to TT_{BLIND}.

Significant differences were also found between TT_{1000} and TT_{BLIND}, in 3000m, 3500m, 4000m, 4500m, and 5000m segments $t_{11}=1.8$, P=0.023, $\eta^2=0.33$, $t_{11}=2.4$, P=0.010, $\eta^2=0.33$, $t_{11}=2.7$, P=0.006, $\eta^2=0.39$, $t_{11}=4.0$, P=0.000, $\eta^2=0.59$, $t_{11}=2.3$, P=0.002, $\eta^2=0.32$, respectively. No, further significant differences were found (Figure 5-18).

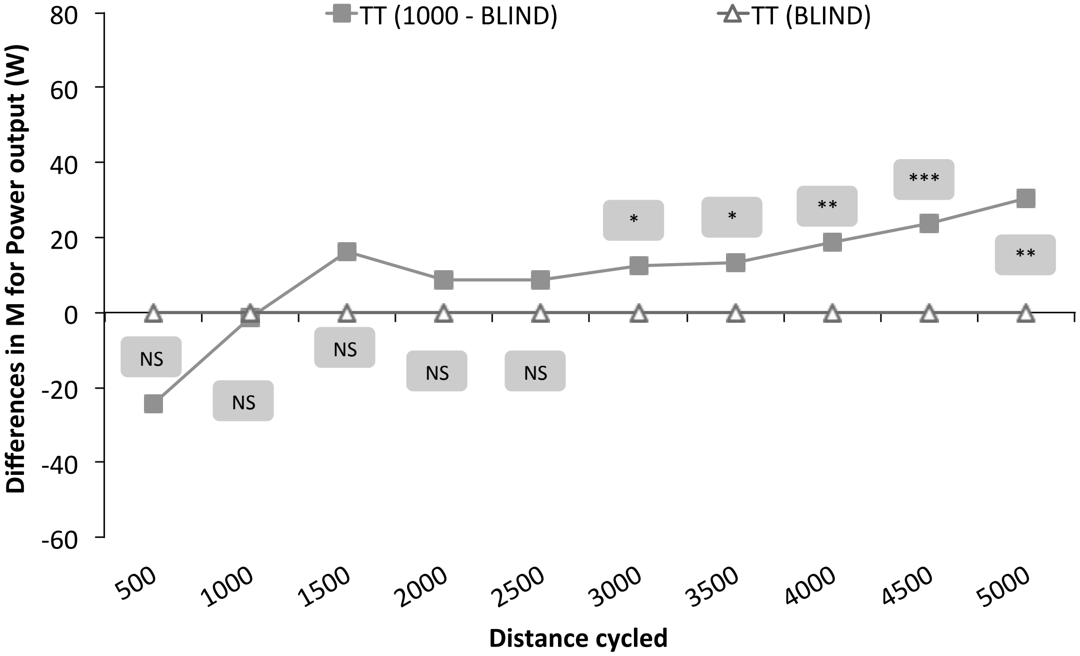


Figure 5-18 Differences in mean power output between TT_{1000} and TT_{BLIND} compare to TT_{BLIND}.

5.3.3 Heart rate and Rating of fatigue

Two-way repeated-measure ANOVA revealed no trial-by-distance interaction for HR ($b.min^{-1}$) $F_{36,396}$=1.6, P=0.153, η_p^2=.13, while one-way repeated-measure ANOVA revealed no differences between trials in overall HR $F_{4,44}$=1.6, P=0.214, η_p^2=0.13. Mean and standard deviation data for HR outcomes are presented in (Table 5-1). One-way repeated-measure ANOVA revealed differences between trials in rating of fatigue directly after the race $F_{4,44}$=6.1, P=0.001, η_p^2=0.36. Bonferroni-corrected post hoc paired samples t-tests revealed differences in fatigue level directly after the race between TT_{ALL} and TT_{BLIND} (t_{11}=3.6, P=0.002, η^2=0.54), and between TT_{PRIME} and TT_{BLIND} (t_{11}=5.7, P=0.000, η^2=0.75.). No further differences were found between TTs after warm-up, before the start of the race and after 5 minutes form the race, $F_{4,44}$=0.6, P=0.531, η_p^2=0.05, $F_{4,44}$=0.6, P=0.587, η_p^2=0.05, $F_{4,44}$=0.7, P=0.523, η_p^2=06 (Figure 5-19).

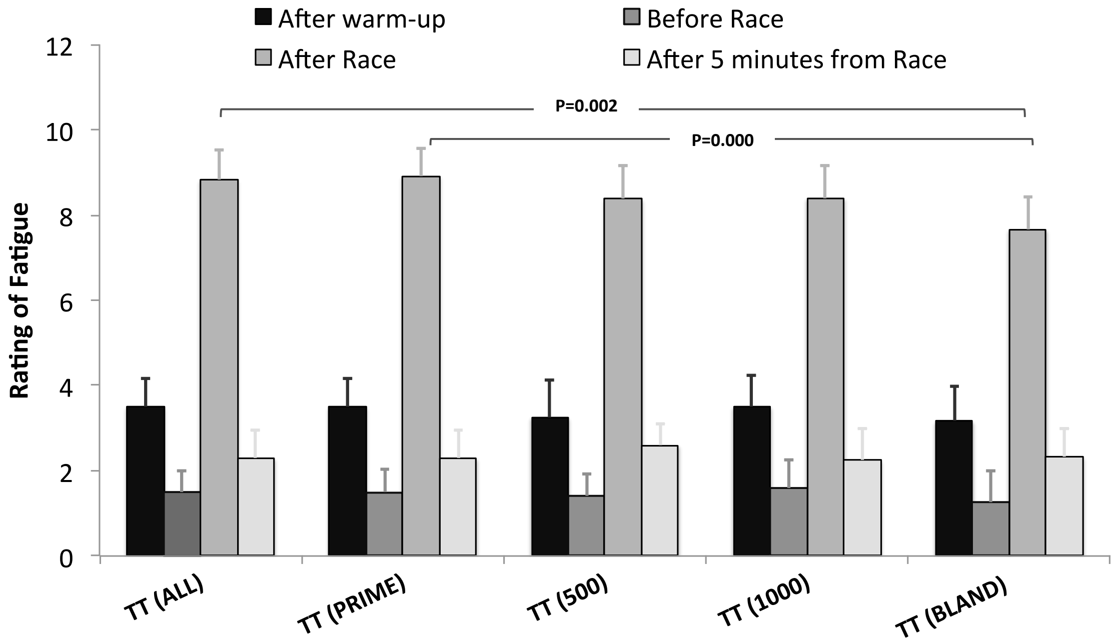


Figure 5-19 Differences between time-trial in the level of fatigue.

5.3.4 Time-Trial Eye-Tracking Outcomes: Information Gaze Frequency and Duration

Participants percentage of gaze duration and frequency data for primary through to octonary information sources calculated over the full 5 km in TT_{ALL}, are presented in (Figures 5-20 and 5-21). Overall percentage of gaze duration for ‘Primary’ source of information and ‘other’ in TT_{ALL}, TT_{PRIME}, TT_{500}, and TT_{1000} are presented in (Figure 5-22). Total frequency for ‘primary’ source of information and ‘other’ in TT_{ALL}, TT_{PRIME}, TT_{500}, and TT_{1000} are presented in (Figure 5-23). Percentage of gaze duration for ‘primary’ source of information in segment-by-segment basis for TT_{ALL}, TT_{PRIME}, TT_{500}, and TT_{1000} are presented in (Figure 5-24). Total frequency for ‘Primary’ source of information in segment-by-segment basis for TT_{ALL}, TT_{PRIME}, TT_{500}, and TT_{1000} are presented in (Figure 5-25).

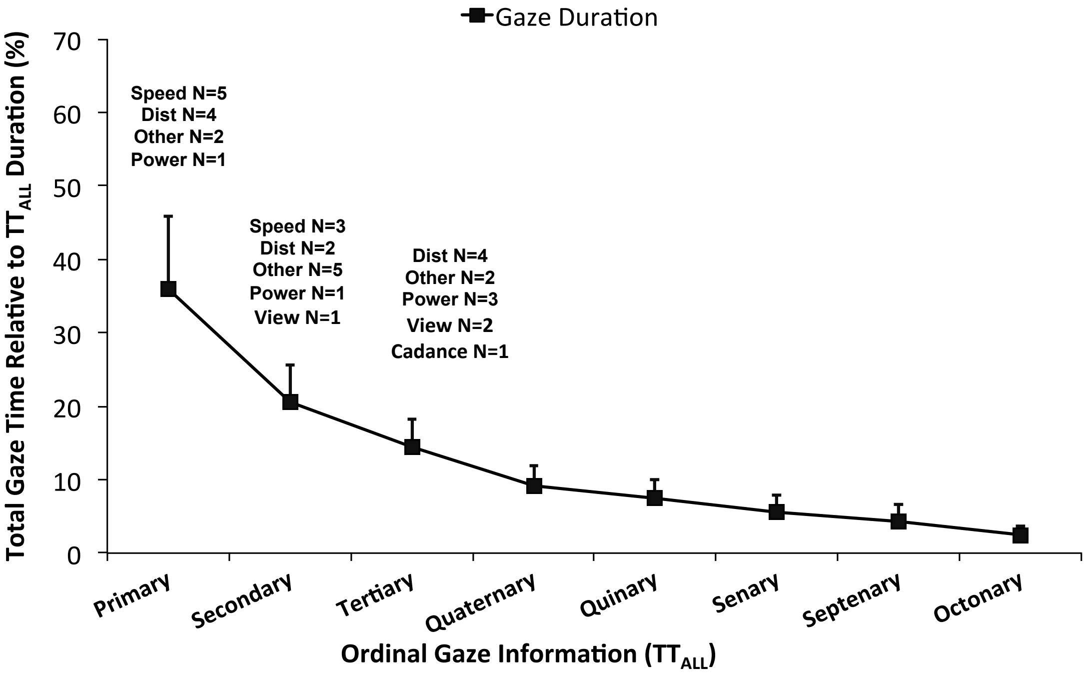


Figure 5-20 TT_{ALL} Ordinary percentage of Gaze information.

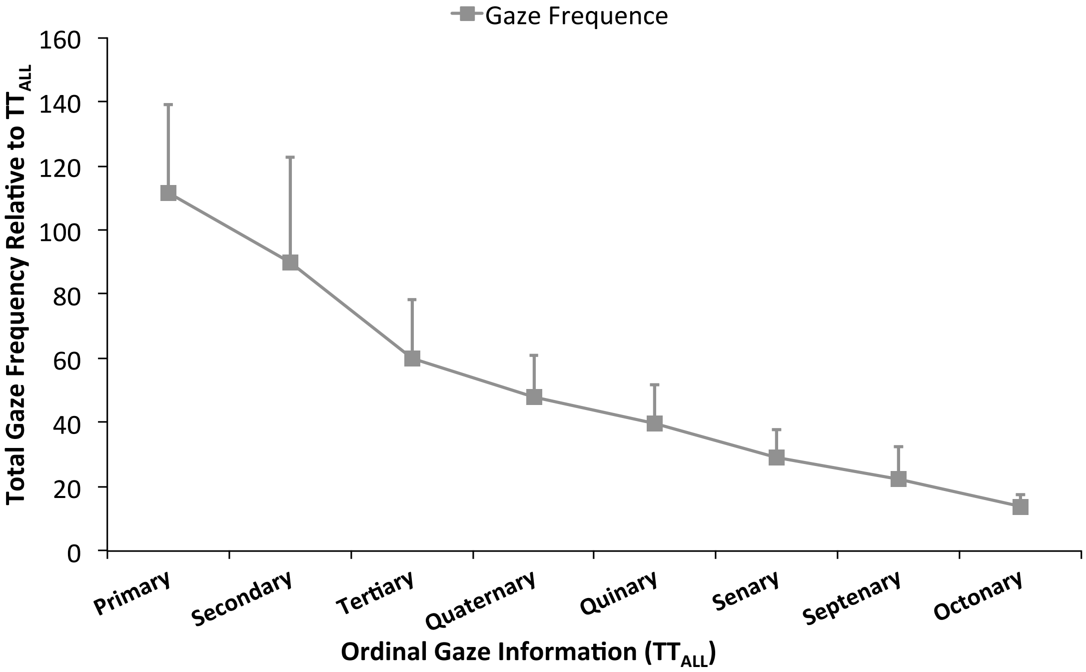


Figure 5-21 TT_{ALL} Ordinary Gaze Frequency.

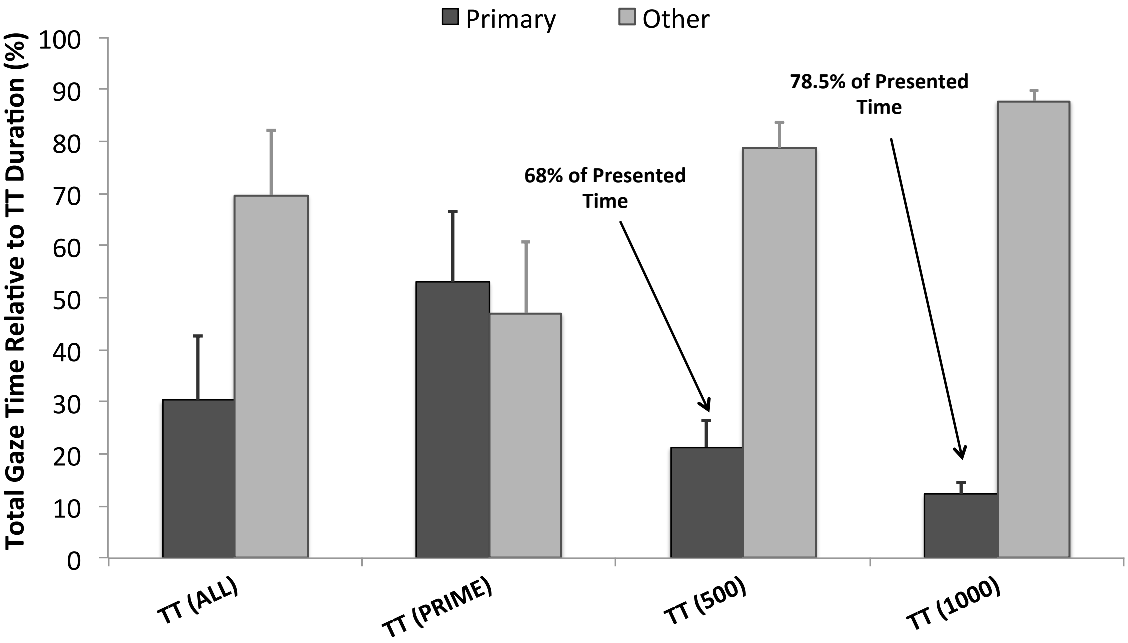


Figure 5-22 Overall percentage of gaze information in TTs.

