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THE PSYCHOBIOLOGICAL MODEL OF PACING IN ENDURANCE PERFORMANCE

By

Akram Mohammad Amin

Thesis submitted to the University of Kent

in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

2014

This thesis was supervised by Samuele Marcora of School of Sport and Exercise Sciences (University of Kent).

Abstract

Pacing is the mechanism that athletes use in order to attempt to control their speed in such a manner that they can cover a specific distance or perform in a set time without failing. Several theories and models have been proposed on pacing and the regulation of pacing strategies. The aim of this thesis was to present a new prominent model of endurance performance for pacing, the Psychobiological model for pacing and analyse its single factors.

The Psychobiological model for pacing has based its theory on five factors to explain pacing and performance: i) the perception of effort, defined as "the conscious sensation of how hard, heavy and strenuous the exercise is"; ii) the potential motivation that represents the individual's willingness to exert effort; iii) the distance- or time trial duration to cover; iv) the time/distance elapsed/remaining and; v) the previous experience/memory of perceived exertion during exercise of varying intensity and duration.

In chapter 2 we elucidated the influence of VO_{2max} during a 30 min running time trial. Results showed that runners of different VO_{2max}, pace themselves using different speed in order to avoid reaching maximal RPE and, thus, exhaustion, before the end of the time trial. However, no difference has been found in pacing strategy which does not depend on $VO_{2max.}$

In chapter 3 we discussed the effect of knowledge of distance to cover on pacing and performance during a 5 km running time trial. Results showed that knowledge of distance to cover and learning from previous experience is an important determinant in pacing and pacing strategy. Individuals when informed of the correct knowledge of distance to cover where able to pace themselves faster and complete the performance test significantly faster than when the knowledge of distance to cover was incorrectly provided.

In chapter 4 we assessed the effect of knowledge of distance/time remaining on pacing by using a 5 km time trial to account for knowledge of distance and a 30 min cycling time trial to account for knowledge of time remaining. Results demonstrated that time/distance feedback plays an important role for performance. The significant difference in distance/time to complete the performance test showed that participants who were aware of the remaining time/distance to be covered were able to choose a pace during the time trial compared to when they were blind to the distance/time feedback.

Finally, in chapter 5 we analysed the efficacy of motivational verbal encouragement provided at different phases during a 30 min cycling time trial. Results showed the determinant role of verbal encouragement in relation with RPE and the importance of the timing at which to provide it. Individuals who were verbally encouraged at the end of the cycling performance showed a faster pace and overall they covered a greater distance compared to when they were encouraged at the beginning of the time trial.

Overall, this thesis demonstrated that the psychobiological model of endurance performance for pacing proposed in the recent years is, indeed, a valid and effective model to explain human performance and it provides new insights in the study of pacing, compared to other existing models of pacing.

Acknowledgments

My thesis would not have been the same without the help of others. I therefore take this occasion to firstly thank the Iraqi Ministry of Higher Education and Scientific Research for providing me the financial means to complete this work and the Iraqi Cultural attached in London.

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Last of all, but the greatest feeling in my heart no word can express the gratitude for the love, support, and the inspiration my family gives to me every day of my life.

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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List of Abbreviations and key terms

Closed loop exercise: Exercises considered self-regulated tasks, in which it is known the end-point (i.e. determined distance or time). Closed-loop exercise reflects better the competition environment where usually a distance is set which must be completed in the shortest possible time (i.e. 1500 m race, 5000 and Marathon).

Open loop exercise: Exercises defined by the absence of a known end-point (Coquart and Garcin, 2008). When the exercise task is constant-workload or incremental exercise test to exhaustion, the goal is to last for as long as possible and the conscious decision to take is simple: do I keep going or do I stop? In these testing conditions, anticipation is not necessary.

Pace: It refers to the speed/power output at which an athlete is running, cycling, swimming etc. during an endurance competition or a test in which the individual is free to vary the workload (time trial). Overall pace is the average speed/power output during an endurance competition or a test in which the individual is free to vary the workload (Abiss and Laursen, 2008).

Pacing: It is the act of self-regulating speed/power output during endurance competitions or tests in which the individual is free to vary the workload (time trials) (deMorree & Marcora, 2013).

Pacing Strategy: It is the way an athlete distribute his/her speed/power output throughout an endurance competition or a test in which the individual is free to vary the workload (time trial) (Abiss and Laursen, 2008).

.**PPO**: Peak power output

RPE: Rating of perceived exertion (or perception of effort)

TT: Time Trial

TTE: Time to Exhaustion

TtC: Time to Completion

CHAPTER 1

GENERAL INTRODUCTION

Topic and key concepts of the thesis

The aim of this thesis is to better understand the determinants of pacing and performance during self-paced endurance exercise and/or time trials.

Before proceeding with the discussion it is necessary to clarify two operational key concepts:

A limiting factor refers to any variable "acting as a limit". Limit means "the point, edge or line beyond which something cannot or may not proceed". Therefore, it applies exclusively to type of tasks that show and test exhaustion such as time to exhaustion tests. In other words, in order to be limiting, a factor must cause exhaustion.

A determinant, on the other hand, is a factor or circumstance that influences or determines a given variable. This may be established with several types of experiments not necessarily conducted under exhaustion. By assuming that an element is not a limiting factor of a variable, it cannot be excluded its influence on such a variable as determinant.

Therefore, the methodology of the present thesis has involved using experimental and quasi-experimental studies. The choice of the factors to investigate was guided by the psychobiological model of performance. The effect of these factors on pacing was measured in changes in pace and pacing strategies.

Pacing

It is self-explanatory that the time to complete a race determines victory or defeat during the competition. It is, therefore, imperative for an athlete to choose the most effective strategy to balance his/her energy expenditure and power output/speed in order not to arrive at the end of the competition prematurely exhausted (Foster et al., 1994).

It is important to distinguish between pace, which expresses the actual speed/power during the competition, and the pacing strategies employed in a race, which are usually chosen prior to the competition, although these can also change during competition (see list of abbreviations and key terms section for more details).

Pacing strategies

Different types of pacing strategy can be employed:

The negative pacing strategy consists in a gradual increase in speed over the duration of the event. This strategy is supposed to reduce the rate of carbohydrate depletion, minimise oxygen consumption and lower the accumulation of fatigue-related metabolites early on in the event. Such a strategy is commonly seen in prolonged exercise tasks (Abbiss and Laursen, 2008).

The positive pacing strategy consists in a gradual decrease in speed over the event's course. The adoption of a positive pacing strategy results in an increased VO_2, increased RPE and greater accumulation of fatigue related metabolites during the early stages of an exercise task (Abbiss and Laursen, 2008).

The all-out pacing strategy consists in an extremely high acceleration phase, particularly in shorter events (e.g. 100 m sprint and 1 km cycle TT) (Abbiss and Laursen, 2008).

The even pacing strategy consists in keeping the same pace throughout the competition. It has been suggested that under stable conditions a constant pace is optimal for prolonged (>2 minutes) locomotive events such as running, cycling, rowing and skiing (Abbiss and Laursen, 2008).

The parabolic shaped pacing strategy consists in the adoption of both a positive and negative pacing strategies, which result in a ‘U’, ‘J’ or reverse ‘J’ shaped speed/power profile (Abbiss and Laursen, 2008).

Finally, the variable pacing strategy consists in varying power and speed during the race depending on the circumstances. It can be varied and not follow any trend as the previous pacing strategies described (Abbiss and Laursen, 2008). Researchers have shown that in middle and long distance events athletes will frequently reduce speed during an exercise bout to increase speed again in the latter section of the exercise.

Models of performance

As research on human performance moves forward, several different models have been developed in order to explain mechanisms of fatigue and thus of physical performance. These models move away from traditional peripheral fatigue models (Fitts, 2008, Fitts, 2006, Allen et al., 2008) to more innovative ones focused on central aspects of fatigue (Amann and Dempsey, 2008b; Amann and Dempsey, 2008a; Amann, 2010; Gandevia, 2001; Taylor and Gandevia, 2008; Noakes, 2000, 2012); and psychobiological aspects (Marcora et al., 2008, 2009; Marcora and Staiano, 2010; deMorree and Marcora, 2013).

The first studies on the mechanisms leading to fatigue during exercise date back to more than 100 years ago. Two renowned researchers in this area were A. V. Hill and A. Mosso. Hill and his colleagues performed experiments on isolated muscles mainly and concluded that substances so called "poisonous" (muscle metabolites) produced by the muscles during exercise were the main factor leading to fatigue (Hill et al., 1924; Hill et Lupton, 1923). On the basis of these experiments, A.V Hill proposed a model predicting that just before the cessation of maximal exercise the oxygen demand of the exercising muscles exceeds the myocardial capacity to provide such oxygen. According to this model the heart was the sole factor determining human performance and, as claimed by Noakes (1997), A.V Hill’s idea was that the main limiting factor to exercise was the inability of the cardiovascular system to provide enough oxygen to active. This model became one of the most prominent models of exercise tolerance for the next 90 years. Mosso, instead, designed experiments taking into account the role played by the central nervous system (Di Giulio, 2006). While Hill and Mosso shared similar ideas on the presence of "poisonous" substances leading to fatigue and therefore on the reasons behind the (sudden) cessation of exercise, Mosso made an important discovery in his studies, showing that the brain has great influence on the fatigue process. In one of his studies, he showed how mental fatigue following hours of teaching at university had a detrimental effect on repeated exercises involving finger flexion (Di Giulio, 2006).