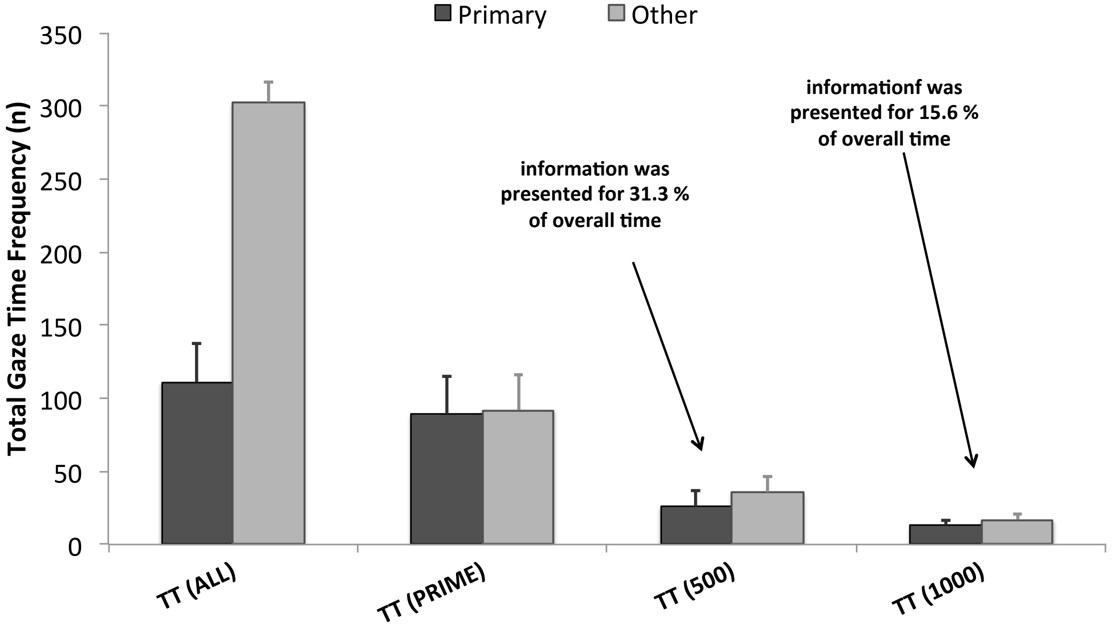


Figure 5-23 Overall gaze frequency in TTs.

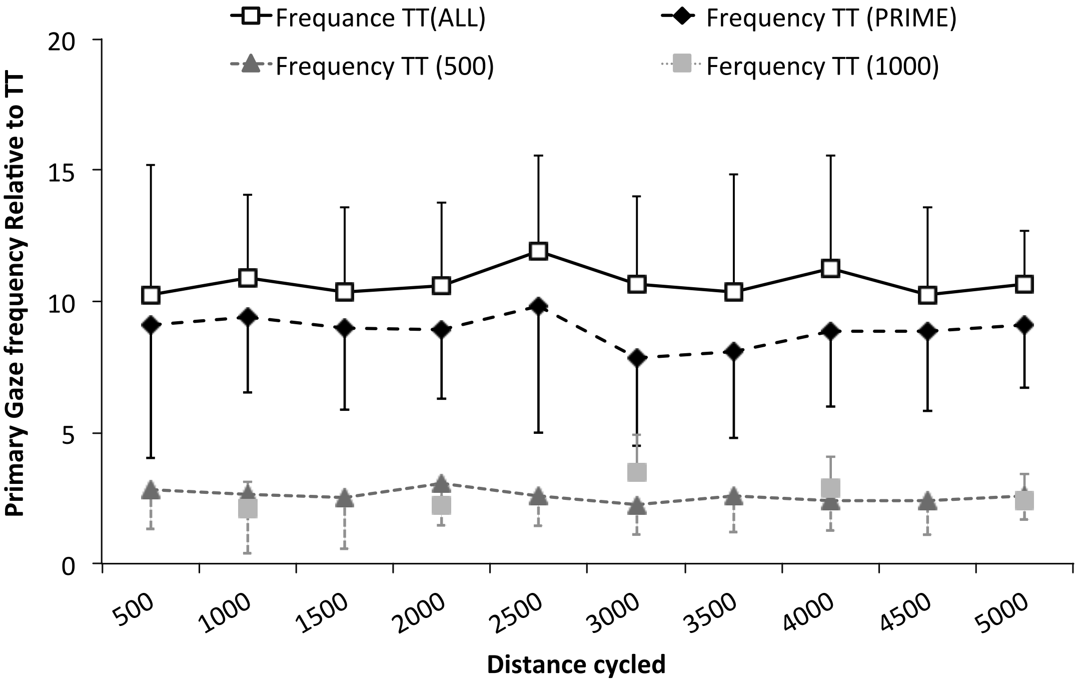


Figure 5-24 Percentage of primary gaze information related to TTs duration.

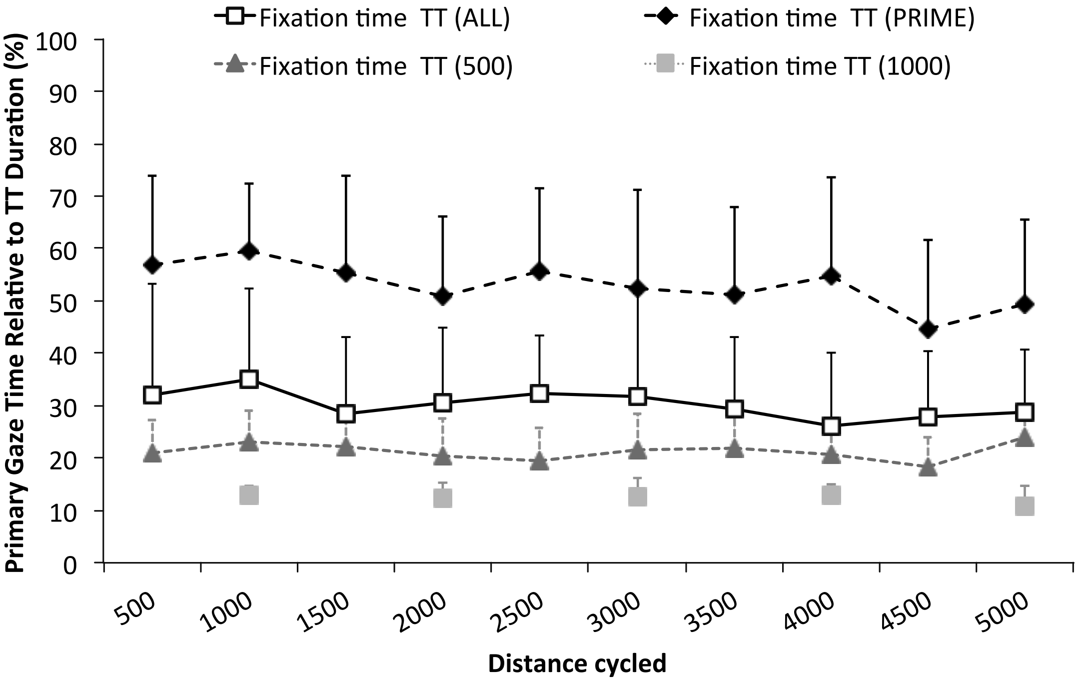


Figure 5-25 Primary gaze frequency related to TTs.

5.4 Discussion

The primary finding of this study was that participants develop a similar pacing strategy and perform similarly, when they were provided with primary information even when it was presented for a limited time. This indicates that cyclists can achieve comparable standards of performance with relatively little feedback information. This is similar to Mauger *et al.*, (2009b), who found that providing cyclists with split lap time feedback improve performance, indicating that even short accurate performance feedback is advantageous during exercise. However, the finding of the present study is remarkable, considering that some of the participants were distance blinded and received no distance feedback. The finding of this study argue most of previous pacing models (DeKoning *et al.*, 2011; Faulkner *et al.*, 2008; Foster *et al.*, 1994; Noakes *et al.*, 2006; Garcin *et al.*, 2012; Tucker, 2009; Ulmer, 1996; St Clair Gibson *et al.*, 2006) that agreed that pacing behaviour is primarily driven by knowledge of the endpoint. In fact, most of the previous pacing models have agreed how important feedback information is in regulating pacing and performance. However, they placed importance on the knowledge of the endpoint, whether defined by distance or time. Our results are in agreement with previous models about the role of feedback information in pacing regulation and performance, since no differences in performance were found between conditions when participants had provided with feedback (Figure 5-1 & 5-2). Moreover, our finding can add that preferred feedback information improved performance. However, the findings of the present study raise questions about the exclusivity of endpoint knowledge as the source of feedback that universally informs pacing decisions. This is because, first, in TT_{ALL} the type of preferred feedback differed between participants, with 6/12 mostly looking at speed, 1/12 at power and only 5/12 at distance (Figure 5-20). This was similar to Boya *et al.* (2017) and Boya & Micklewright (2016). In the first study, they found that participants differ in information acquisition, in which experienced cyclists were found to prefer ‘speed’ as the primary source of information, while the majority of novice cyclists were found to prefer ‘distance’. In the second study, 8/14 participants were found to prefer ‘speed’, while only 3/14 participants had preferred ‘distance’. Secondly, no differences in pacing and performance were found between TT_{ALL} and TT_{PRIME} (Figure 5-1, 5-2, 5-5 and 5-12). This indicates that knowledge about the endpoint is not necessarily what participants need, as has been previously known, and there is other performance related information important in pacing decisions. Previous study stated that varying the type of feedback is insufficient to influence performance and pacing (Albertus *et al.*, 2005; Les Ansley *et al.*, 2004), but, the present study adds that individuals' behaviour and the way participants interpret feedback information affects pacing and performance considering decision-making as phenomena where information can be treated differently (Gidlöf *et al.*, 2013). The results indicate that participants may differ in the way they react to the feedback information and this is mediated by their previous experience. A further observation about the important of preferred feedback was identified during TT_{BLIND}; significant differences in performance and pacing strategy were found in comparison to other TT when participants were provided with primary source of information.

Another interesting finding in this study was that, at the onset of the TTs, the highest PO was produced during TT_{BLIND}, while the lowest PO was produced during TT_{PRIME} (Table 1), (Figure 5-2 and 5-16). This may indicate that when participants were informed that no type of feedback would be provided, although they were experienced cyclists, some type of unconfident accrued leading to a faster start. The present result support the idea that exercise intensity regulation could be optimised by the motivation from performance feedback. This was more obvious at the last 2km in TT_{BLIND} which a change in pacing strategy was observed comparing to other TTs (Figure 5-8 to 5-11, & 5-15 to 5-18). This indicates that although pacing strategy is predetermined at the onset of exercise, some type of feedback is required to regulate the exercise and maintain the intensity at the certain level especial toward the end of exercise point. In fact, both the significant slower completion time and the decrease in power toward the end of the bout might be because of the uncertainty at the beginning of the race. This supports, to a certain extent, the notion suggested by Tucker & Noakes (Tucker, 2009) that the interpretation of afferent signals lead to uncertainty at the beginning of the bout. The no feedback in TT_{BLIND} leads participants to distribute the energy improperly and finish the race before using the stored energy; significant differences in perceived fatigue were observed (Figure 5-19). The perceived of fatigue using the 10 point ROF scale were found to be lower directly after the race in TT_{BLIND} compare to TT_{ALL} and TT_{PRIME}, that might indicate that participants were not fatigued at the end of the TT when they were deprived from the preferred feedback. A recent research including a series of studies by Micklewright *et al.*, (2017), found that ROF is a valid scale to track perception of fatigue.

A further interesting finding in our study was that, although participants had received feedback information for about 31.3%, and 15.6% of overall time in TT_{500} and TT_{1000} respectively (Figure 5-22,and 5-23), No change in pacing strategy was found between TTs when participants had information feedback presented with no overall performance change. This was similar to Albertus *et al.* (2005) and Micklewright *et al.* (2010) both studies found that some type of feedback, even if it is inaccurate, seems to help cyclists to complete the race and avoid premature fatigue. However, both studies used distance feedback as a main source of performance information. The fact that renders this study different is that participants were treated differently in term of information provided during the experimental condition depending on the preferred information in $TT_{ALL,}$ identified via visual behaviour. Hence, the present study expanded on this idea and shows that preferred performance information feedback, even for a limit time, helps cyclists to avoid premature fatigue.

The end spurts were only observed in TT_{ALL} when distance feedback was given among all participants, indicating the usefulness of distance feedback. Although, participants were unable to show the end spurts at the end of TT_{PRIME}, plus a decrease in PO and speed was observed at the last 500 m of the race. This might be because an underestimated of the endpoint lead to an early increase in speed and power from 4 km (Figure 5- 5_8, 5-12_15), since the majority of participants had no distance knowledge. However, they were able to perform in a similar manner, if not better, even though just 5/12 participants had distance feedback provided. This indicates that distance feedback is not the only source of information that athletes use during the race, and that decision could be made based on other information, but still an important reference source and in combination with other information especially at the end of exercise.

5.5 Conclusion

In conclusion, the present study is the first to show that providing participant with preferred information, not necessarily distance information, even for a limited time is enough for experienced cyclists to perform similarly in laboratory-controlled environment. And that distance knowledge is important source of feedback but in combination with other performance information.

6 Chapter Six: Cyclists' Visual Behaviour in Real World

6.1 Introduction

The visual system plays an essential role in guiding the athlete's search for substantial information underlying skilful behaviour. During daily activities, athletes use eye movement to select relevant information to be processed and used in variety of tasks (Foulsham *et al.*, 2011). In sports, the ability to identify relevant visual information is essential for performance; visually exploring the environment during a cycling TT allows key features to be identified such as environmental characteristic, the action of opponents, road and balancing, in which they are important for pacing behaviour and affect pacing decision. It has been suggested that interaction with the environment is a critical determinant for the regulation of the effort (Smits *et al.*, 2014; Renfree *et al.*, 2014). Active visual exploration is a crucial part of interacting with the environment and the perceiving world around us (Wexler & Van Boxtel, 2005); it helps to understand how athletes behave in such environment, what cyclists seek to make pacing decision, and which type of information is more important.

Visual search strategy and the way athletes acquire information have an essential effect on cycling during real competition. In my initial finding from the previous laboratories based studies, I found that differences in information seeking behaviour between expertise and novices in both fixation time and the number of frequency switching between information. 'Speed' was found to be the primary source of information for the majority of experienced cyclists, while distance was for the novice group. In addition, this study found participants spent quite a lot of time seeking performance information in both groups approximately 60-70% of overall time. Chapter four, presented as a conference paper Boya & Micklewright (2016) found that there were differences in performance and pacing strategy when participants were deprived from the preferred information, even though other information was presented, indicating that some type of information is invaluable for experience cyclists. In a follow-up study, chapter five, it was found that providing experienced cyclists with preferred source of information even for limited time is enough to perform similarly. However, all the studies were laboratory-based studies that used a Velotron Cycling Ergometer and all the environmental and external circumstances were controlled, and therefore participants did not need to balance or navigate obstacles that, on a moving bicycle on the road, would otherwise impose demands on the visual system and information acquisition.

Visual perception in sport is related to the necessity of athletes to perceive the environmental structure. Gaze is highly specific to the task and integration of motors action such as hand, head, and body movements (Land, 2009; Foulsham *et al.*, 2011). Depending on the expertise and skills level, athletes perform diverse perceptual search strategies (Goulet *et al.*, 1989), highlighting the role of visual search strategies in providing the necessary information to make decisions. The location and duration of the fixations are assumed to reflect the perceptual decision-making strategy used to extract information from the environment (Williams *et al.*, 1994). Therefore, from a heuristic perspective, the decision-making processes regarding future action is based on the priority of the information and their relationship (Raab, 2012).

During human locomotion, the visual search patterns have been studied in both cars driving and walking, it has been investigating to understand how humans use vision for obstacle avoidance and safe driving (Falkmer & Gregersen, 2005; Patla & Greig, 2006; Marigold *et al.*, 2007). A few studies have also compared visual behaviour between real-life and simulated environments (Dicks *et al.*, 2010; Foulsham *et al.*, 2011). Both studies showed differences in gaze behaviour between participants in real-life and laboratories based tasks. Participants were found to spend more time seeking the path and paid a faster attention to the pedestrian in real-life than when they were asked to watch the video of their own walk. This indicates that measuring visual behaviour in highly controlled environment such as laboratories video simulation may not reflect the correct understand of important information. In sports, most of the previous visual search studies, to my knowledge, are laboratory based, including the cycling experiments presented in the three previous chapters. However, Vansteenkiste et al (2013) investigated the way in which visual behaviour guides bicycle steering in a simple bicycling task. And more recently Zeuwts *et al.* (2016) compared cyclists' visual behaviour in real cycling path, or during watching a film of the same road. Thirteen participants were randomly signed in to either a high-quality or low-quality road path, eleven months letter participants visual behaviour were measured during cycling task while watching their previous path video in the laboratory. A significant correlation in gaze behaviour was found in low quality road path between real-life condition and the laboratory task, but not for the high quality path. This, perhaps indicates that under certain conditions, laboratory experiment might provide valuable gaze information in real-life. However, to my knowledge, no previous study has investigated cyclists' visual behaviour in real life to understand information acquisition as part of the perceptual-action processes in regulating pace.

Measuring cyclists' gaze behaviour on road and exploring the amount of time cyclists spent seeking performance information would help us to better understand cyclists' visual behaviour and the role of performance information in pacing decision during competitions, and whether participants would prefer different type of performance information or no. Therefore, the aim of this study was to measure cyclists performance and the information acquisition behaviour among cyclists performing a road-based 10 mile cycling TT. The purpose was to test our previous conclusions from the laboratory studies that athletes attend to a relatively few sources of information during a time trial.

6.2 Methods

6.2.1 Participants

Thirteen experienced male cyclists were recruited for this study, however; only ten participants had a good pre and post calibration and therefore, were included in the data analysis. Mean ± 1SD age, stature and body mass was 34.2 ±

12.2 years, 177.3 ± 6.8 cm and 74.3 ± 8.9 kg. Participants had 10-mile cycling time trial experience for an average of 13.2 ± 12.2 years.

6.2.2 Design

A non-experimental design was used in which participants performed a single 10 mile cycling time trial on a public road. An out and back lollipop course format was used between the University of Essex and the approach to Thorrington, as presented in Figure 6-1. The time trial course was available on STRAV website, and most of the subjects were familiar with the course, however, unfamiliar participants were asked to do course familiarization trial using their bike. Visual behavior was measured across 15.85 km cycling time-trials at every 2.5 miles (4 km) part from the last segment which was measured at 3.85 km. Cycling time-trial completion time (s), speed (km.hr-1), power output (W), distance (km), pedaling cadence (r.min-1) and heart rate (b.min-1) was measured. Participants wore, as previously described in chapter 2, SMI-iView ETG-tracking device to measure the type of information they looked at, and the frequency and duration with which they did so.

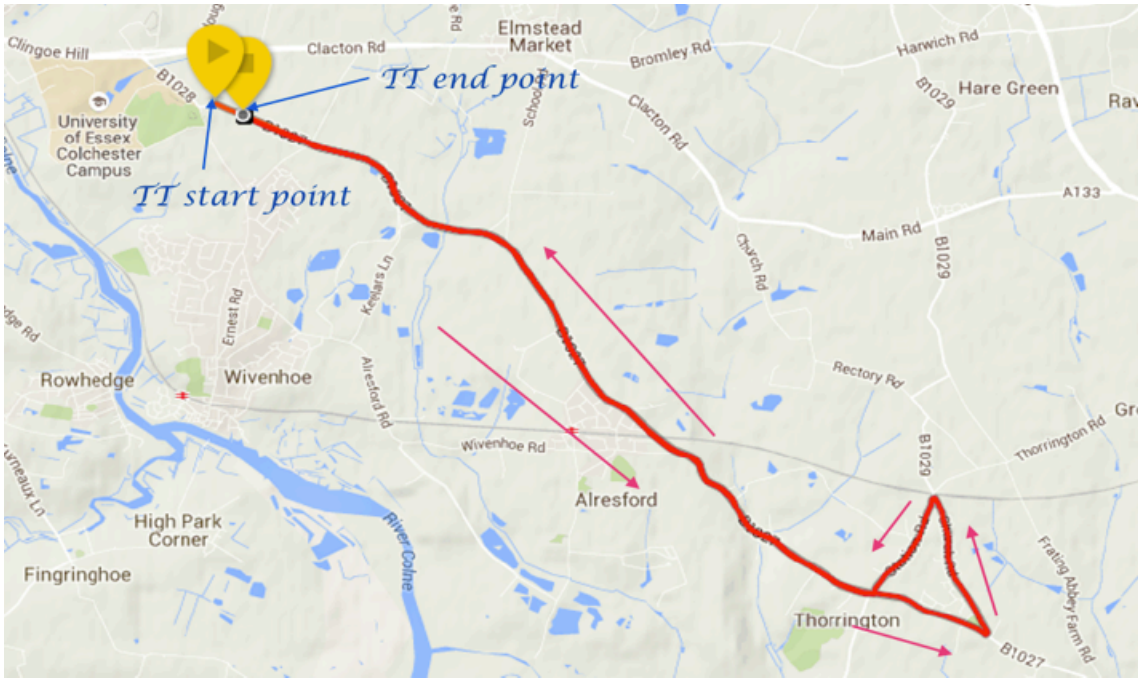


Figure 6-1 A screenshot showing the cycling TT map, and the start and end point.

6.2.3 Procedure:

Pre-testing procedures were carried out as explained in Chapter 2 (2.3.7). The study was explained to the participants including the eye tracking equipment and time-trial cycle set-up. A three point calibration was performed and the calibration was checked at the beginning and the end of each test. Participants were given an opportunity to test the bike, carry out a standard distance warm up (Figure 6-2) and make further adjustments if necessary. After cycling to the start point ‘warm-up’ figure (6-1&2), participants were followed by the test leader (researcher), they were asked if further bike adjusting is needed, all the attached devices were reset, then asked to start the TT when they were ready. The researcher, in case of any technical problems, followed all participants. All the data were collected and saved at the end point of the race. All participants were debriefed about the purpose of the study once they had completed the trial.

Figure 6-2 A screenshot showing the warm-up start and end point.

6.2.4 Cycle and Feedback Configuration

All participants used the same laboratory bicycle (Figure 3-6) fitted with a specially adapted handlebar mount capable of attaching several different cycle computers (Figure 6-4). The extra handle bar mount was necessary attach separate devices to display heart rate (Suunto Ambit3), power output (SRM), speed, distance and time (3 x VDO M2 cycle computers). Displaying feedback on different devices ensured sufficient spatial separation, added confidence to the process of identifying what participants looked at. The special mount was also positioned higher than the handlebars to reduce the range of head and eye movements and the associated risk of eye movement measurements being out of range of the eye-tracker scene camera. Part of the SRM power control screen was covered, so participants were able to see only power output data. The Sunnto Ambit 3 monitor was attached using the manufacturers handlebar mount (Figure 6-5).

Figure 6-3 The adjustable seat and handlebar, and the experimental designed bike.

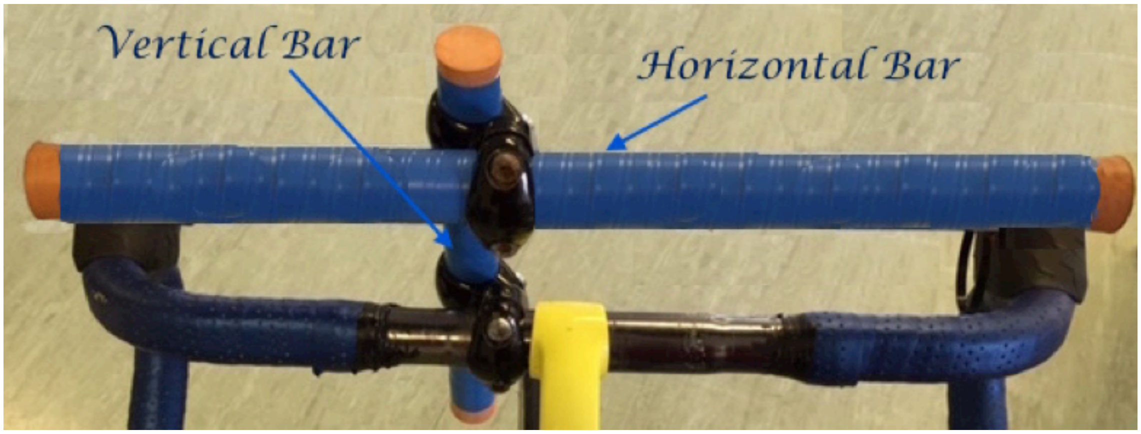


Figure 6-4 The attached two vertical and horizontal bars.

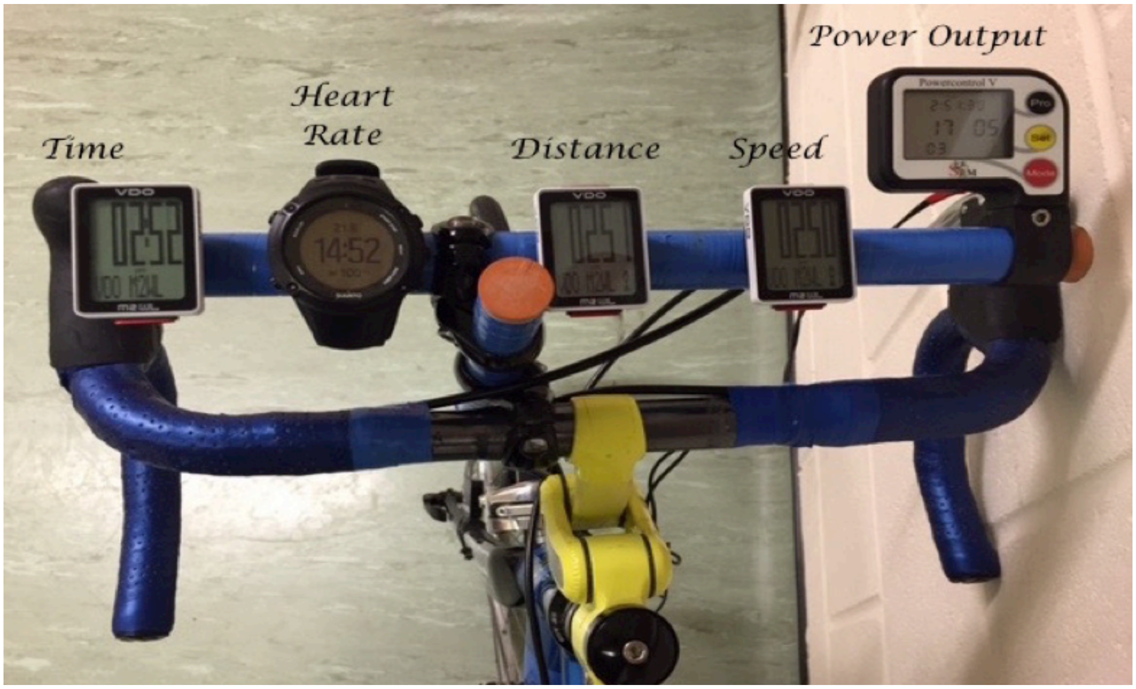


Figure 6-5 The attached 3 VOD M2 devices, Sunnto HR watch and the SRM screen.

6.2.5 Physiological measures

Participants wore a Suunto Ambit 3 Peak chest strap and heart rate was continuously recorded during the time trial. At the end of each time trial, heart rate date was transferred from the Ambit 3 unit and, as described in chapter two, an average was calculated for each 4 km segment.

6.2.6 Visual Behaviour

The SMI iViewX sunglasses Eye Tracking Glasses device was fitted to each participant and a three-point calibration was performed in accordance with the manufacturers recommendations. Each calibration was performed outside to ensure that the device has been calibrated to subjects eye under the same weather and lighting conditions as the time trial. Eye-movement was recorded to measure the gaze behaviour (fixation time, frequency and the total gaze) from both eyes. The ETG was connected to a customized Samsung Galaxy S4 smart recorder, which was put either in a small hip bag carried by the participant around, or in the back pocket of the cycling sweater, depending on participant choice and comfort.

6.2.7 Data analysis

Time-Trial average cycling speed, power, cadence, and heart rate was downloaded from the SRM power-control device and calculated on participant-by-participant basis for the whole time-trial and for each 4 km segment. A Be-Gaze 3.2 analysis software for the SMI was used to combine the scene video and the eye-tracking recording to ‘an overall gaze video’. The gaze videos were subsequently reviewed and manually coded, using Video-Coder 2 program (see section 2.3.9), against nine predetermined categories. Five of the categories related to performance information feedback that were speed, elapsed distance, power output, heart rate and elapsed time. Visual fixation times were also coded for the bike gearing system, road and traffic (car, traffic signal and roundabouts). A final category ‘unknown’ which represent the losing of signal and/or when the signal “tracking marker” was disappeared from the scene camera due to the cyclists racing position. To normalize absolute visual fixation times for inter-participant differences in time-trial performance, primary to nonary fixation data were all converted from absolute time (ms) to percentage of time-trial completion time.

6.3 Results

6.3.1 Time Trial Performance

The mean completion time for the time trial was 28.7 ± 1.6 sec. All the mean and standard deviation data for performance time-trial outcomes (speed, completion time, power, cadence, and heart rate) are given in (Table 6-1) for both segments and overall time-trial. Performance data for speed, power out put and cadence are presented in figure (6-6,6-7& 6-8).

Table 6-1 Mean and (1SD) for performance and heart rate data for the whole time trial and segments.