Although A. V. Hill’s model of exercise has influenced many physiologists in the last century, it has also often been the object of criticism, in particular for not considering brain mechanisms that might determine exercise tolerance. Secondly, these models were not designed to explain self-paced exercise but to explain the decline in muscle force during time to exhaustion tests without accounting for differences in pacing and the psychophysiological mechanisms behind this factor.

However, most exercise physiologists spent the majority of the twentieth century focusing on fatigue studies which did not consider the part played by brain during exercise. Studies such as Noakes (1988, 1997, and 2000) Kayser (2003) and Noakes and St Clair Gibson (2004) challenged this theories and presented evidence to support a fresh idea according to which the brain is responsible for limiting the exercise rather than critical conditions of the cardiovascular system or any other peripheral organ systems. Thus, new ideas regarding the limitation of physical activity emerged, where fatigue began to be seen not as a physical event, but as a sensory one, and greater attention began to be given to the sensations during exercise (Jones and Killian, 2000; Noakes et al., 2004). As Thomas Kuhn states, we are witnessing to phase four in the scientific revolution, where theories on exercise performance are re-tested and new theories established (Kuhn, 1962).

Recently, Amann and Dempsey (2008b) proposed an inhibitory, sensory feedback model that explains task failure during constant-power tests and time trials by an inhibitory afferent feedback system. Such a system serves as a protective mechanism preventing peripheral muscle fatigue to develop beyond a critical threshold, which may lead to potential damage to the muscle (Amann, 2007, Amann and Dempsey, 2008b). Afferent feedback from type III and IV afferent nerve fibres, located in the muscles and stimulated by the accumulation of metabolites such as H + or inorganic phosphate, are supposed to mediate the inhibition of the central motor output. Although afferent feedback may have some influence on performance, it would be very little at the best. Indeed, if afferent feedback were the main limiting factor for pacing, then there would be only one pacing strategy possible, the positive one (Marcora et al, 2008; 2010). It is likely that the effect of afferent feedback on performance increases when the length/duration of the test is reduced. Finally, the afferent feedback model is not able to explain the end-spurt phenomenon, as at the end of a race we would expect a decrease in pace if afferent feedback were limiting the performance. On the contrary, the end-spurt consists in an increase of pace toward the end of the test.

Noakes and colleagues (St Clair Gibson and Noakes, 2004, Noakes et al., 2004) have proposed a more complex central governor model in which afferent sensory feedback coming from many different organs (e.g., skeletal muscles, heart, lungs, skin, and the brain itself) are processed at subconscious level by an intelligent system located in a not yet identified part of the brain. Central to this model is the hypothesis that the duration and intensity of exercise (depending upon the type of performance test) is set in anticipation by the CNS in order to avoid homeostatic failure. Moreover, this central governor in the brain controls pacing strategies in response to afferent feedback from different physiological systems. This is a feed-forward homeostatic mechanism as the extent of locomotor muscle recruitment is controlled in order to complete the exercise task within the physiological limits of the body, i.e. to avoid catastrophic homeostatic failure (Noakes, 2012).

The Central Governor and the Inhibitory Feedback models proposed respectively by Noakes (2000, 2012) and Amann and colleagues (2008a, 2008b; 2010) are strongly based on physiological reflexes and subconscious constructs to explain exercise performance regulation and limitation in humans. These models underestimate the importance of the role of psychological factors as exercise performance modulators. However, the importance of the psychological factor to modulate performance has been reported since the 1960’s (Ikai and Steinhaus, 1961).

Indeed, a series of seminal studies were conducted on the effects of different motivational strategies on endurance performance, suggesting the important role of this variable in physical performance: Cabanac (1986) demonstrated how monetary incentives increased the duration of an isometric exercise. Moreover, he found a high correlation ($r = 0.989$) between the value of the prize offered and the duration in minutes of the exercise. Similarly, Corbett et al. (2012) noted how the presence of a competitor increased the performance on a 2000 m cycling time trial (TT) and how social facilitation could affect human performance.

Marcora and colleagues (Marcora et al., 2008, 2009; Marcora and Staiano, 2010; Marcora, 2008a, 2008b, 2010) proposed a psychobiological model for pacing and performance which gives greater attention to perceptual and motivational factors, and their respective influence on the conscious process of decision-making and behavioural regulation. This model explains exhaustion on the basis of the psychological exercise (in)tolerance, while the Central Governor and Inhibitory Feedback models explain that these phenomena depend on the subconscious and anticipatory process (i.e., not subjected to willingness), or physiological inability (i.e., the participant has a physiological limit).

Psychobiological model

The psychobiological model proposed by Marcora and colleagues (2008, 2009, and 2010) has been designed with the aim to explain exercise performance using a complete and more integrated scientific approach across the research areas of physiology, neurophysiology and psychology. Therefore, this model seeks to explain not only the physiological mechanisms behind the exercise performance, but also clarify a vast number of psychological factors, which are closely linked to performance but still remain unexplained ,if not neglected, by the majority of sport scientists. Among these neglected psychological factors we can mention:

- End-spurt as the increase in central motor drive/power-output measured at the end of intense time trials (Amann and Dempsey 2008b).
- Social facilitation or presence of a competitor (Wilmore, 1968; Corbett et al., 2012).
- Monetary rewards (Cabanac, 1986).

The psychobiological model is based on three assumptions:

1. Endurance performance is considered as a voluntary behaviour and not as a physiological result of a machine.

2. Voluntary behaviours, including endurance performance, can be explained using psychological constructs and theories. This assumption constitutes the psychological level of explanation of this model.

3. Our mind is ultimately generated by neuron activity in the brain and is affected by physiological factors. This assumption constitutes the biological level of explanation of this model.

Psychological level: Theory

The psychobiological model is based on Brehm's motivational intensity theory (Brehm and Self, 1989; Wright, 2008). In general, motivation has been described as any type of mechanism that defines the direction and the resource mobilization for a specific behaviour (Elliot, 2006). Brehm's motivational intensity theory postulates that any goal-oriented behaviour is directly affected by two variables: Effort (or motivation intensity) and Potential Motivation.

Effort (or motivation intensity) is defined as the function to execute a specific behaviour. Thus, the intensity of effort is regulated by the difficulty of such behaviour. According to Wright (2008) effort is a variable utilized to overcome any possible impediment on the way to obtaining your goal. Such effort follow the same logic of "the least effort" principle postulated by Tolman (1932). Indeed, any individual will mobilize no more than the effort required to achieve the goal in order to reduce the chance of any futile depletion and/or complete exhaustion of resources. Moreover, the effort mobilized is proportional to the extent of difficulty up to the point where the arduousness of the task is so high that success is impossible. At this point a complete disengagement of the subject can be observed (Brehm and Self, 1989).

Potential motivation is the maximum effort a person is (potentially) willing to mobilize for accomplishing a goal and refers to the amount of justified effort. Potential motivation is determined by the magnitude of success, the more important is for the individual to achieve a goal, and the more effort is justified.
According to motivational intensity theory, the level of potential motivation is defined by the subjects' actual needs, whilst the extent of the incentive is related to the performance, or the means of success for satisfying higher order needs (Wright, 2008). Among the motivational theories, Brehm's theory differs from previous ones for the fact that effort is not considered directly

related with the strength of the motives producing a certain behaviour. Instead, Brehm introduces the concept of potential motivation as maximal limit set for which the effort is correlated with the task’s difficulty (Wright, 2008).

According to Brehm’s Theory individuals engage in a task until the effort required reaches the maximum level of effort they are willing to invest for succeeding in that task (the so-called potential motivation, Figure 1A and 1B) or when the task is perceived as impossible despite very high potential motivation (Figure 1C; Wright, 2008).

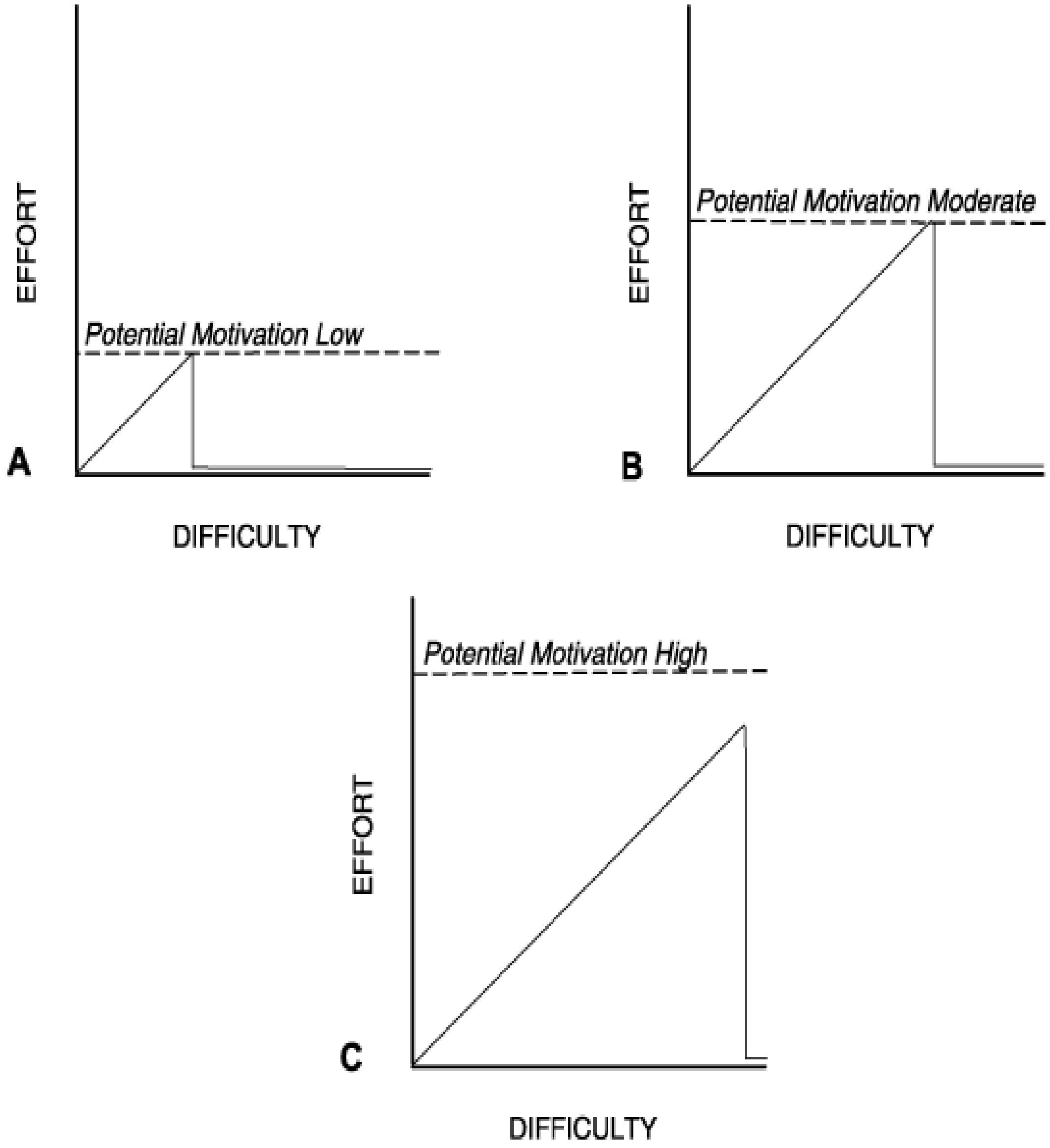


Figure 1

Effort as function of challenge difficulty at low (A), moderate (B) and high (C) intensity levels of potential motivation (Wright, 2008).

Based on Brehm's theory Marcora and colleagues (2008, 2009, and 2010) designed a psychobiological model where exercise performance is a variable regulated by two factors in open-loop exercise and by five factors in closed-loop exercise:

In open-loop exercises several principles apply:

Potential motivation is defined as the maximum effort an individual would be willing to exert in a physical task (Brehm and Self, 1989).

The Perception of Effort is defined as the conscious sensation of how hard, heavy, and strenuous exercise is (Marcora, 2010).

Similarly, Marcora and colleagues (2008, 2009, and 2010) proposed to approach the study of pacing by considering it as a self-regulated behaviour and a form of decision-making process where the primary factors influencing exercise regulation are still the perception of effort and potential motivation. However, the conscious decision-making process to consider for this type of exercise is more complex (i.e. at which speed do I run at the beginning, middle, and end of the race? What kind of pacing strategy will I use?). Three additional conscious factors allow for such a complex decision-making process and affect the pacing strategies chosen to avoid reaching maximal effort and thus premature exhaustion before the end of the trial:

The subject's memory of the effort perceived during previous exercises of different intensities and durations.

The subject's knowledge of the total time trial time/distance to cover, which refers to the awareness of the time, speed or power needed to complete the task and to plan the suitable strategy to complete the task in the shortest time.

The subject's awareness of the elapsed time/distance remaining, which refers to the feedback given on the time/distance remaining to complete the task.

Based on these five factors, individuals would choose the pace they are going to employ throughout the task on a moment-by-moment basis. As Marcora (2008; 2010) suggested, in order to finish the task, individuals would normally choose a certain pace at the beginning and halfway through the task to make sure to complete the task. Only near the end, when individuals know that they are approaching the end of the task and changing the pace will not compromise their performance, they will increase their speed/power. This speed/power increment at the end of the task is known as end-spurt.

In this context, well-motivated subjects voluntarily disengage from any form of sub-maximal endurance exercise when perception of effort reaches such an intolerable level that continuing it is not worthy anymore. In terms of physical performance, withdrawing from a physical task can be interpreted as the inability to sustain the intensity required if we consider open-loop exercises and as decreasing in speed and/or changing of cadence/gear when we refer to closed-loop exercises.

The Psychobiological model is supported by studies showing changes in exercise to exhaustion by using a manipulation that does not affect any physiological variables (Crewe et al., 2008; Marcora et al., 2009 Marcora and Staiano, 2010; Noakes, 2004; Presland et al., 2005). In 2010, Marcora and Staiano demonstrated that the average power output produced during an all-out sprint after a time to exhaustion cycling exercise was ≈ 3 times greater than that required during a high-intensity endurance test. Those results showed that central and/or peripheral muscular fatigue (Amann and Calbet, 2008) and/or physiological catastrophe failure (Fitts, 1994) could not explain the individuals' endurance task disengagement.

Moreover, Marcora et al. (2009) demonstrated how cognitive states such as mental fatigue produce a significant impairment in performance and an increase in the perception of effort, irrespective of any changes on physiological variables such as ventilation, heart rate, oxygen consumption, blood lactate and cardiac output.

This experimental evidence suggests that endurance-exercise performance may be ultimately regulated by the perception of effort, and not due to physiological failures (e.g., cardio respiratory or energetic). Moreover, Marcora and colleagues (Marcora et al. 2008, 2009; Marcora and Staiano, 2010) demonstrated how perception of effort was more than an epiphenomenon correlated with physiological variables. They actually proved that perception of effort is the primary variable to strictly correlate with endurance performance in such a way that any changes in RPE always reflected changes in task performance.

In light of the above considerations, the psychobiological model for pacing during endurance competitions can explain phenomena such as the end-spurt which are common in endurance competitions. Such a phenomenon can be explained if we consider pacing as a goal-directed behaviour in which the aim is to reach the finish line in the shortest time possible. Because precise conscious anticipation of perceived exertion intensity near the end of the race is not possible (and because finishing the race, is paramount), endurance athletes usually choose a slightly conservative pace for most of the race. However, near the end, when the information provided by the conscious perception of effort at a certain workload is more reliable, athletes usually realize that they can significantly increase (running) speed without reaching exhaustion before the finishing line, and decide to go for an end-spurt. It is evident that inhibitory afferent feedback from fatigued locomotor muscles cannot prevent this conscious decision-making process.

Psychological level: Constructs

Perception of effort (or perceived exertion)

Definition of perception of effort

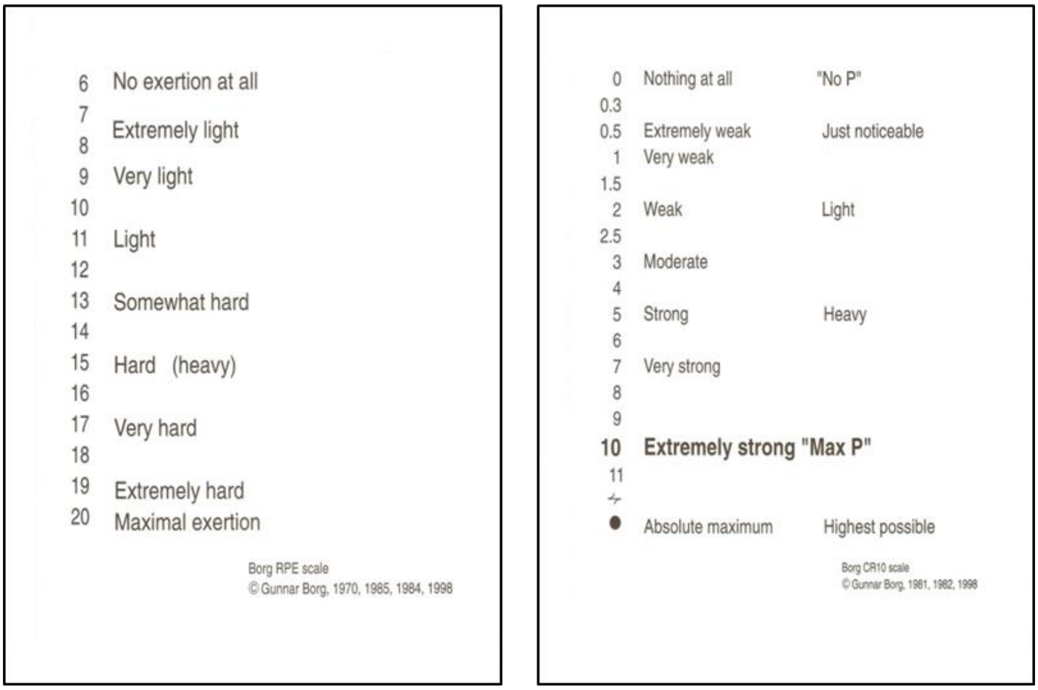
Gunnar Borg was the first to provide a definition of perception of effort (or perceived exertion) as “the feeling of how heavy and strenuous a physical task is” (Borg, 1970, 1998). This definition, developed specifically for physical tasks can be in reality applied to any physical or cognitive task. We experience effort not only during physical exertion, but also during mental concentration and self-restraint. As far as physical activity is concerned, perception of effort is mainly related to the active limbs and heavy breathing.