		4 km	**8 km**	**12 km**	**15.9 km**	**overall**
Time Trial	Speed (km/hr^{-1})	36.16 (3.2)	33.5 (1.7)	32.4 (1.9)	33.9 (1.3)	34 (1.3)
	Completion time (s)	401.4 (36.8)	430.5 (22.2)	446 (27.3)	409.7 (16.4)	1687.7 (66.2)
	Power (watts)	276.6 37.8)	250.5 (23)	249.4 (16.2)	254 (18.2)	257.6 (21.6)
	Cadence (r.min^{-1})	87.3 (9.5)	81.04 (7.1)	80.1 (7.7)	86 (8.2)	83.6 (7.2)
	Heart Rate (b.min^{-1})	170.9 (5.7)	177.1 (5.9)	181.5 (4.4)	181.8(3.9)	177.8 (4.2)

All values presented are time trial means ± (1SD) for each segments (4 km, 8 km, 12 km, 15.9 km). Values presented in overall column are calculated as the mean ± (1SD) for the whole TT (0-15.9) km.

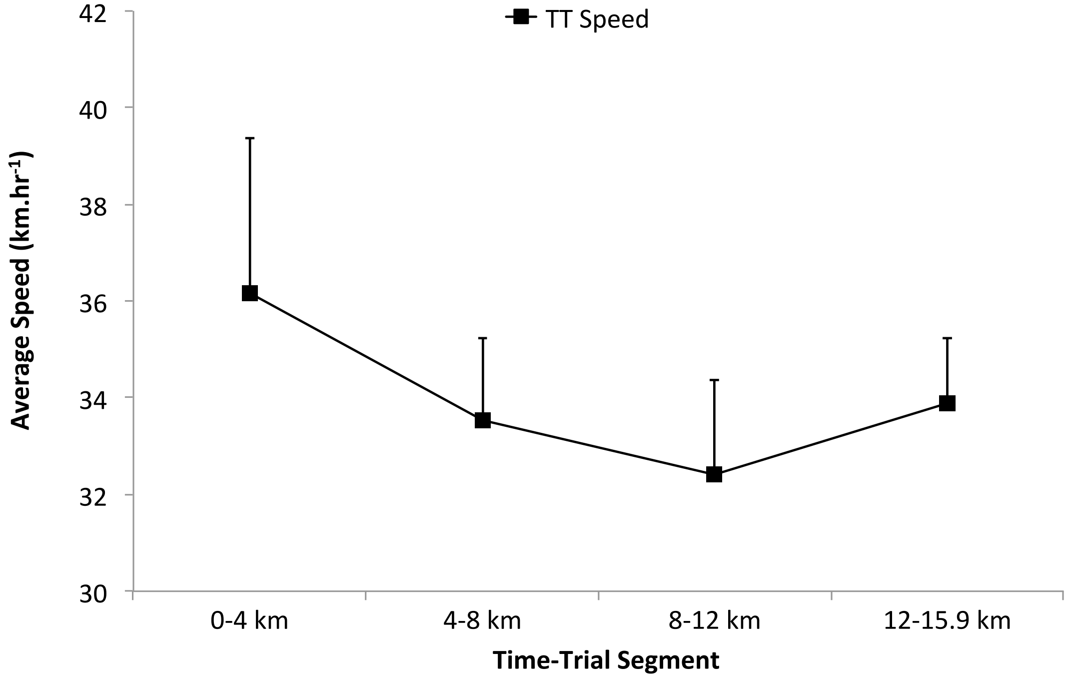


Figure 6-6 Average speed as pacing profile.

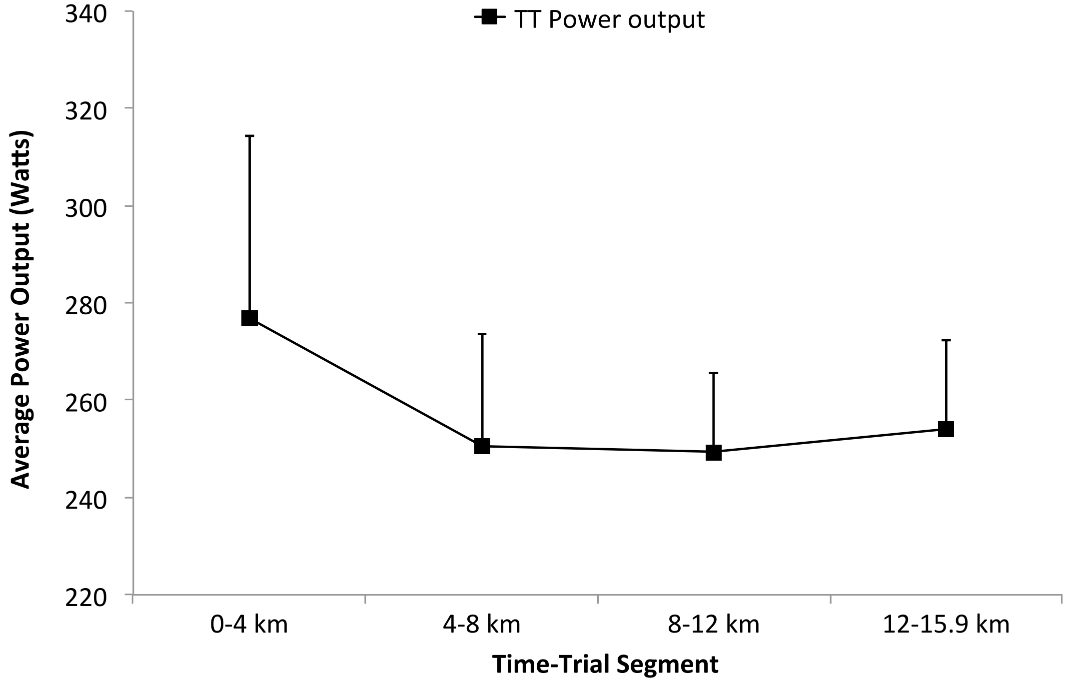


Figure 6-7 Average power output as pacing profile

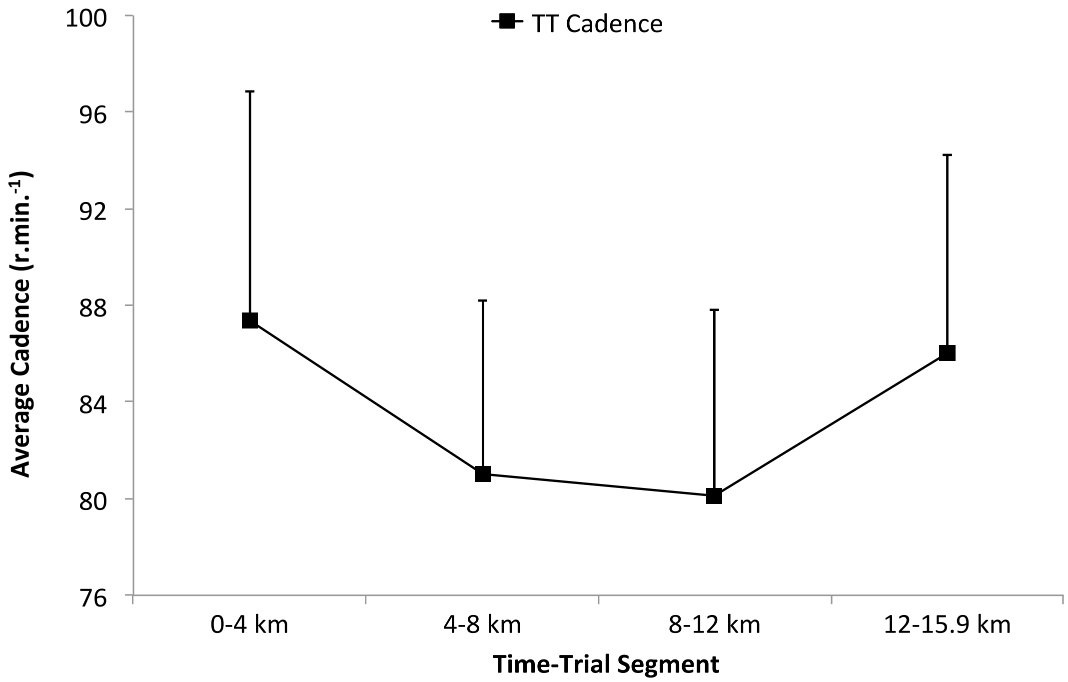


Figure 6-8 Average cadence.

6.3.2 Visual behaviour

The percentage of time participants spent looking at the primary point of interest was 53.6% ± 12.7%, 9 out of 10 participants were looking at the road as a primary point of interest, while unknown category was the highest for 1 participants. Over all percentage of fixation and frequency data are presented in figure (6-9& 6-10).

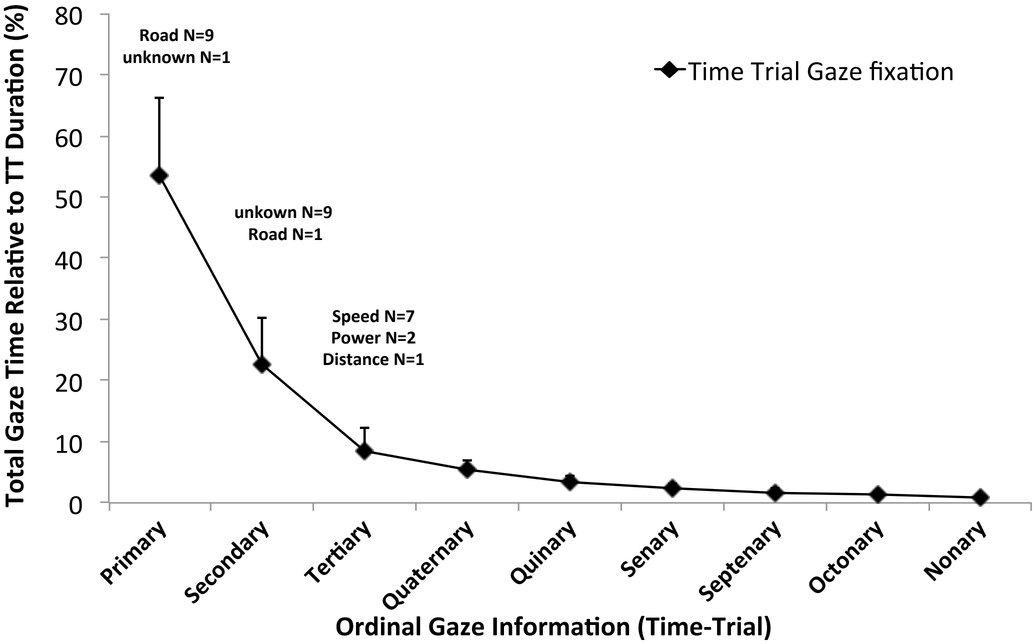


Figure 6-9 Overall mean relative gaze duration data for primary (most looked at) through to nonary (least looked at) information sources calculated over the full 15.9 km distance. Corresponding number of subjects with the type of information looked at is presented alongside the data points for primary to tertiary sources of information.

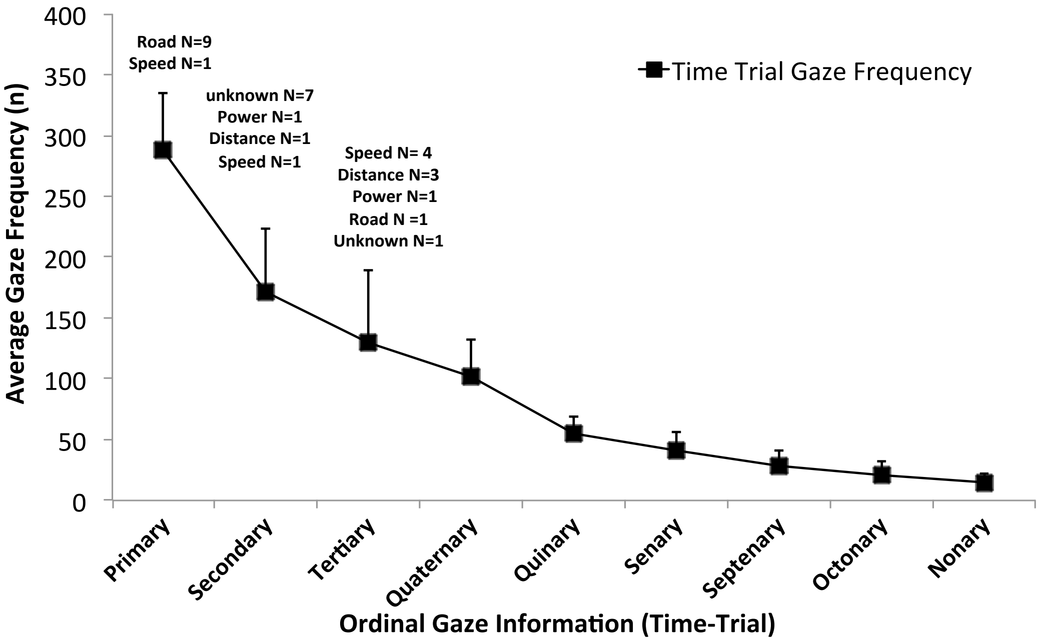


Figure 6-10 Overall mean gaze frequency data for primary (most looked at) through to nonary (least looked at) information sources calculated over the full 16.1 km distance.

Gaze percentage of fixation time and frequency in a segment-by-segment basis for primary, secondary and tertiary information are presented in figure (6-11-16).

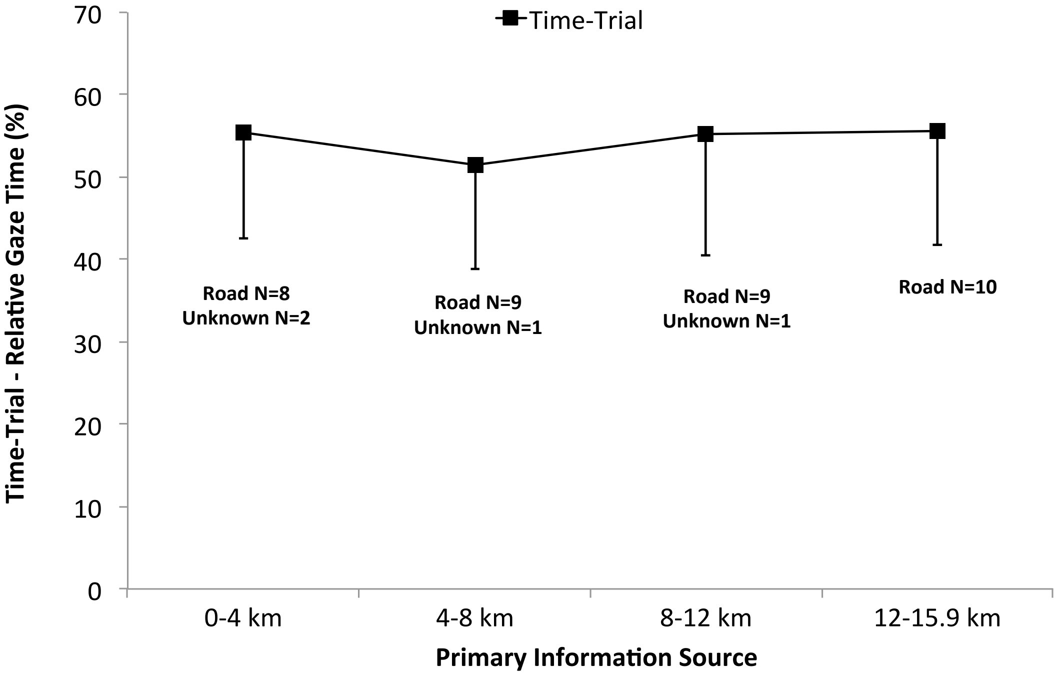


Figure 6-11 Mean gaze duration data for primary information source.