Measuring perception of effort

Perception of effort is commonly measured with the Borg rating of perceived exertion (RPE) scale, which was introduced by Gunnar Borg in the 1960’s (Borg, 1970) or with the category-ratio (CR10) scale introduced a few years later (Borg, 1982). Both scales are illustrated in Figure 2. The 15-point Borg RPE scale is an equidistant interval scale and the rating grows linearly (in line) with exercise intensity, heart rate, and oxygen uptake (Borg, 1998). In fact, the scale goes from 6 to 20 so that the rating corresponds on average to the heart rate divided by 10.

The Borg CR10 scale is a category-ratio scale that can be used for rating effort, but also for rating other perceptual intensities such as pain. The CR10 scale was created to enable direct estimations of intensity levels for inter-individual comparisons. The rating on this scale increases in a nonlinear and positively accelerating manner (Borg, 1982). Moreover, a black dot at the bottom of the scale is used to rate values higher than 10 making it an open scale and thus avoiding mechanisms such as “ceiling” effects. Both the 15-point RPE scale and the CR10 scale have been shown to be valid and reliable tools as long as all standardized procedures are correctly executed (Borg, 1998).

According to these standardized procedures the participant must have a clear understanding of the definition and nature of the measure and be fully instructed about the scale. Other important factors are the Anchoring of the words of the scale, or verbal anchoring, and the consequent link with the actual number, which is the measurement collected. Moreover, it is important to have at least one familiarization session with the scale during a physical task. This familiarization will help the participant to learn how not to overestimate or underestimate the scale in relation to his/her perception. In addition to this, familiarization can be used to anchor the highest and lowest intensity perceived by the participant. Such method will increase the precision of the measurement when used in the following session (Noble and Robertson, 1996).



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

Borg RPE scale
© Gunnar Borg, 1970, 1985, 1984, 1998

0	Nothing at all	"No P"
0.3		
0.5	Extremely weak	Just noticeable
1	Very weak	
1.5		
2	Weak	Light
2.5		
3	Moderate	
4		
5	Strong	Heavy
6		
7	Very strong	
8		
9		
10	**Extremely strong "Max P"**	
11		
●	Absolute maximum	Highest possible

Borg CR10 scale
© Gunnar Borg, 1981, 1982, 1998

Figure 2

Borg’s RPE scale (left) and CR10 scale (right). From Borg (1998).

Factors influencing perception of effort

Perception of effort is influenced by several physiological and psychological factors.
Perceived exertion increases as the workload increases in an incremental task and reflects the relative exercise intensity. Perception of effort also increases with time-on-tasks when the same exercise intensity is sustained for a prolonged period of time (Hunter et al., 2004; Pincivero et al., 2004; Robertson et al., 2003; Smith et al., 2007; Søgaard et al. 2006). This increase in effort with time-on-tasks is often considered a sign of muscle fatigue. However, there are several other factors that might underlie the increase in perception of effort over time. A mismatch exists between the increase in perception of effort and the loss in muscle strength during sustained low-force contractions (Smith et al., 2007; Søgaard et al., 2006). One possible explanation for this mismatch is that perception of effort might have a cognitive component. This would fit with recent findings according to which mental fatigue causes an increase in perception of effort during constant-workload cycling in the absence of physiological changes (Marcora et al., 2009).

Perception of effort correlates with a variety of physiological factors. First of all Borg’s original scale (6-20) actually follows variables such as heart rate and oxygen uptake (Borg, 1970). Furthermore metabolic changes such as blood lactate or level of muscle glycogen (Baldwin et al. 2003) have an effect on the perception of effort. Environmental changes such as temperature or altitude (hypoxia) also have an impact on perceived exertion. They increase RPE at the same workload of exercise when comparing high temperature to lower one and hypoxia with normoxia environment in which participant are performing the physical task (Romer, 2007a).

Due to its subjective nature, perception of effort can also be affected by psychological and social factors, although it has been pointed out that these factors might be more salient in light and moderate exercise intensities than at high exercise intensities (Noble & Robertson, 1996). Psychological factors that have been shown to influence perception of effort include personality, mood, self-efficacy, and locus of control (Robertson & Noble, 1997). That social factors can influence (ratings of) effort, is shown, for example, by a study where participants rated a lower effort when they were tested with a co-actor than when tested alone (Hardy et al., 1986). Moreover, It has been shown that male participants report significantly lower perceived effort during cycling when the experimenter is female than when the experimenter is male (Boutcher et al., 1988).

Very interestingly, Marcora and colleagues, in a series of studies (Marcora et al. 2008, 2009, Marcora and Staiano, 2010), demonstrated how perception of effort is more than an epiphenomenon correlated with physiological variables. They actually assumed that perception of effort is the primary variable to strictly correlate with endurance performance in such a way that any changes in RPE always reflects changes in task performance. They demonstrated this assumption by isolating RPE from physiological variables such as muscle fatigue, blood lactate concentration, ventilation, heart rate, maximal oxygen consumption and stroke volume.

Potential motivation

Potential motivation refers to the upper limit of what people would be willing to do to satisfy a motive (Brehm and Self, 1989). It varies according to factors traditionally thought to determine motive strength such as internal states, needs (e.g. food deprivation), potential outcomes (e.g. searching food, pain avoidance), and the perception that producing a certain behaviour properly will lead to satisfy such need and provide the desired outcome (Wright, 2008, Brehm and Self, 1989).

Potential motivation should moderate the relation between difficulty and effort so long as success is perceived to be possible. Where success is believed to be impossible, effort should be low regardless of potential motivation (Wright, 2008). The more important the motive which drives the behaviour, the higher the standard people set in terms of potential motivation.

Very little has been done so far on potential motivation and endurance performance in terms of psychological interventions aiming at modulating potential motivation. One of the reasons is probably the difficulty to measure motivation pre and ongoing a physical task. Some manipulations to increase endurance performance have involved music (Nakamura et al., 2010), verbal encouragement (Andreacci et al., 2002), motivational self-talk (Blanchfield etal.,2013) and competition (Viru et al., 2010; Corbett et al. 2012) in attempting to change potential motivation and improving performance. However, those studies were able to produce changes in RPE and often did not include any measurement of motivation during the task. A possible explanation is that manipulation such as music and self-talk may alter the perceived ability of the individual and thus reduce the RPE by increasing their self-efficacy (Rudolph et al., 1996). However, it is still unclear what the relationship between potential motivation and perceived exertion is. Moreover interventions such as music may alter the mood which may cause a change in RPE and thus in performance (Silvestrini and Gendolla, 2007).

Memory of perception of effort during previous exercise of different intensities and durations

Several studies have underlined the importance of memory of prior experience as an important factor to create a successful pacing strategy (Noakes et al. 2005). Ulmer et al. (1996) suggests that the memory or knowledge of previous experience along with knowing the end point of the race can help the brain to create the optimal pacing strategy for a competition. Basically, the brain uses the knowledge of the endpoint to create a pacing strategy and the memory of previous experiences in similar races to match the RPE he perceived in the past with the one he will perceive. The more accurate the memory of previous experiences is the more accurate will be the pacing strategy adopted. During exercise, perception of effort is consciously interpreted through the mental representations and boosted by using similar events experienced in the past (Noakes et al. 2005).

Given that conscious perception of effort increases over time even when the workload is kept constant and depends on the level of fitness (Duncan et al., 2006), then memory of perceived exertion during exercise bouts at different speeds/durations at the current level of physical fitness. This becomes an important determinant cognitive factor to understand pacing mechanisms during endurance competitions. Endurance athletes refine this memory during the training sessions preceding the competitive event.

Knowledge of total time trial time/distance to cover

Knowing the exact end-point of the competition has been defined of crucial importance in order to generate an appropriate pacing strategy (Noakes et al., 2005; Mauger et al., 2009; Ulmer et al., 1996). Indeed, not knowing the distance to cover or time required to complete a race does not enable to athlete to formulate an efficient pacing strategy. For this reason, any athlete, whose pace is either high, medium or low level, will always need this information to decide what pacing strategy to adopt. Running a marathon and running a 10 km race require completely different paces and thus such information is of paramount importance in order to avoid either premature exhaustion or completing the race without having pushed as hard as possible. A study from Ansley and colleagues (2004) demonstrated how an incorrect knowledge of the time to perform produced a negatively affected the athlete’s performance during a series of Wingate tests. In another study by Nicolopoulos et al. (2001) it was suggested that if the difference among the trials performed is less than 15%, experienced athletes may not alter their pace or pacing strategy significantly.

Knowledge of elapsed time/distance remaining

Constant feedback during a competition about the time/distance left has been suggested as an important factor for pacing and pacing strategies (Marcora, 2010). However several studies have proposed that this variable is not crucial in order to employ a successful pacing strategy (Albertus et al., 2005; Mauger et al., 2011; Wilson et al., 2012). These studies provided discontinuous feedback and evaluating the effect of this manipulation on time trial and RPE. However, the manipulation applied in a study by Albertus et al. (2005) measured the difference in performance when feedback was incorrect on the base of an inaccuracy of no more than 15% of the distance from the correct one. Although the athlete's performances did not show any significant difference, Albertus et al. did not take into account that if the mismatch of the incorrect information of time/distance during an exercise compared to the correct one is sufficiently small then the subject would not be able to consciously detect the difference between the correct and incorrect information. This typology of design may interfere in testing the hypothesis on the importance of feedback of distance/time remaining on physical performance.