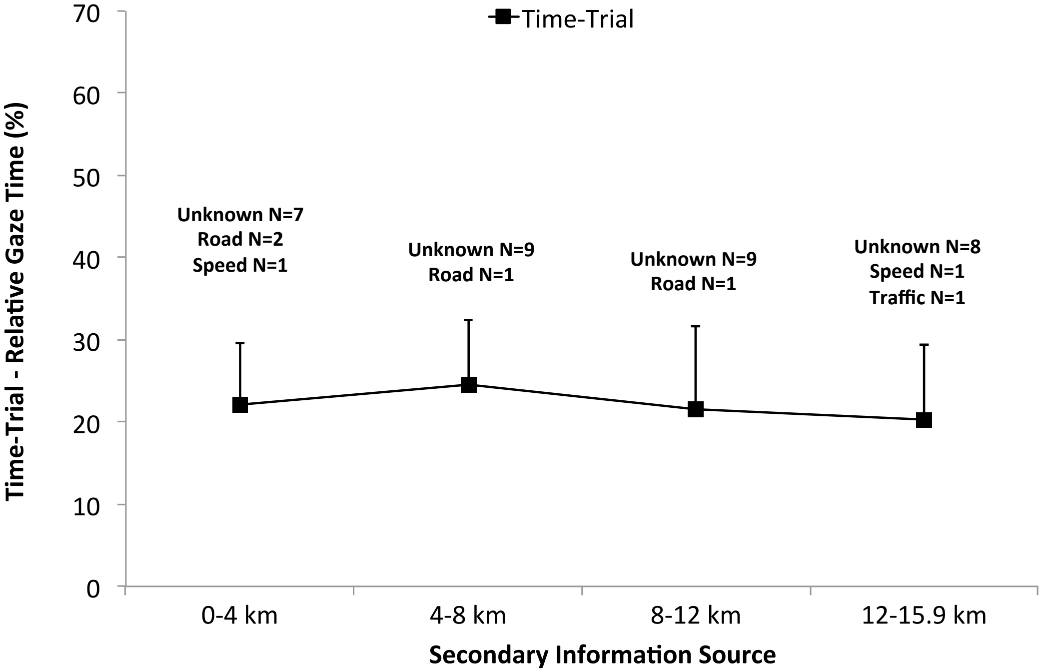


Figure 6-12 Mean gaze duration data for secondary information source.

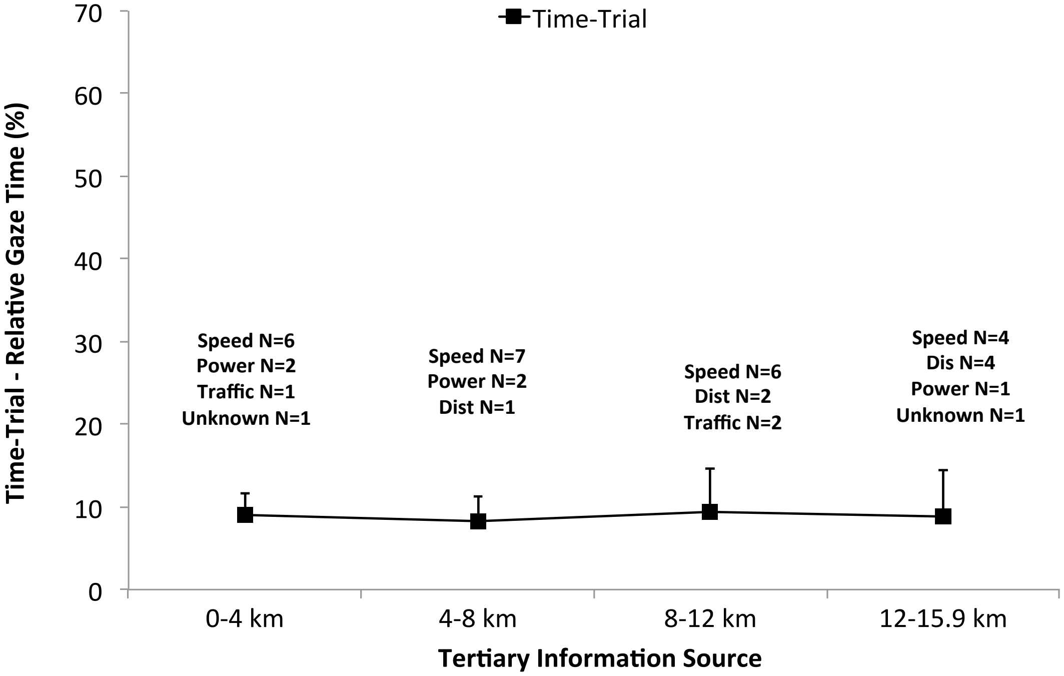


Figure 6-13 Mean gaze duration data for tertiary information source.

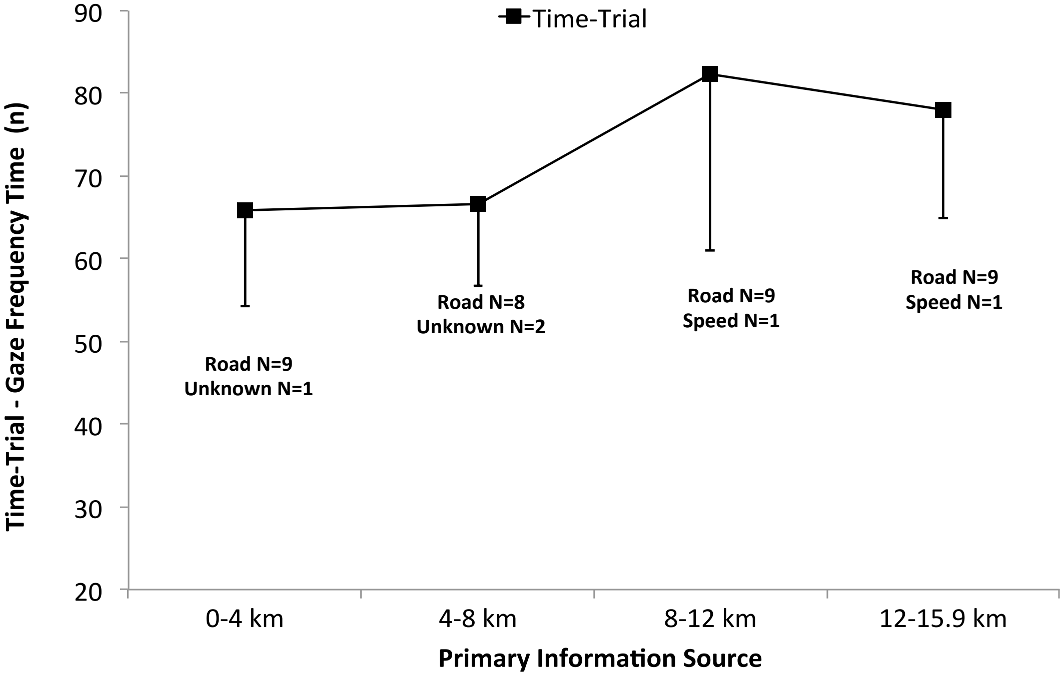


Figure 6-14 Mean gaze frequency data for primary information source.

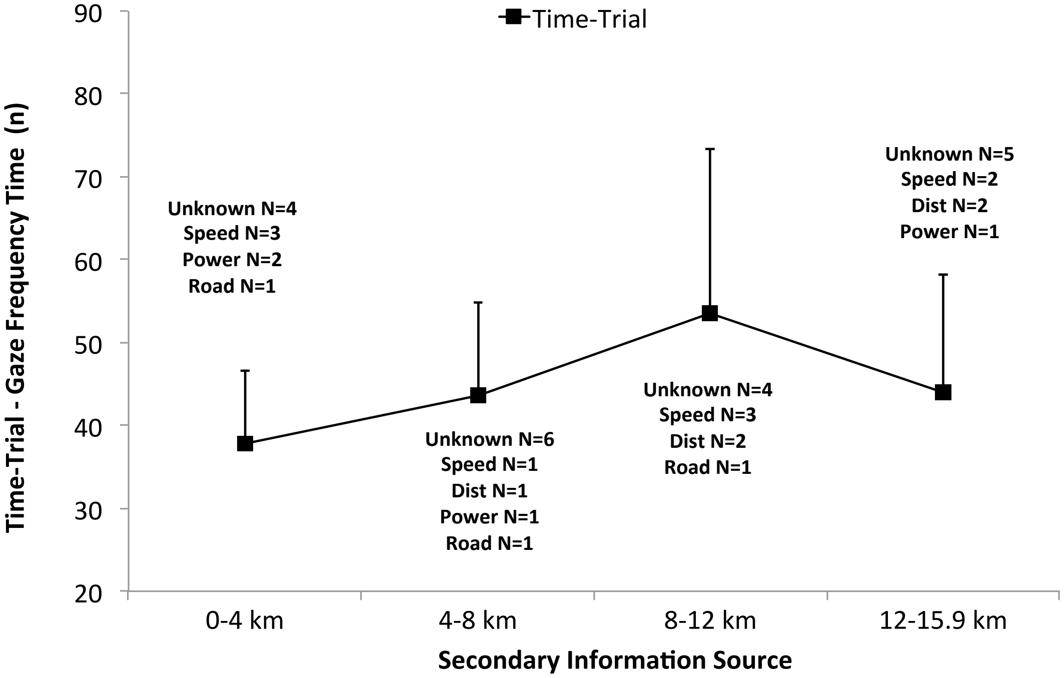


Figure 6-15 Mean gaze frequency data for secondary information source.

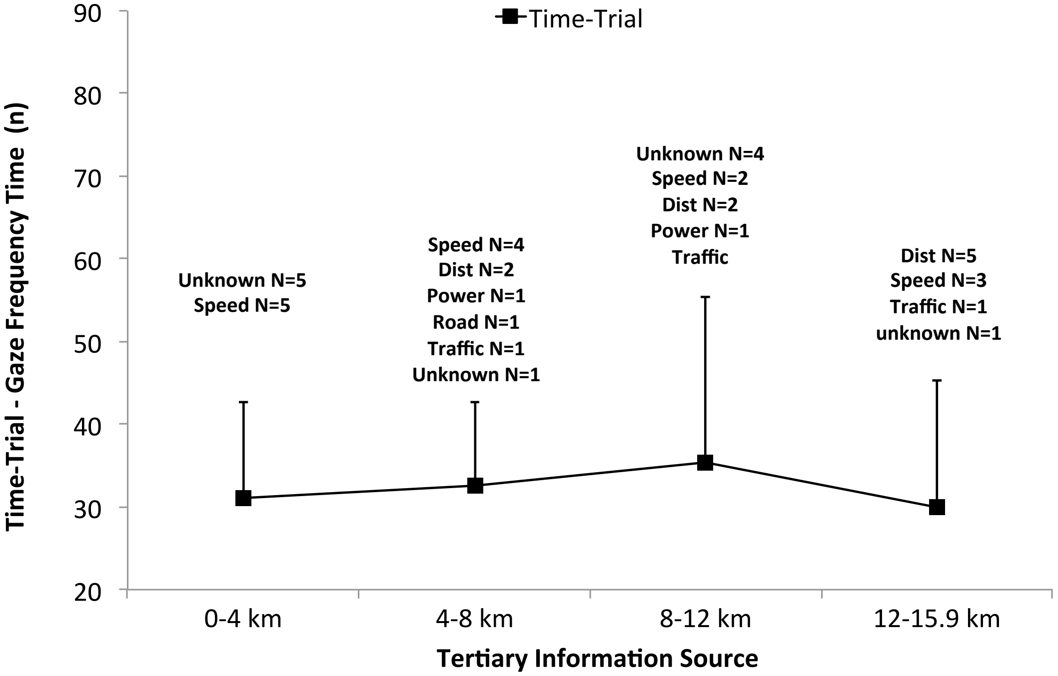


Figure 6-16 Mean gaze frequency data for tertiary information source.

Performance data along side with percentage of fixation time spent looking at performance information is presented at figure (6-17).

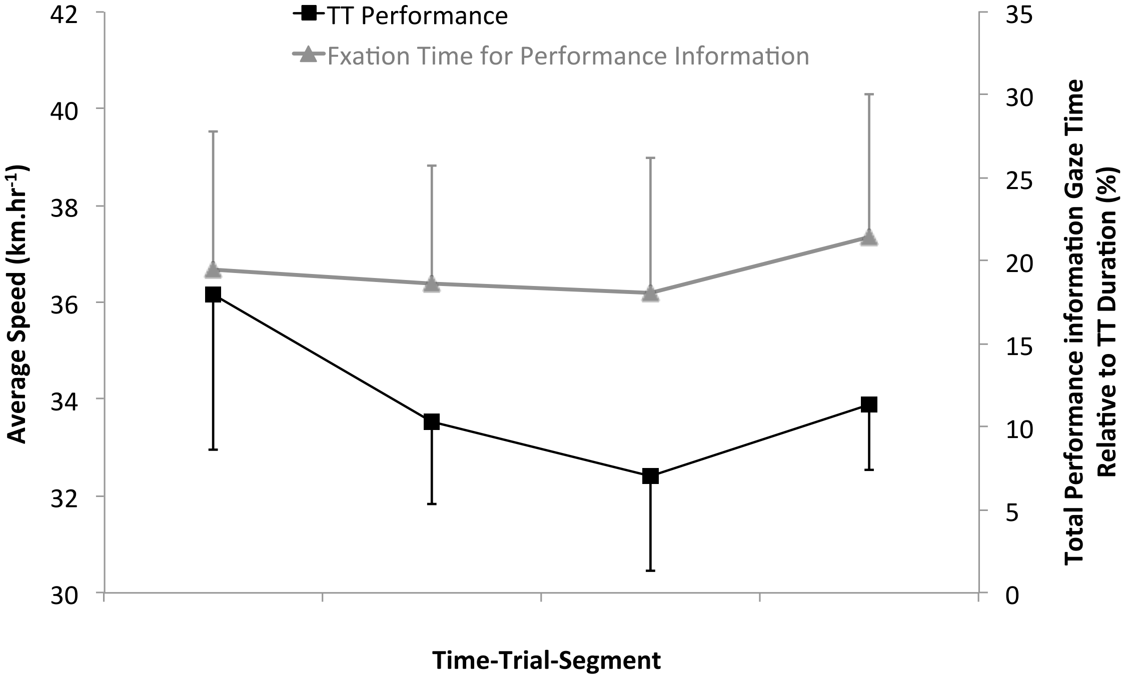


Figure 6-17 Average speed along side with gaze fixation for performance information

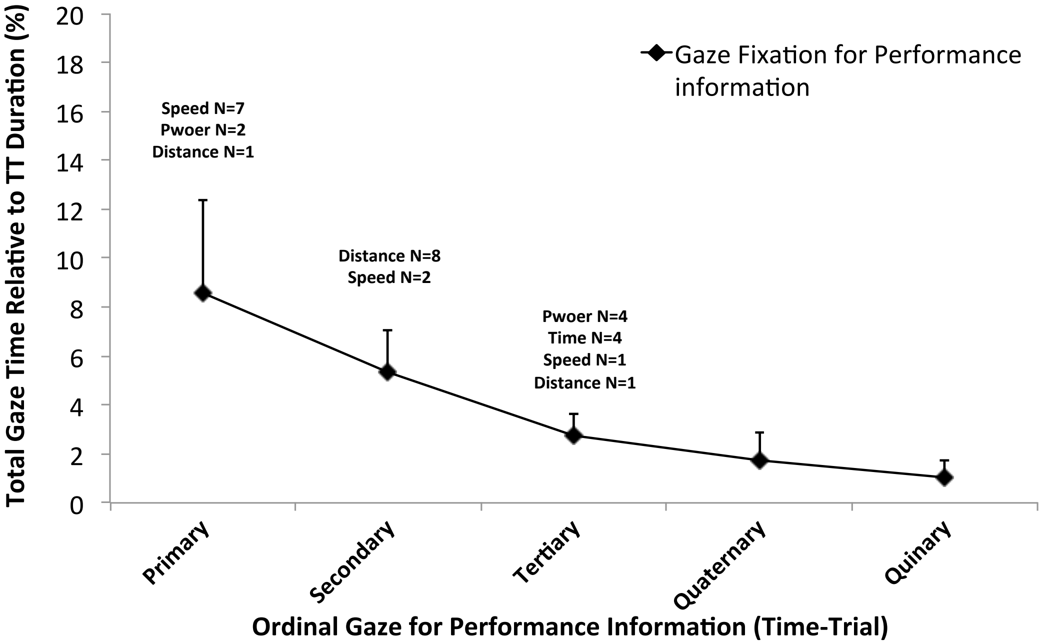


Figure 6-18 Overall mean relative gaze duration data for primary through to quinary information sources calculated over the full 15.9 km distance. Corresponding number of subjects with the type of information looked at is presented alongside the data points for primary to tertiary sources of information

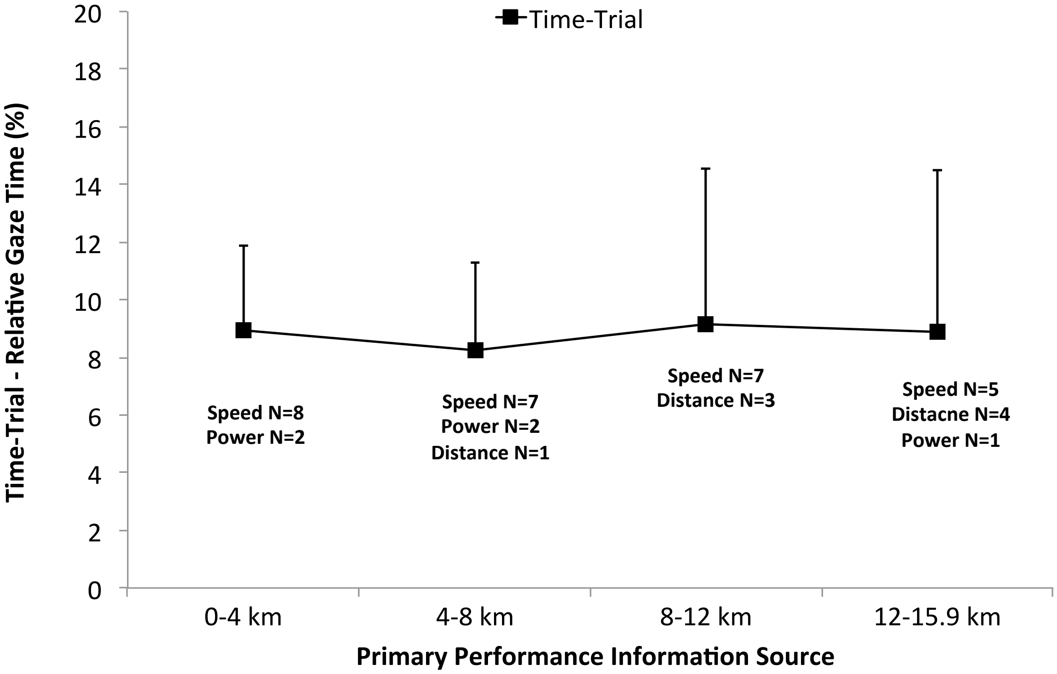


Figure 6-19 Mean gaze fixation data for primary performance information source.

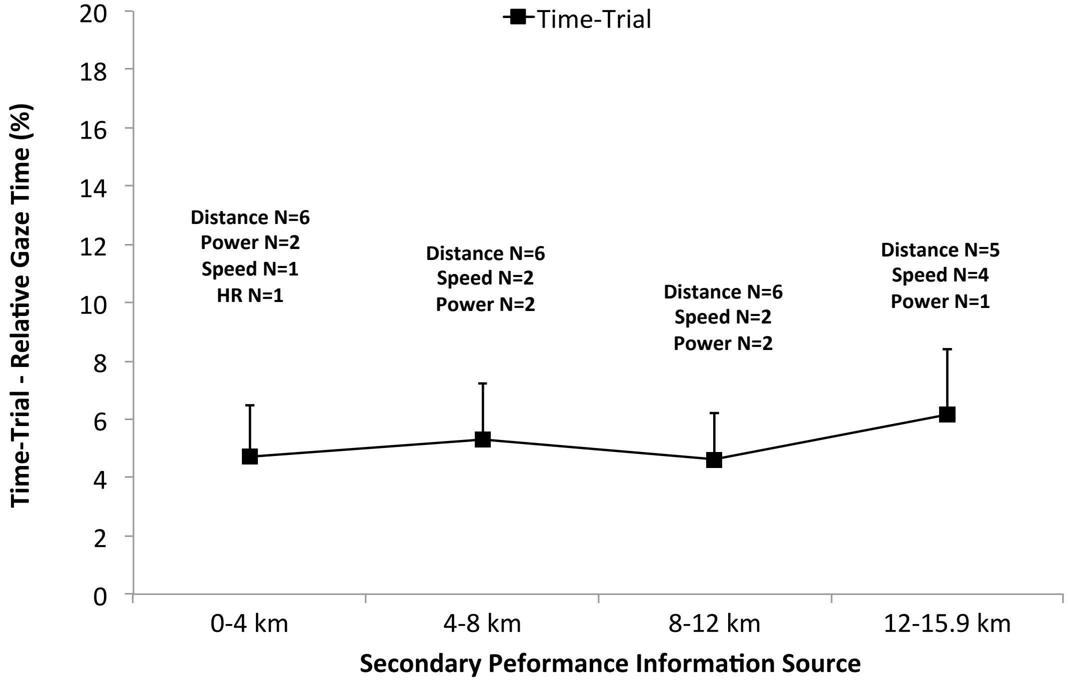


Figure 6-20 Mean gaze fixation data for secondary performance information source.

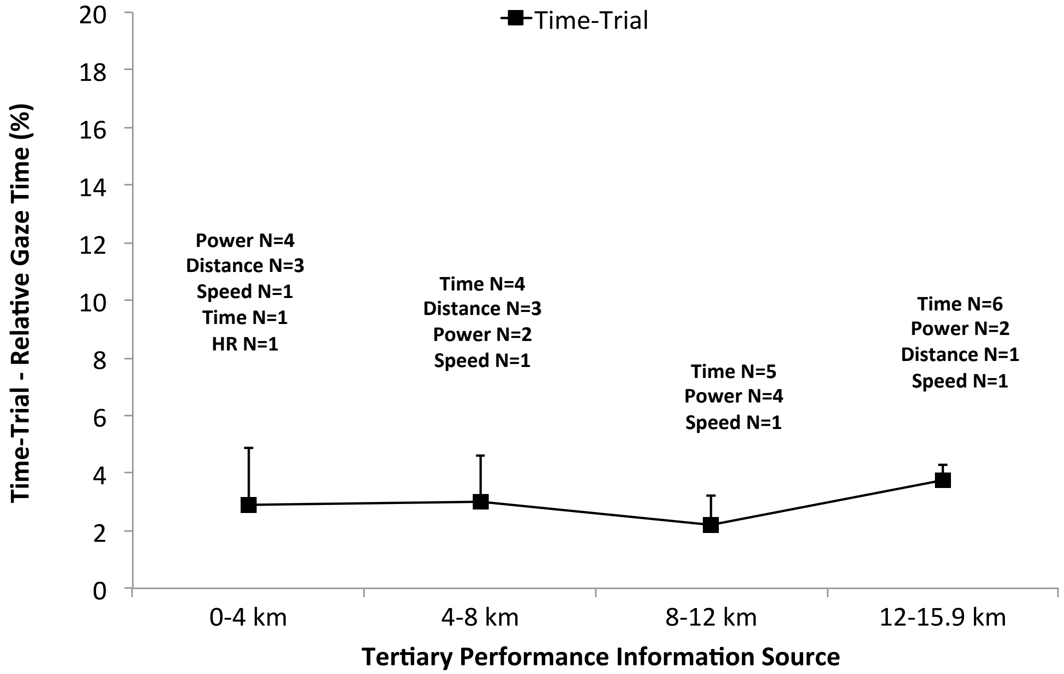


Figure 6-21 Mean gaze fixation data for tertiary performance information source.

6.4 Discussion

The main finding of this study was that gaze was driven to the road as the primary point of interest, with approximately 54% of the over all of the completion time (Figure 6-9). Moreover, the road category was the primary point of interest for both gaze fixation and frequency for the overall as well as segment-by-segment level (Figure 6-11& 6-14). This was similar to Zeuwts *et al.* (2016) that found that gaze behaviour was more directed towards the path ‘road’ in real-life.

The novelty in the study is that, to my knowledge, this study is the first to measure cycling visual behaviour in a real-world time-trial. No previous research has investigated cyclists’ visual behaviour in real life during cycling TT, apart from a recent study, which compared cyclists’ visual behaviour in real-life and in the laboratory while watching a video of the same road as a validation study (Zeuwts *et al.*, 2016). Moreover, this is the first study to present the extent to which cyclists’ seek/use performance information during cycling in a real world. In the first study Boya *et al.* (2017) although a difference in information seeking behaviour was found between novices and experts cyclists, both groups showed high gaze demands on performance information. This study showed that the time participants spent looking at performance information was approximately 20% of the overall time (Figure 6-17). This was similar to (Dicks *et al.*, 2010; Foulsham *et al.*, 2011) in which both studies found significant differences in visual behaviour between the lab and real-life. The amount of time participants spent looking at performance information, reflect and provide us with a better understanding of the overall time participants seek/need performance information in real competitions. This is similar to what was found in study three (Chapter five), in which varying the amount of preferred performance feedback information did not affect performance.

Although, the demand on performance information was less in the real-life, the priority in the type of performance information did not change. ‘Speed’ was the primary source of performance information for 7/10 participants, PO 2/10, while only 1/10 participant was seeking ‘distance’ feedback as a primary source of performance information (Figure 6-18). It has been suggested in Micklewright *et al.*

(2010) that experienced cyclists may pace themselves effectively according to speed and power feedback. Furthermore, it was found in the previous three chapters, that experienced cyclists were seeking ‘speed’, highlighting the role of performance information in addition to the endpoint. This result might indicate that knowledge regarding distance/time is not the only piece of information that determined pacing behaviour as it has been previously argued by (DeKoning *et al.*, 2011; Faulkner *et al.*, 2008; Foster *et al.*, 1994; Noakes *et al.*, 2006; Garcin *et al.*, 2012; Tucker, 2009; Ulmer, 1996; St Clair Gibson *et al.*, 2006). However, distance feedback was the secondary source of performance information for 8/10 participants (Figure 6-18), which was similar to our finding in the previous chapters. This might indicate that (a) distance information required less processing time by cyclists; (b) that the necessity of distance information is combined with other performance information such as ‘speed’; (c) the important of distance information vary according to the elapse distance. Whilst we cannot ignore the (a) point and further research is required, the segment-by-segment level of gaze behaviour support the above (B and C) point, it showed that the demand on distance information increased toward the end of the TT (Figure 6-19). While no participant was seeking distance knowledge at the start of the time-trial as the main point of interest, it became the primary source of performance information for 4/10 participants in the last segment, indicating the role of distance knowledge at the end of the race. An additional support to this was observed when seeking ‘time’ increased as a tertiary source of performance information from 1/10 participant at the start of the TT, to 6/10 participants toward the end of the race (Figure 6-21). However, it is also important to mention that 5/10 and 1/10 participants were seeking ‘speed’ and ‘power’ respectively as the primary source of information at the end of the race, indicating that distance is an important reference source but in combination with other information.

The amount of time cyclists spent seeking performance information increased at the end of the TT to 21.5% (Figure 6-17), this highlight the important of performance feedback for cyclists to make a further pacing adjustment and decision whether to maintain the current level or change it to meet their aims especially at the end of the race. This is similar to Smits *et al.* (2016) That found differences between experienced cyclists, whom did or did not receive performance related feedback, at the end of the race. The increased acquisition behaviour towards the end of the race is consistent with the behaviour observed during a self-paced running task (Chinnasamy *et al.*, 2013), and self-pace cycling (Boya *et al* .,2017)

An overall reversed-J pacing strategy was observed during the time-trial (Figure 6-6& 6-7), in which participants start the race very fast, an even pacing strategy in the middle followed by an increase in the PO ‘therefore pace’ toward the end of the race. This was similar to (Garland, 2005) in which a reversed-J shape pacing strategy was observed in pacing profile of elite rowers during 2000 m rowing competition. In addition (Edwards & Polman, 2012) stated that such a strategy is often observed in endurance exercise.

Although this study has produced some novel data regarding cycling visual behaviour in real-life not entirely observed previously. There are many limitations associated with nature of the eye-tracking technology, and the designed experimental bike that was used. The most significant one was the design of the ETG, and specially the scene camera. Although the scene camera has been designed to capture a person’s natural gaze behaviour to a high standard, however, it has an angle with a range of 90 degree that limits the scene video captured/recoded especially during cycling position. This was obvious and recognizable when participants were looking ahead at the road leading to disappearing of the tracking marker from the video due to the limitation of the scene camera, this differed between participant according to the participants height and their cycling position, ending up with a high percentage of unknown category up to 20% of the gaze fixation, ending as a secondary point of interest whether for the whole time-trial or the segment-by-segment level (Figure 6-9, 6-10, 6-12& 6-14). From the researchers point of view, the unknown category can be divided to mostly road ahead and traffic. However this did not effect seeking performance information due short distance and being with the range of scene camera which was because of the specially added bar (Figure 6-3 & 6-4).