Biological level

Biological bases of perception of effort: Afferent sensory dependent or centrally generated?

To date, the perception of effort has mainly been investigated from a psychological perspective, mostly related to physical activity. Although it is possible to delineate its correlations with several psychophysiological variables, its actual "origins" in the brain are still unclear. Proposed at first as a sensation, effort has been treated like other sensations such as pain, leading most to think that the sensation of effort is generated from physical stimuli (different afferent sensory inputs such as proprioception, pain and thermal discomfort) and that these stimuli are processed in perceptual areas in the brain.

The significant correlations between RPE and multiple physiological markers would support this theory. However, it is important to acknowledge that the correlation between two variables does not always consist in causation. In fact, several studies have used spinal blockades such as lidocaine and epidural anaesthesia aimed at blocking the afferent input (from muscle spindles and Golgi tendon organs and type III and IV afferent fibers) that have shown no effect on RPE (Galbo et al., 1987, Gallagher et al., 2001, Kjaer et al. 1999). A possible explanation is that perception of effort is centrally generated by forwarding neural signals (corollary discharges) from motor to sensory areas of the cerebral cortex. Corollary discharge describes “internal signals that arise from centrifugal motor commands and that influence perception” (McCloskey, 1981, p. 1415). Central motor commands can be defined as “a discharge or pattern of discharge that is generated within the central nervous system and that leads to the excitation of spinal α-motoneurons” (McCloskey, 1981, p. 1421).

Corollary discharges are thought to have perceptual consequences in two distinct ways (McCloskey, 1981). On the one hand, they are thought to modify the processing of incoming sensory information to enable, for example, the discrimination between self-generated and external stimuli. Several corollary discharge circuits of this type have now been uncovered across the animal kingdom (Crapse & Sommer, 2008; Poulet & Hedwig, 2007). On the other hand, corollary discharges may give rise to sensations of various kinds in their own right (McCloskey, 1981). This is the type of corollary discharge pathway that is thought to be involved in perception of effort.

Evidence that corollary discharges play an important role in perception of effort can be found in experiments based on the prediction that conditions where the central motor command, necessary to achieve a given muscular performance is increased, should lead to increased perception of effort, while a decrease in central motor command should lead to decreased perception of effort (McCloskey et al., 1983).

Neurophysiology of perception of effort

The neurophysiology of the perception of effort is poorly understood. To date, few studies have been conducted to neurophysiologically measure perception of effort. Williamson and colleagues have carried out several experiments using hypnosis to experimentally manipulate perception of effort (Williamson et al, 2006).

In their studies, they have used single-photon-emission computed tomography (SPECT) to measure regional cerebral blood flow (rCBF) distribution in several cerebral cortical areas. They showed that, compared to a control condition, participants rate their effort significantly higher for constant-workload cycling under the hypnotic suggestion that they are cycling uphill; similarly, they rate their effort significantly lower when under the hypnotic suggestion that they are cycling downhill (Williamson et al., 2001). The uphill condition elicited a significant increase in rCBF distribution to the right thalamic region and right insular cortex, whereas the downhill condition elicited a significant decrease in rCBF distribution to the anterior cingulate cortex and the left insular cortex.

The second study compared RPE and rCBF during actual and imagined (by hypnotic suggestion) handgrip exercise (Williamson et al., 2002). In this case, a group of participants with high hypnotizability was compared with a group of participants with low hypnotizability. It appeared that, during the imagined exercise condition, the high hypnotizability group gave significantly higher ratings of perceived exertion compared with the low hypnotizability group.

There was no significant increase in RPE in the low hypnotizability group during the course of the 3 min of imagined handgrip exercise. Significant between-group differences were found in rCBF distribution change scores between actual and imagined exercise conditions in the anterior cingulate cortex, the right inferior insular cortex, and the left inferior insular cortex. Together, these studies suggest that medial prefrontal region (anterior cingulate cortex), insular cortex, and possibly the thalamus are brain areas that might be involved in perception of effort.

Recently, Fontes and colleagues have assessed which brain areas are activated during effortful cycling exercise, by using functional magnetic resonance imaging (fMRI) when cycling on an MRI compatible cycle ergometer (Fontes et al., 2013). They found that the primary motor cortex, primary somatosensory cortex, and cerebellar vermis were significantly more activated when cycling than during rest. Moreover, they compared cycling that was perceived as “hard” (RPE > 15 on 6-20 scale) with cycling that was perceived as less than “hard” (RPE ≤ 15). These preliminary analyses (based on the data of four participants) suggest that the posterior cingulate cortex and the precuneus are involved in perception of effort.

Outline of the thesis

Apart from the general introduction and general discussion, this thesis consists of four parts (chapters 2-5), which were initially written as stand-alone papers. For this reason, in the following chapters there may be sections whose contents slightly overlap

Aims of the Thesis

General aim

The general aim of this thesis is to verify if the predictions (factors) of the psychobiological model are determinants of performance. When possible, these predictions will be manipulated directly, such as the knowledge of end-point, time/distance feedback and previous experience. However, RPE and potential motivation will not be directly manipulated as it was in the studies which will be described in Chapter 2 and Chapter 5. In Chapter 2 RPE and potential motivation were manipulated to prove the different strong relation between RPE and VO_{2max} among different groups of subjects, while in Chapter 5 to show where potential motivation could have not been directly measured.
The studies discussed in this thesis were designed following the principle of refutation expressed by Karl Popper (1963). Each of the study is considered risky as each prediction is tested in a way that if the effect of performance was dissociated from the one of the factors proposed. Therefore,it is possible that the psychobiological model may be refuted.

The aim of the single chapters is as follows:

In the first study described in Chapter 2, the aim was to demonstrate that the relation between VO_{2max} and RPE predicts the pace adopted during a 30 min running time trial. We tested the hypothesis that individuals with higher VO_{2max} values would be able to maintain a much higher peak power output

(PPO) for the same RPE compared with individual with lower values of VO_{2max}.

In the second study, we used an ABA design to show that knowing the distance to cover during the race is a key information for a faster pace and a different pacing strategy. We tested the hypothesis that individuals will perform significantly better when they are provided with the correct knowledge of distance during a time trial task. In addition, we observed the effect of memory of prior experiences on time trial performance.

The third study aimed at demonstrating the importance of feedback on the distance/time covered as determinant to choose a faster pace and pacing strategy. We hypothesized that when subjects are provided with continuous feedback they will have a faster pace and perform significantly better compared to when they are not aware of the remaining elapsing time and distance to cover.

In the fourth study, the aim was to show the effect of verbal encouragement during different phases of a cycling time trial motivation, RPE, pace and performance. This study was designed to test the hypothesis that individuals will perform better on a 30 min time trial when verbal encouragement is provided during the last 15 min rather than during the first 15 min, when not provided at all or when provided throughout the task.

CHAPTER 2

VO2MAX AFFECTS PACE DURING A 30 MIN RUNNING TIME TRIAL IN HUMANS

Introduction

Pacing strategy defined as distribution of work during an exercise task is an important factor determining performance over a wide range of endurance events such as running, cycling and rowing (Abiss & Laursen, 2008). Asking an athlete to complete a task in the fastest time or covering the longest possible distance in a set time is the most common and appropriate model to study pacing. Indeed, to fulfil this request, an athlete adopts a strategy that does not take into account tactical aspects or the behaviour of opponents.

Different factors can have an effect on performance and pacing during time trials. It is known that physiological aspects such as muscle fatigue or hydration status can have a negative effect on performance (de Morree and Marcora, 2013; Winger et al., 2009); similarly, among the environmental factors, hypoxia and ambient temperature curtail performance (Clark et al., 2007). From a psychological point of view, it has been shown that factors such as motivation, music, deception or unawareness of the distance covered during a task may determine an alteration of performance and/or pacing (Corbett et al., 2012; Atkinson, 2004). In school children, it has been shown that age, gender and cognitive development can also affect pacing strategy (Micklewright et al., 2012). Furthermore, runners adopt different pacing strategies when running during hilly time trial events (Townshend et al., 2010).

Although the positive correlation between maximal oxygen consumption (VO_{2max}) and performance during self-paced endurance tasks is well established (Hawley and Noakes, 1992; Balmer et al., 2000; Impellizzeri et al., 2005), the effect of VO_{2max} on pacing is poorly understood. Lima Silva et al., (2010) showed that performance level affects pacing strategy during a 10 km running race simulation, as better-performing athletes had a fast start followed by a reduction in speed and final end-spurt; while less skilled athletes started with a more conservative pace which they kept till the final end-spurt. Moreover pace was significantly different between groups, with a higher pace for athletes who performed better than others. In particular, they suggested that important determinants of the different paces and pacing strategies chosen by the low- and high-performance runners were the peak running velocity (speed) achieved during an incremental test to exhaustion, the lactate threshold and the running economy. Interestingly, although the two groups of participants were characterized by different performance levels, there were no differences in regards to the maximum oxygen uptake. Therefore, it is not clear whether people with different VO_{2max} adopt different pacing strategies.

VO_{2max} is one of the most important determinants of perception of effort described in psychophysical terms as the relationship between workload (speed or power output) and ratings of perceived exertion (RPE). Therefore, based on the results of Lima Silva et al. (2010) we hypothesised that fit and unfit athletes regulate their workload to maintain RPE within similar levels in order to avoid premature exhaustion – i.e. to avoid reaching maximal RPE before the end of the trial. However, due to their lower perception of effort, fitter athletes should be able to exercise at a higher workload (overall pace). Therefore, an athlete’s VO_{2max} should affect the average pace during a time trial, with fitter athletes being capable of exercise at a higher workload for the same RPE.