Another limitation of this study was the absence of the competitor; cyclists in our study performed the TT individually. It has been found that competition effect performance and decision-making (Corbett *et al.*, 2012; Emily L Williams *et al.*, 2015). Therefore, studies with the presence of competitor are required to measure the demands placed on the visual behaviour. A further limitation was the designed bike that has been used in this study. Although the bike was adjustable and participants were fitted to the bike to a high standard, they were using the bike for the first time and some sort of discomfort might have been experienced; however, this could affect the over all performance but not visual behaviour. In the future, it may be possible to measure the cyclists' visual attention using a more advance eye-tracking technology and participants own

6.5 Conclusion

This study is the first to directly measure cyclists' visual behaviour during time-trial in real life. The data shows that gaze fixation was directed to the road as the main point of interest. The demand on total performance information was approximately 20%, and speed was the primary source of information for the majority of participants. This study agree with the previous three studies concerning the importance of knowledge of the distance to pacing in conjunction with other primary performance information source such as speed or power.

7 General Discussion and Conclusions

7.1 Introduction

The aims of this thesis was to investigate the information acquisition during a self-pace exercise to better understand the role of information feedback in effort regulation and pacing decisions to achieve an optimal performance. Theories of teleoanticipation (Ulmer, 1996), the central governor model (Noakes et al., 2005), psychobiological model (Marcorra 2009), anticipatory-RPE model (Tucker and Noakes, 2009), and Hazard score (De Koning, 2011) are based on the end-point or the knowledge of the exercise duration to determinant the pacing strategy. However, recent research suggests pacing is a decision making process that is based on an interaction between perception and action (Smits *et al.*, 2014), in which athletes make decisions based on the most relevant information (Renfree *et al.*, 2014). A recent interesting framework by Micklewright *et al.*, (2016) stated that the one-dimensional conscious-subconscious debate in pacing literature has limited our understanding of pacing-decision making process, instead suggesting a multidimensional process that influence pacing behaviour. A limitation of previous pacing research is that information uptake processes have been inferred from deception methods, the use of deception in pacing studies has been systematically reviewed (Jones *et al.*, 2013), rather than being directly measured. Therefore, the aim of this thesis was to use an eye-tracking technology to investigate athlete's visual behaviour and directly measure what information athletes seek during exercise. This thesis represents a significant advancement of knowledge of how cyclists acquire information during a time trial, and raises important questions about the emphasis placed on endpoint knowledge in previous model. A series of self-paced protocol studies were undertaken to provide insight into information seeking behaviour and how performance information my effect the regulation of pacing strategy during self-paced exercise.

Chapter 3 investigated differences between novices and experienced cyclists in information acquisition. Chapter 4 examined the role of preferred feedback information in pacing and performance. Chapter 5 investigate the effect of reducing exposure to preferred feedback on pacing a performance. Lastly, in chapter six cyclist's information acquisition processes were measured during a road-based 10-mile time trial.

7.2 Main Finding and Recommendations

Study one

- Differences in visual information acquisition were found between novices and experienced cyclists. Speed was the primary source of information for majority of experienced cyclists, while distance was for novices
- Experienced cyclists showed to be more selective and less switching between information than novices.
- Knowledge of distance remaining/completed is not the only performance information feedback that influences pacing and performance especially for experienced cyclist, but there is other performance information that cyclists could used to pace themselves.
- The difference in information acquisition observed in this study may reflect differences in motivational regulators; with perhaps performance orientated decisions in experts compared to completion-orientated decisions in novices.

Study two

- Cyclists deprived of their preferred information source had a slower time trial performance.
- Varying the type of performance information effect pacing decisions and performance.

- If too much, unnecessary, information is available perhaps this distracts or confuses participant's attention and diminishes performance.

Study three

- The availability of preferred performance information, even for a limited time, has relatively little effect on pacing and performance. Therefore, coaches and athletes should consider regular interval preferred performance feedback during exercise.
- Information acquisition preferences vary among cyclists. A piece of information could be useful for one cyclist yet less important for another. Therefore, coaches and researchers should consider providing participants with preferred performance information.

Study four:

- Cyclists consider performance information less during real world time trial.
- 'Speed' was the primary source of information for the majority of the cyclists 7/10, followed by distance 2/10 and power output 1/10.
- The type of preferred performance information varied based on previous experience.

7.3 General Discussion

The aim of this thesis was to investigate athlete's information acquisition and examine the role of different type of feedback information in determinant of pacing and performance. Differences in information acquisition were found between experienced and novices' cyclists during the experimental TT (chapter 3). In addition, experienced cyclists were found to be more consistent in the information they look at; of note is the fact that they looked at primary information for longer and less frequently. Expertise were found to be important and played a significant role in information acquisition. Interestingly, while knowledge about distance was of greater interest for novice participants, information about 'speed' was for the experienced group. The results highlight differences in information acquisition that bring to question the common information-processing mechanisms introduced by previous pacing models (DeKoning *et al.*, 2011; Faulkner *et al.*, 2008; Foster *et al.*, 1994; Noakes *et al.*, 2006; Garcin *et al.*, 2012; Tucker, 2009; Ulmer, 1996; St Clair Gibson *et al.*, 2006). In particular, the assumption in previous pacing models that the integration of endpoint awareness with perceived exertion is the primary and universal driver of pacing decisions, regardless of athletic experience or individual feedback preferences. It may be possible that decision-making among experienced cyclists was different to novices and indeed different between individuals which resulted in a need to seek out more varied sources of information. This is consistent with the idea that individuals use information in an adaptive way according to the perceived demands of a situation or problem.

In a practical context, this study highlights the importance of prior experience in performance seeking information as well as suggesting that knowledge about distance is not the only/most important performance information that might influence the decision-making process and therefore performance and pacing. Such a finding raised the question of whether knowledge of distance is the determinant of pace, as put forward in previous models, and if so, why experienced cyclists prioritised feedback about speed? One explanation is that processing distance feedback requires less cognitive effort, and therefore time, compared to speed. A further explanation is that the important of distance knowledge differ according to the elapse time.

The differences between participants in information acquisition opened up a question of the roll of primary information in pacing and performance. And this was investigated in a follow up study. The study showed that the most looked at information ‘primary’ influence pacing and performance. Participants were found to differ in the type of information they look at mostly, with speed being the primary source of information for most participants. Moreover, a different pacing strategy was followed when cyclists were deprived of their preferred information. Such evidence strongly suggests that it can no longer be assumed that all pacing behaviour is primarily driven by knowledge of the endpoint only and that, in addition, individual feedback preferences are important.

Study 3 was designed to examine how frequently cyclists need the preferred performance information before pacing and performance suffer. The study showed that restricting the availability of preferred information to 15 seconds every 20% and 10% of a 5 km TT had little effect on performance and pacing strategy compared to the information being continuously available. An interesting outcome of the above laboratory studies is that perceived exertion did not exist in the list of primary sources of information acquisition for any of the participants. That does not mean perceived exertion is not an important factor in pacing decisions as predicted by many of the previous models. It does however highlight to methodological complexities of investigating pacing decisions in terms of the acquisition and utilization of external referents, which can be easily observed using methods like eye-tracking.

A limitation of the previous laboratory studies is that the methods ignore navigation, balance and collision avoidance demands on visual attention that would occur while cycling on a real road. Thus, in study 4, visual behaviour was measured using a mobile eye-tracker during a road-based 10 mile TT. Results showed that the amount of time participants spend seeking performance information was about 20% of the over all performance time that was much less than what was found in the laboratory study, in which participants were found to seek performance information above 50%. Nevertheless, after looking at the road and other non-information objects, speed remained the preferred type of performance information, similar to experienced cyclists preferred information in study one. Moreover, the study showed that reliance on distance information increased towards the end of the TT. The results of this study triangulate with study 3 in the sense that cyclists seem to be able to pace themselves with relatively little exposure to performance feedback information. Such results may be of interest to athletes, coaches, and researchers, owing to the ecological validity of the field-based design.

The data from this thesis has provided an insight into cyclist's visual behaviour, in which has huge potential in revealing information acquisition patterns, in both laboratory and real-world cycling TT, provide support and expand the notion that performance feedback influence pacing and performance but this may vary depending on the previous experience. Eye fixation time, and the order in which subjects look at objects of regard, are also a useful measure of information acquisition. Such information could help understanding participants' behaviour during complex situation, in which it reveals information about complex situation that require athlete to select a choice between a number of alternative possibilities. The thesis highlights the complexity of the decision-making processes that play an important role in the regulation of effort. The information acquisition process using eye-tracking technology has provided some important new data in the nation of feedback information and pacing decision. Further, it has also produced some important new data not entirely consistent with previous models of pacing about the attention to, and use of, feedback information. Till date, most of the previous pacing models (DeKoning *et al.*, 2011; Faulkner *et al.*, 2008; Foster *et al.*, 1994; Noakes *et al.*, 2006; Garcin *et al.*, 2012; Tucker, 2009; Ulmer, 1996; St Clair Gibson *et al.*, 2006) emphasise the role of knowledge of distance/time on pacing strategy and pacing decision yet the majority of cyclists were found to primarily look at 'speed' when measured using eye-trackers.

The methodology used in this thesis provided a more focussed method of measuring feedback information. Most of the previous studies collected evidence using limited indirect observation methods where participants were subjected to deception or blinded with regard to performance feedback information. Such approach entails a number of limitations, including the following: 1) the emphasis on a singular source; 2) Individual differences in feedback preferences are not considered; 3) Within trial change on the focus placed on feedback information. Eye-tracking technology provides a more sophisticated method of directly measuring the information athletes' look at during self-paced exercises. It enables detailed information to be gathered regarding the way in which athletes select information in an exercise trial. The eye-tracking technology has provided a more direct method to overcome the limitations of deception and blinded studies.

This thesis provides evidence and represents a significant advancement of knowledge in comparison to previous models. These being the theories of teleoanticipation (Ulmer, 1996), the CGM (Noakes et al., 2005), the anticipatory-RPE model (Tucker and Noakes, 2009), and the psychobiological model, which were mainly based on the end-point or duration of exercise in presenting pacing strategies. The data shows that pacing-decision is a complex process and plays a vital role in exercise regulation that dies not necessarily rely on the knowledge of distance or time as it previously known. However, the first study showed that knowledge of the endpoint might in fact be a secondary to other information such as (speed, or PO) in informing the actions of participants. The information acquisition was different between groups, 'first study' and indeed different between individuals (study 2,3, and 4) that resulted in a need to seek out more varied sources of information. This is, in fact, consistent with the notion that individuals use information in an adaptive way, according to the perceived demands of a situation. It is a more complex process depends on some performance information that varies between individual.

The study of visual behaviour and information acquisition using eye-tracking device has extended the knowledge of pacing research and produced some important new data about the attention paid to, and use of, feedback information in pacing regulation. Eye fixation time and fixation sequences were discovered to be important in revealing information about the way in which athletes seek or select important cues during complex or novel situations. It also facilitates the understanding of the use of information in complex situations, such as that required to select an option between numbers of alternative possibilities.

The information acquisition pattern and the role of performance feedback in experienced and, to a certain point, novice athletes has been established both in the laboratory and in the real world. However, all the studies in this thesis, apart from the first study, examined experienced cyclists. It is unknown whether elite cyclists or untrained cyclists would employ the same mechanisms. Moreover, studies included in this thesis have concentrated on short distance exercise events. Therefore; in event with longer durations, ‘such as 20 km, 40 km’ cycling TT, it is not necessary that the differences in information seeking or/and the priority of performance information remain the same, in order for them to be applicable to some of the principles found in these studies for events with longer durations. Thus, visual behaviour and the importance of performance information should all be tested with regard to longer distance cycling events.

Finally, this thesis has produced a new method for the investigation of visual attention and decision-making during paced exercise and some entirely new data with regard to the notion of feedback information investigation. However, the eye tracking technology is not without limitations. The most notable one is the limitation of the ETG scene camera, especially in cycling position, and also the inability to distinguish information from small device ‘screens’ such as GPS; therefore, a more advanced eye tracking technology would help improve the quality of the research in future. A further limitation of using eye tracking is that it does not reveal information about the way in which participants use information and form the decision; therefore, other tracing methods are required, such as thinking aloud, which can be used in conjunction with eye tracking.

These series of studies are the first to measure cyclists’ visual behaviour directly to understand information pick-up as part of the perceptual-action processes in pacing regulation, and demonstrated that the formation of a pacing decision is a complex process that could be influenced by different types of information in different segments.

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APPENDICES

Appendix 1

EXAMPLES OF CONSENT FORM

UNIVERSITY OF ESSEX

FORM OF CONSENT TO TAKE PART AS A SUBJECT IN A RESEARCH PROJECT

CONFIDENTIAL

Title of project / investigation: **Information acquisition differences between experienced and novel time trial cyclists**.

Brief outline of project, including an outline of the procedures to be used: If you agree to take part in this study you will be asked to complete a two 10 mile cycling time trails on two separate occasions. During each trial we will record performance (time), pace change (power), heart rate, and you will be asked to wear an eye-tracker. A large screen will be positioned to the side which various types of real time information will be displayed (Speed, Power, Elapsed Time, Elapsed Distance and Heart Rate). An RPE scale will also be displayed on the screen. None of these procedures will require you to stop or slow down during the trial. All of the data collected in this study will be treated as confidential and securely stored electronically with access only available to the investigators Dr Dominic Micklewright and Mr Manhal Boya. The data collected from you and other participants may be published in academic journals with you anonymity retained. At the end of the study you will be provided with a copy of your data and provided with feedback from one of the investigators. You have the right to withdraw from the study at any time before, during or after the experimental without giving a reason in

I, ... *(**subject's** full name) agree to take part in the above named project / investigation, the details of which have been fully explained to me and described in writing.

Signed .... Date ....

(Subject)

I, DOMINIC MICKLEWRIGHT / MANHAL BOYA certify that the details of this project / investigation have been fully explained and described in writing to the subject named above and have been understood by him / her.

Signed .... Date ....

(Investigator)

Appendix 2

EXAMPL OF PAR-Q FORM

Name: **D O B:**

Address: **Postcode:**

Email: **Mobile:**

Physical Activity Readiness Questionnaire (PAR-Q)

If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you significantly change your physical activity patterns. If you are over 69 years of age and are not used to being very active, check with your doctor. Common sense is your best guide when answering these questions. Please read carefully and answer each one honestly: check YES or NO.

1. Has your doctor ever said you have a heart condition and that you should only do physical activity recommended by a doctor? Yes ☐ No ☐
2. Do you feel pain in your chest when you do physical activity? Yes ☐ No ☐
3. In the past month, have you had a chest pain when you were not doing physical activity? Yes ☐ No ☐
4. Do you lose you balance because of dizziness or do you ever lose conciousness? Yes ☐ No ☐
5. Do you have a bone or joint problem (for example, back, knee, or hip) that could be made worse by a change in your physical activity? Yes ☐ No ☐
6. Is your doctor currently prescribing medication for your blood pressure or heart condition? Yes ☐ No ☐
7. Do you know of <u>any other reason</u> why you should not do physical activity? Yes ☐ No ☐

If yes, please comment: ____________________

YES to one or more questions:
You should consult with your doctor to clarify that it is safe for you to become physically active at this current time and in your current state of health.