Methods

Subjects

Twenty male subjects were recruited among sport science students of the University of Bangor and athletes from the local running and triathlon clubs. Their main baseline characteristics are shown in Table 1. The main inclusion criteria for participation in the present study were adult age and a history of distance running for at least 30 min twice a week in the previous 6 months. A medical questionnaire was administered to exclude subjects with conditions contraindicating maximal exercise. The study protocol was approved by the Ethics Committee of the School of Sport, Health and Exercise Sciences (SSHES) of the University of Bangor. All participants were informed of the purpose and procedures of the study, related benefits and risks and had to give their signed informed consent before taking part.

Variable	High n = 10	Low n = 10	P level ANOVA
Age (yrs)	31 ± 5	33 ± 11	0.700
Stature (cm)	178 ± 6	177 ± 4	0.711
Body mass (kg)	71.6±6.4	79.7±6.0	0.020
Body fat (%)	7.8±3.7	15.9±4.1	0.001
VO2max (mL/kg/min)	61.5±2.1	49.2±2.1	<0.001
Max heart rate (bpm)	189 ± 6	184 ± 1	0.714
Time trial performance (m)	7300±376	6479±667	0.024
Running sessions per week	4 ± 1	4 ± 2	0.996
Average session duration (min)	62 ± 24	46 ± 21	0.073
Total distance run per week (km)	38 ± 19	26 ± 13	0.062

Table 1

Subjects baseline characteristics. Unless otherwise noted, values are means ± SD. VO_{2max} = maximal oxygen consumption. High, high VO_{2max} group and Low, low VO_{2max} group.

Study design

The research assistants administering the time trials were unaware of subject treatment allocation to avoid experimenter bias on our primary outcome variable. Subjects visited the Physiology Laboratory twice. During the first visit, body size and composition, as well as maximal oxygen consumption (VO_{2max}) were measured. After a minimum of 24 h, subjects came for the second visit. On this occasion, the subjects' physiological and perceptual responses were monitored during a standardized constant speed run at sub maximal intensity. Ten minutes after this standardized sub maximal run, subjects performed the 30 min time trial.

Subjects were asked to avoid smoking, alcohol, tea, coffee, and required to drink, on average, 2.5 L of water in the 24 h prior to each visit. They were also instructed to have a light meal at least 3 h before reporting to the Laboratory and to maintain their usual diet throughout the study. All visits were scheduled between 9 am and 7 pm, and environmental conditions in the Laboratory were always between 20 and 21.5° C (temperature), and 35 and 45 % (humidity). In the 24 h before Visit 1 and 2, subjects were asked to avoid strenuous exercise.

Time trial

Subjects were required to run as far as possible in 30 min on the Woodway motor-driven treadmill set at 1% inclination. The treadmill was regularly checked for accuracy of speed, inclination, and distance measured. Feedback on elapsed time was available, but subjects could not see the treadmill's speedometer and the HR monitor display, which were covered with cardboard and thick white tape. The time trial started with subjects standing on the treadmill belt while speed was increased up to 9.0 km/h. After this speed was reached, subjects were free to increase or decrease running speed at their will using the + and - buttons on the right side of the treadmill. Once the 30 min were elapsed, subjects stopped running immediately and placed their feet on the platforms at the sides of the belt while the distance ran in the time trial was recorded. This was our operational definition of endurance running performance. A fan was placed in a standardised position in front of the subject during the entire duration of the trial and he/she was allowed to drink water. Every 3 min, speed, HR and RPE were recorded as described above and used for statistical analysis. Strong verbal encouragement was provided by a research assistant. Furthermore, a cash prize for best performance was given to motivate maximal effort during the time trial. In a preliminary in-house reliability study conducted in a similar group of 10 male runners tested twice without a habituation trial, this 30 min time trial demonstrated good reliability with a test-retest correlation coefficient of 0.91 and a coefficient of variation of 3.8% (Marcora and Bosio, 2007).

Other measures

Maximal oxygen consumption was measured with the Zan automated metabolic gas analysis system while running on the Woodway motor-driven treadmill following the modified Åstrand protocol described by Pollock et al.(1978). Briefly, subjects ran at a fixed self-selected speed between 8 and 12.9 km/h. After 3 min at ground level, inclination was increased by 2.5% every 2 min until exhaustion. Stature, body mass, and body fat percentage were assessed by mean of a wall-mounted stadiometer (Model 26SM, Seca, Hamburg, Germany) and a standing bioelectrical impedance analyzer (TBF-305, Tanita Corporation, Tokyo, Japan) using the proprietary sex-specific equations for athletes.

Statistical analysis

Unless otherwise noted, data are presented as mean ± SD. A one way ANOVA was used to assess the difference among groups in the distance ran in the time trial. A two-way (group x time) ANOVA with repeated measures on the time factor was used to assess the effect of fitness level on pacing strategy, i.e. speed, HR and RPE recorded every 3 min during the 30 min time trial (10 time points). A significant interaction (group x time) was followed-up by tests of simple main effect at each time point. In case of a non-significant interaction, only the main effect of group was considered. Relevant assumptions were checked and appropriate corrections employed if necessary. Significance was set at 0.05 (two-tailed) for all analyses. A P level between 0.05 and 0.10 was considered a trend. Power analysis have been conducted to choose the sample size based on a two-way ANOVA with two groups, an alpha error probability of .05 and a power of 0.80.

Results

ANOVA showed a higher performance for the High VO_{2max} group (7301 ± 376 m, $p<0.031$) compared to the Low groups (6479 ± 667 m respectively). Two way repeated measure ANOVAs did not detect significant group x time interactions for speed ($p= 0.463$), RPE ($p= 0.333$), and heart rate ($p= 0.780$). Significant main effects on time were found for speed, RPE, and heart rate (all p values < 0.001), but the only significant main effect on the whole group was found for speed ($p= 0.030$) (Fig. 5). Follow up tests show that all runners adopted a negative pacing strategy with a significant increase in speed at the end of the time trial. Both RPE and heart rate increased linearly during the time trial. Heart rate percentage, when normalized by its maximal value obtained during the initial assessment, did not show any interaction group x time ($p= 0.401$) or main effect of group ($p= 0.401$).

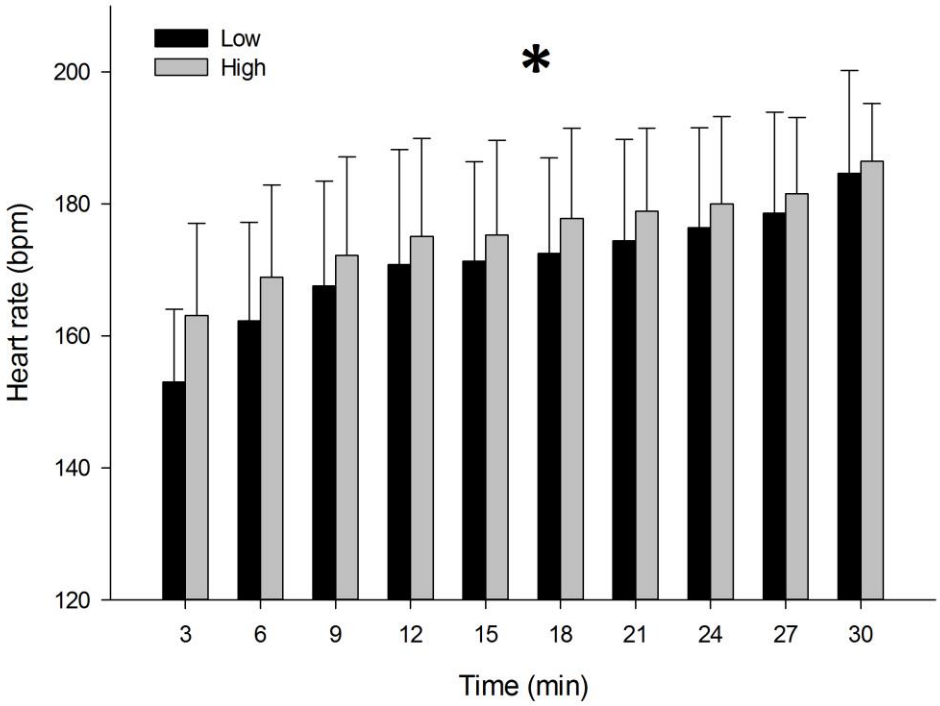


Figure 3

Average heart rate (bpm) per every 3 min across the two groups of different VO_{2Max}. Data are presented as mean ± SD. * represents main effects of time.