NO to all questions:
It is reasonably safe for you to participate in physical activity, gradually building up from your current ability level. A fitness appraisal can help determine your ability levels.

I have read, understood and accurately completed this questionnaire. I confirm that I am voluntarily engaging in an acceptable level of exercise, and my participation involves a risk of injury.

Signature ____________________

Print name ____________________

Date ____________________

Having answered YES to one of the above, I have sought medical advice and my GP has agreed that I may exercise.

Signature ____________________

Date ____________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the 7 questions.

Appendix 3

INFORMATION SHEET

Differences between experienced and novice cyclists in information seeking behavior during 10 mile time trial.

Dear Participant,

Thank you for showing an interest in participating in the study. Please read this information sheet carefully before deciding whether to participate. This letter will inform you about the research procedure and other issues and help you to decide whether you will meet the criteria or no. If you decide to volunteer we thank you for your participation. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

What types of participants are needed?

The tests involved are cycle based; therefore, we are seeking to recruit male volunteers between the ages of 18-45 years, who participate regularly, and to a high level, in road cycling, as well as physically active with the ability of completing 10 mile cycling but no previous cycling time-trial or racing competition. As part of this study you will be asked to take the physically active questionnaire. Should you answer ‘yes’ to any of the questions, for your safety, you will not be able to participate in this study, but we thank you for your interest.

What will participants be asked to do?

If participating, you will be asked to visit our lab two times, each visit will lasting less than 1 hour. Participants in this research will cycle 2 * 10 mile (16.93 km) time trial on a cycling ergometer (Velotron) on two occasions separated by 7 days. In the first visit participants will be asked to full out some questionnaires and sign the form of consent, during the test subject will be asked to wear a heart rate monitor and a head-mounted eye-tracking device attached to a cycling helmet.

The procedure before the test

You will be asked to follow some simple rules prior to attending for your test:

- No intense physical exercise for 24 hours before the test, only very light exercise on the day of your test is allowed.
- No alcohol for 24 hours before the test.
- No solid food in the last 2 hours before test.
- No caffeine 4 hours prior your test.

What if you decide you want to withdraw from the project?

You are totally free to participate, and, if at any stage you wish to leave the project, even after you have given inform consent to participation in this research, and then you can. There is no problem should you wish to stop taking part and it is entirely up to you. There will be no disadvantage to yourself should you wish to withdraw.

What will happen to the data and information collected?

Your data will be used for research; all your data will be processed confidentially. This mean that your data will only be visible for researchers, and your name will never be named or used. Results of this project may also be published, but any data included will in no way be linked to any specific participant.

What if I have any questions?

Questions are always welcome and you should feel free to ask the researchers any questions at anytime. See details below for specific contact details.

This project has been reviewed and approved by the Ethics Committee of the biological science department- university of Essex.

Many Thanks,

Manhal Boya,	Dr. Dominic Micklewright.
Email: mnbboy@essex.ac.uk	Email: dpmick@essex.ac.uk
Tel: 074 29 060 368.	

Appendix 4

PRESONAL & TRAINING HISTORY COLLECTION FORM

Name:

Date of Birth: / / /

Mass:

Stature /Height:

Training History

- How long have you been training?
- How long have you been cycling?
- Have you participated in any cycling competition, if yes how many?
- Do you have any previous experience with 10 KM cycling time trial,
- If yes, for how long?
- On average during the last three months:
- How many days each week do you train?
- How long do you train each day?

Participant's signature………………… **Researcher signature…………**

Appendix 5

RATING OF PRECIEVED EXERTION SCALE

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

Appendix 6

RATING OF FATIGUE SCALE

10 **TOTAL FATIGUE & EXHAUSTION – NOTHING LEFT**

9

8

VERY FATIGUED

7

6

5 **MODERATELY FATIGUED**

4

3

A LITTLE FATIGUED

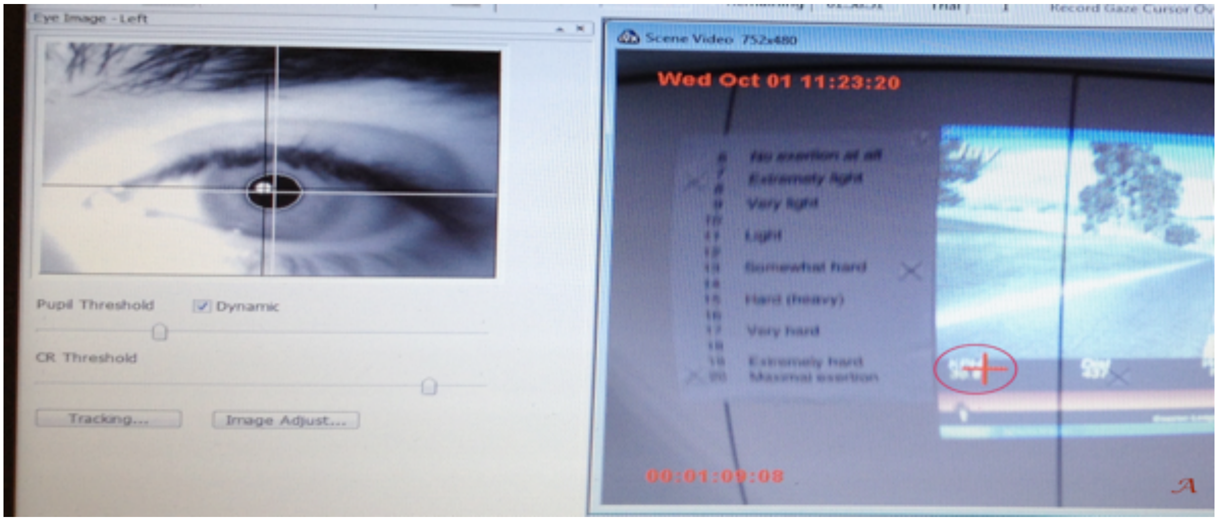
2

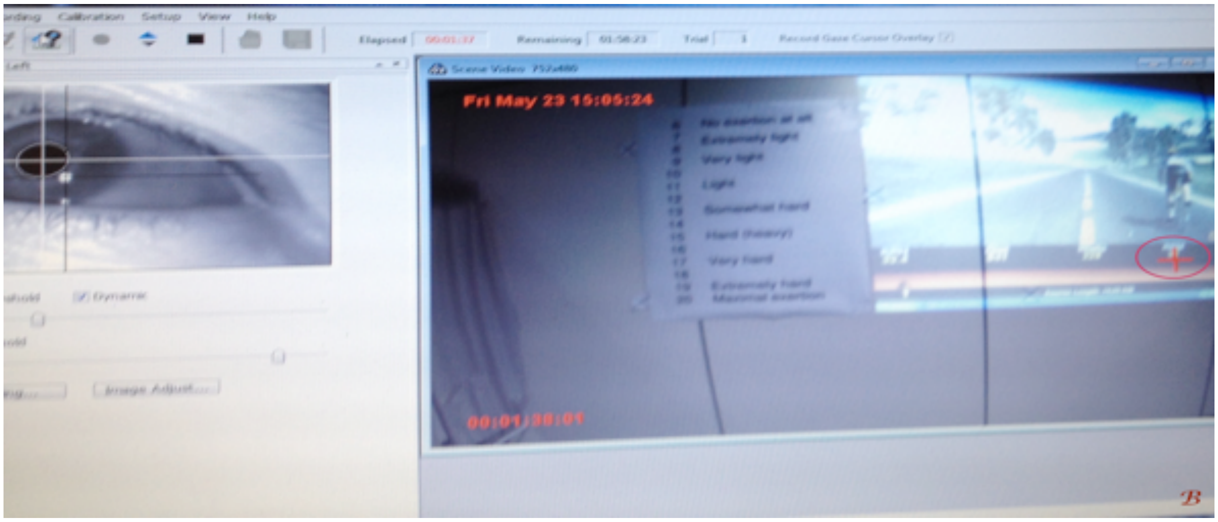
1

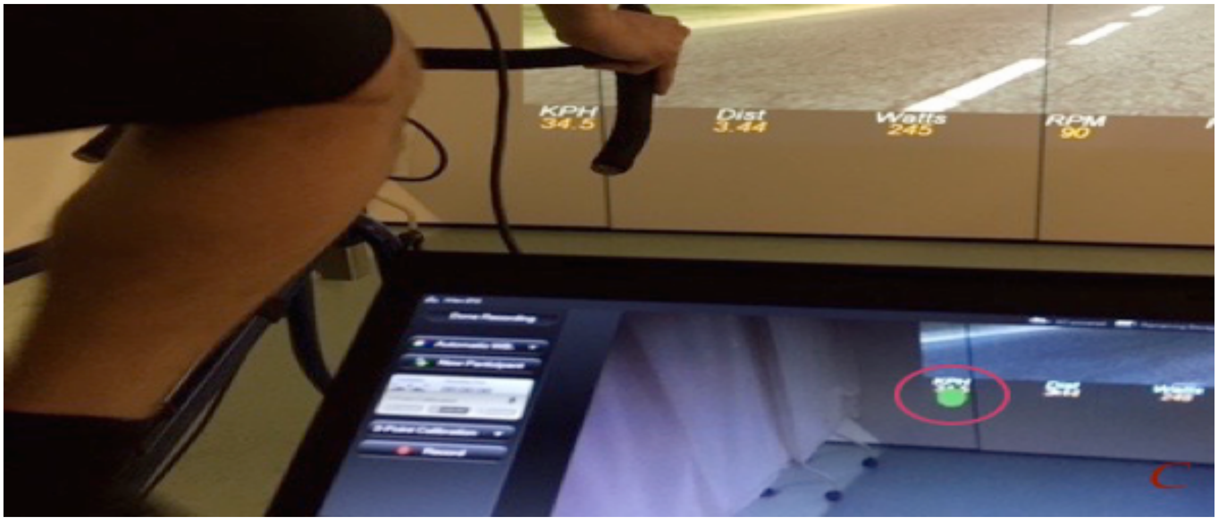
0 **NOT FATIGUED AT ALL**

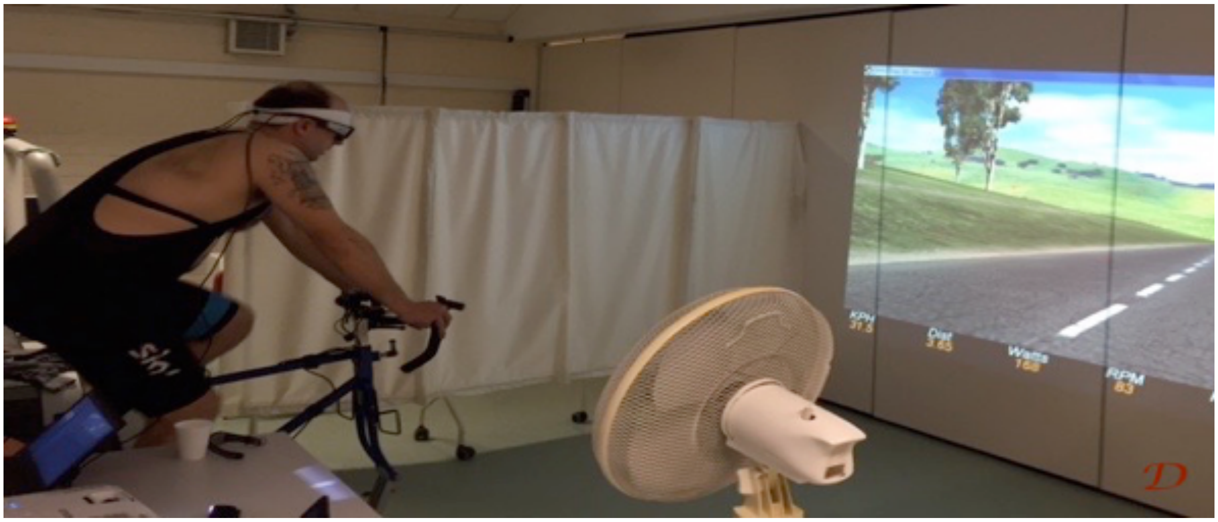
Appendix 7

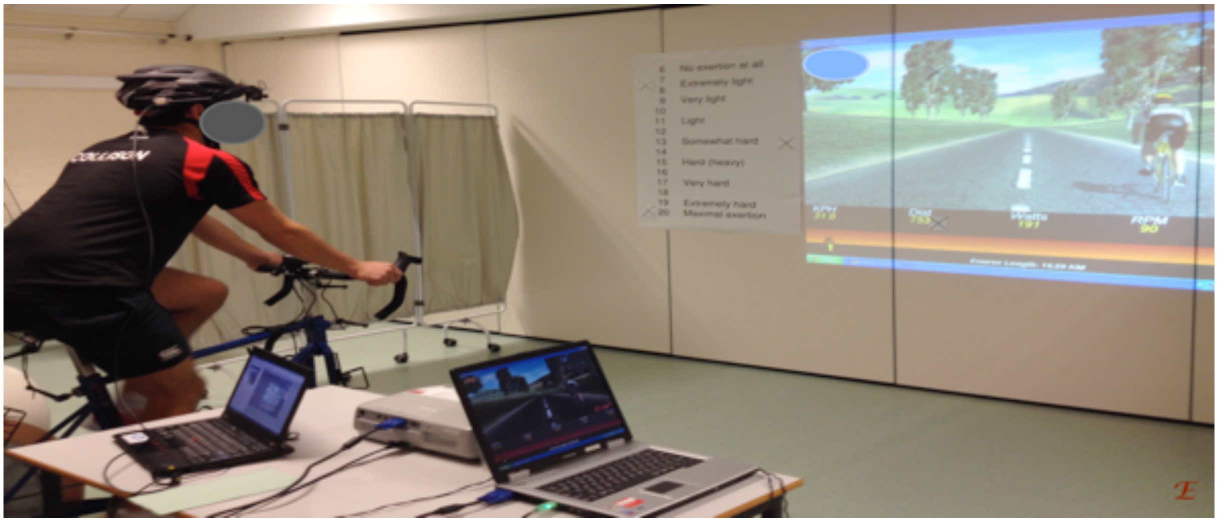
A few pictures in which A) represent a screen shot of eye-tracking video while participant is looking at speed in which the read cross represent participant's point of interest. B) Participant seeking RPM. C) Participant looking at speed using eyeglass eye-tracking device in which the green circle on the computer screen represent participants point of interest. D) Participant wearing eyeglass during cycling time trial. E) Participant wearing iViewX Head Mounted monocular Eye Tracking Device during cycling time trial.






KPH
34.5
Dist
3.44
Watts
245
RPM
90
C


KPH
Dist
Watts
RPM
D


No exertion at all
Extremely light
Very light
Light
Somewhat hard
Hard (heavy)
Very hard
Extremely hard
Maximal exertion
KPH
Dist
Watts
RPM
E