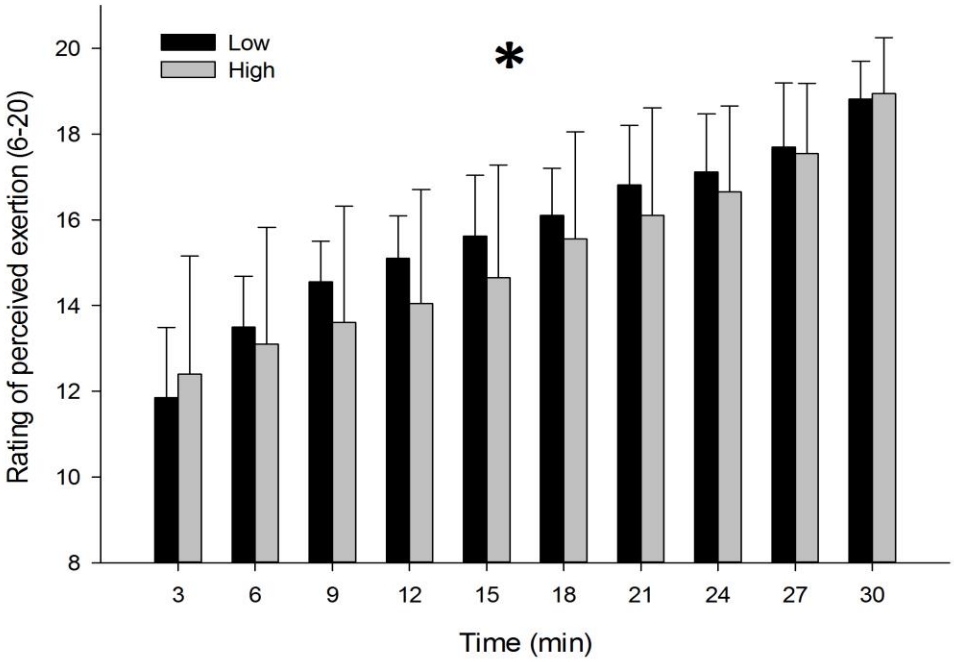


Figure 4

Average RPE per every 3 min across the two groups of different VO_{2Max}. Data are presented as mean ± SD. * represents main effects of time.

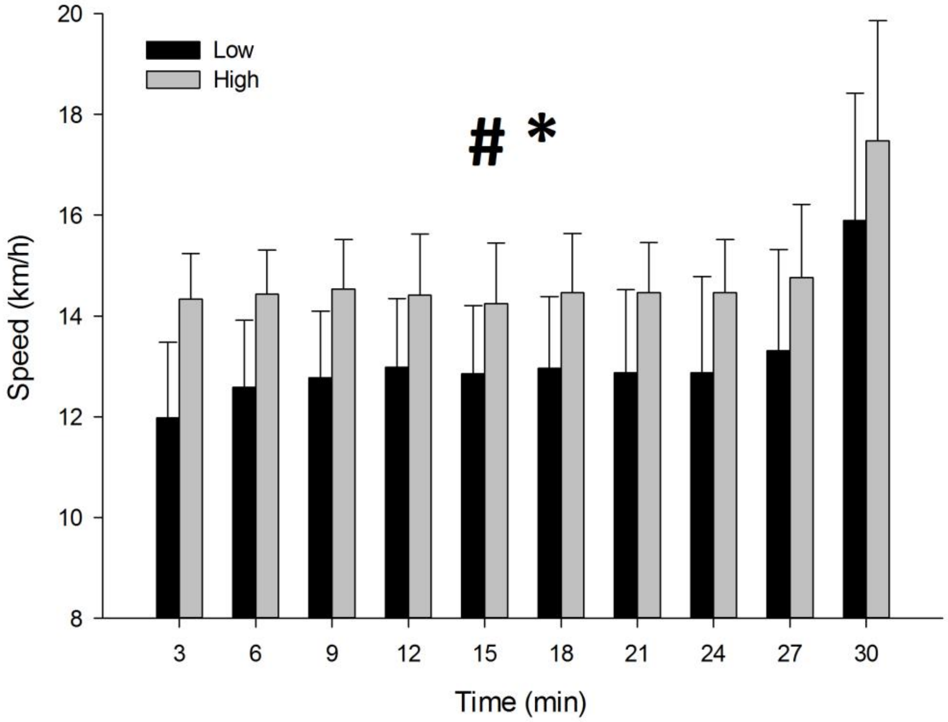


Figure 5

Average speed per every 3 min across the two groups of different VO_{2Max}. Data are presented as mean ± SD. * represents main effects of time. # represents main effects of group.

Discussion

The present findings confirm that athletes with higher VO_{2max} achieve better running performance compared to those with lower VO_{2max}. However, contrary to the findings of Lima-Silva et al. (Lima-Silva et al., 2010), VO_{2Max} does not influence the distribution of work during time trial (pacing strategy).

The identical time course of RPE suggests that runners with different VO_{2Max} are able to maintain the same RPE by choosing different average speeds in order to avoid reaching maximal RPE and, thus, exhaustion, before the end of the time trial.

Training is the most important cause in the improvement of the percentage of VO_{2max} that athletes will be able to maintain during an endurance effort. In the present study the two groups were characterised by similar training volumes and frequency.

Non-significant values for heart rate and RPE demonstrate that the relation RPE/Speed regulates pace during a time trial performance. It is noteworthy that the maximal heart rate was the same in the two groups, and the percentage heart rate at which they were performing the time trial did not show any significant difference by group or interaction. Therefore, the relative intensity during the time trial was the same in all the participants, although the absolute intensity (in this case speed) was different.

All runners, were made aware of the duration of the task at the beginning of the run (30 min; that is an information similar to the knowledge of the distance to cover), and of both elapsing and time to go during the run (that is an information similar to the knowledge of the remaining distance to cover). Furthermore, they were accustomed to races (and training) where distances ranged from 5/10 km to Marathon-length; therefore they had experience and memory of their own perception of effort during these diverse tasks. Assuming that the potential motivation was the same for all the participants (because all of them received the same instructions and incentive), the only conscious action they needed to perform during their run was to adjust the speed along with their immediate perceived effort.

In addition, results of this study show that VO_{2Max} does not seem to influence pacing strategy during a 30 min time trial, although athletes with higher VO_{2max} achieve higher pace and thus running performance compared to the ones with lower VO_{2Max}.

Pacing strategy, which is the distribution of effort during an endurance physical task (Tucker, 2009), was similar in the two groups. It consisted in a uniform pace with an increase in speed towards the end of the trial (end-spurt). As previously highlighted, VO_{2max} and the percentage that can be maintained account for the different average speed kept in the two groups, but these two aspects cannot explain the lack of difference in pacing strategy between groups. The athletes, independently of their VO_{2max}, consciously decided to run the 30 min time trial adopting a different pacing strategy that roughly consisted in a more or less stable speed throughout the rest of the time trial and a final end-spurt (Noakes, 2012).

Because a 30 min time trial is not a common race and none of the participants had previous direct experience with that sort of effort, it is likely that the most efficient strategy would be quiet conservative and prudent. Moreover, this could also suggest that there was a similar level of experience and/or similar prior knowledge of this kind of test in both groups, which is supported by the non-significant difference in the pacing strategies adopted between the groups.

In a previous study (Lima-Silva et al., 2010), in contrast to the present results, some authors showed not only a different pace but also a different pacing strategy adopted by runners of different performance level engaged in a 10 km run. A “U” shape profile of pacing strategy was observed in the better-performing athletes (i.e. a fast start was adopted in the trial followed by a marked decrease of speed, a steady-state phase and a final end-spurt), while a “J” shape was observed in the worse-performing subjects (a similar steady-state pace followed by the end-spurt). Interestingly, Lima-Silva et al. recruited runners with similar VO_{2max} and did not monitor the participants’ perception of effort during the time trial. It cannot be excluded that, in that study, RPE was different between groups and this was due to the athletes’ different training statuses and level of knowledge of the distance to cover.

Conclusion

In conclusion, VO_{2max} is an important determinant of endurance performance but not of the distribution of effort (pacing strategy) during a 30 min time trial. These results support the prediction of the psychobiological model of endurance performance, as the identical time course of RPE suggests that runners with different VO_{2max} choose different average speeds in order to avoid reaching maximal RPE and, thus, exhaustion, before the end of the time trial. Difference in pace among the groups is due to the significant effect that VO_{2max} has on the relationship between speed and RPE, which is in line with the psychobiological model of endurance performance. This suggests that RPE ultimately limits physical performance and regulates the adequate pace that will be chosen during the competition. However, the relation between VO_{2max} and RPE is not a determinant of pacing strategy that may be dictated by the knowledge of prior experience of similar races and the distance of the race.

CHAPTER 3

THE EFFECTS OF KNOWLEDGE OF DISTANCE AND FAMILIARIZATION ON PACING AND PERFORMANCE DURING ENDURANCE RUNNING

Introduction

During prolonged physical activity and endurance sport, it is vital for athletes to ensure that they do not overexert themselves. Individuals must be able to regulate their work output in a way to perform well without exhausting themselves before the end of the competition (Abbiss and Laursen, 2008). For example, long-distance runners cannot sprint flat out at the start of a marathon, as this will probably leave them incapable of completing the rest of the race. Long-distance runners must instead determine a speed at which they can work throughout all stages of the race. The process in which individuals adapt in order to meet these requirements is known as pacing. Pacing strategy is the way an athlete distribute his/her speed/power output throughout an endurance competition or a test in which the individual is free to vary the workload (time trial) (Hettinga et al., 2006).

Sport scientists believe that whilst different athletes may use different forms of pacing strategies depending on the event, the main principle by which these strategies are controlled remains the same (St Clair Gibson et al., 2006). Pacing strategies appear to be influenced by several factors such as the length of the event, the individual’s motivation, the type of event and even the environment in which the event takes place (Tucker and Noakes, 2009).

Pacing is the mechanism that athletes use in order to control their speed so that they can cover a specific distance or perform in a set time without failing (Abiss and Laursen, 2008). Most physiologists have focused on limiting factors of exercise performance rather than on factors that regulate exercise performance (Tucker and Noakes, 2009). Several theories and models have been proposed on pacing and the regulation of pacing strategies, which, however, are still not fully understood (Foster et al, 1993. The central Governor model (CGM) proposed by Noakes and colleagues (Noakes, 2012) and the psychobiological model proposed by

Marcora and colleagues (2008, 2009, 2010 and 2013) are the most relevant models for pacing mechanisms.
Both CGM model and psychobiological model states that correct knowledge of the end-point of the competition is of paramount importance in order to generate a correct pacing strategy (Noakes et al., 2005; Mauger et al., 2009; Ulmer et al., 2006 and de Morree and Marcora, 2013). Indeed, not knowing the distance or the time to perform during a race means that the athletes have not enough information to decide what pace and pacing strategy should be employed during the competition. Moreover, several studies stressed out the importance of the combination of knowledge of distance/time to cover along with experience from priory experience as factors involved in the construct(ion/ establishment) of a detailed pacing strategy (Noakes et al., 2005; Mauger et al., 2009).

The aim of this study was to test the prediction of the psychobiological model for which providing correct knowledge of distance information allows athletes to pace themselves faster than those who had been given incorrect information on the distance to cover.

It was hypothesised that when participants were provided with the correct information, they would pace themselves faster at a 5 km endurance running time trial than when they were provided with incorrect information due to a conscious self-regulation system. In addition, we tested the hypothesis that the effect of prior experience of competition and familiarization would produce a significant positive effect on performance.

Methods

Participants

Fifteen (11 male and 4 female) physically active participants were recruited (age [years]: 26.25 ± 5.38; height [cm]: 168.91 ± 8.43; weight [kg]: 66.33 ± 8.54). All subjects signed an informed consent form describing the study protocol, which was approved by the Ethics Committee of the School of Sport, Health and Exercise Sciences, Bangor University, according to the standards set by the Declaration of Helsinki.

Study Design

A quasi-experimental design was used for this study. No randomisation was performed, as each participant underwent the same type of treatment in the same order in an ABA design. All participants were required to take part in three separate trials on three separate days. The laboratory had a mean temperature of 19.6 ± 1.1°C and a mean humidity of 51.6 ± 2.5%. Participants were asked to refrain from exhaustive exercise in the 24 hour period leading up to their trial and were similarly asked to refrain from drinking caffeine in the 5 hours prior to participating in the study. The trials were booked to ensure that at least 48 hours had passed in between each trial, so that individuals were not running on consecutive days and had enough time to recover from their previous endurance run. Upon first arrival in the lab, both height and weight were measured for each individual. In the first trial, participants were told to run a time trial distance of 5 km, they were allowed to freely pace themselves; however, they were instructed to complete the trial in the shortest possible time.

After the minimum of 48 hours had passed (in order to allow for recovery), participants returned to the laboratory for a second time trial. In this time trial, participants were told that they were to run a total distance of 10 km in the shortest possible time.

However, in reality they would only be running 5 km. In their third and final trial, participants were told to run 5 km, exactly as they had in the very first time trial so as to measure the familiarization effect.

Experimental Treatment

In all three time trials, the participants were able to see their current speed, time, distance covered and even heart rate on the treadmills display. Whilst in the first and final time trials, the participants were provided with correct information on the distance they would be covering (5 km), in the second trial, participants were purposely given false information on the distance. Each participant had been made to believe that they would be running a 10 km endurance time trial on the treadmill when, in fact, they would be stopped after only 5 km. Therefore, the independent variable or manipulated treatment for this study was the athletes' knowledge of the total distance. The dependent variables on the other hand were time to completion, heart rate (HR), Rating of Perceived Exertion (RPE) and, finally, speed over distance in order to ensure the success of the pacing strategy.

Time Trial

Upon arriving in the lab and after filling in the relevant forms, a brief demonstration was given in order to ensure that the participants understood how the treadmill (h/p/cosmos Mercury 4.0, h/p/ cosmos, Nussdorf-Traunstein, Germany) functioned. The RPE scale (RPE; Borg, 1998) was also explained: subjects were shown the scale and asked to rate their perception of effort in relation to previous experience, this is known as memory anchoring (Robertson, 2004). Resting HR was then measured by means of a heart rate monitor (Heart Rate Monitor FS1, Polar Electro, Kemple Finland). Prior to starting the actual time trial, participants performed a three minute warm up, in which they selected a comfortable running speed for themselves, which would then be the same speed for all three trials. During this period, their HR was not to reach any higher than 150 BPM. Finally, it was ensured that the participants knew exactly what they were doing. During each time trial, HR, RPE, time and speed were recorded each from the 1 km mark up to the fifth final kilometre. The participant running was in full control of his speed; however the gradient was set to 1% throughout all trials. In order to keep motivation levels equal between all participants, the experimenter was not to give any words of motivation and all participants were refrained from using any external devices such as MP3 players. The third time trial allowed us to control the familiarization effect and verify whether familiarization had any impact upon pacing and performance.

Statistical Analysis

Data were analysed using IBM SPSS Version 20 using 3 x 5 repeated measures analyses of variance (ANOVAs). The independent variables were Trial (3 levels: 5 km, sham 10 km, 5 km) and Distance (1, 2, 3, 4, 5 km). The dependent variables were Heart rate (HR, bpm), Speed (km/h) and RPE (6 to 20), all measured at the end of each completed kilometre and analysed separately. An additional dependent variable was Time to Completion (TtC, measured in seconds), which was compared between trials using one way repeated measures ANOVAs. All tests were conducted at standard significance level of 0.05 and tested as two-tailed hypotheses. The normality assumption was tested using Shapiro-Wilk W tests. Violations of the sphericity assumption were Greenhouse-Geisser corrected. Power analysis has been conducted based on a two-way repeated measure ANOVA with two groups, with an alpha error probability of .05 and a power of 0.80.

Results

Heart rate (bpm). Results of the 3 x 5 repeated measures ANOVAs on HR (bpm) showed significant main effects of Trial ($p < 0.001$) and Distance ($p< 0.001$) but no significant interaction between these two variables. Pairwise comparisons showed that the main effect of trial arose, because HR was significantly lower in the sham 10 km trial than in either of the 5 km time trials. The mean difference between the sham 10 km trial to the first 5 km time trial was 7 bpm ($p = 0.003$); and to the second 5 km time trial 9 bpm ($p < 0.001$). The difference in HR between the two 5 km time trials was not statistically significant ($p = 0.290$). Data illustrated in Figure 6.

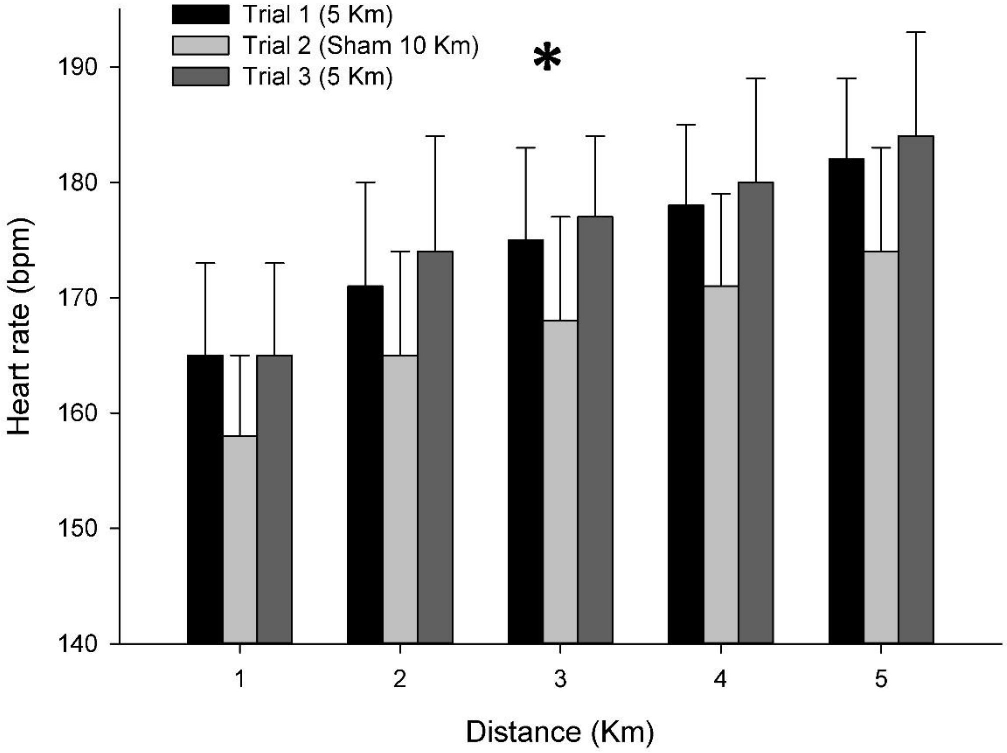


Figure 6

Mean heart rate (bpm) per completed kilometre across the three experimental trials. Data are presented as mean ± SD. * represents main effects of distance and trial.

RPE (6 to 20). Results of the 3 x 5 repeated measures ANOVAs on RPE (6 to 20) showed a significant Trial x Distance interaction ($p < 0.001$). As can be seen in Figure 7, this interaction arose, because RPE was lower in the sham 10 km time trial, but similar in the two 5 km time trials. Descriptive statistics are reported in Table 2.

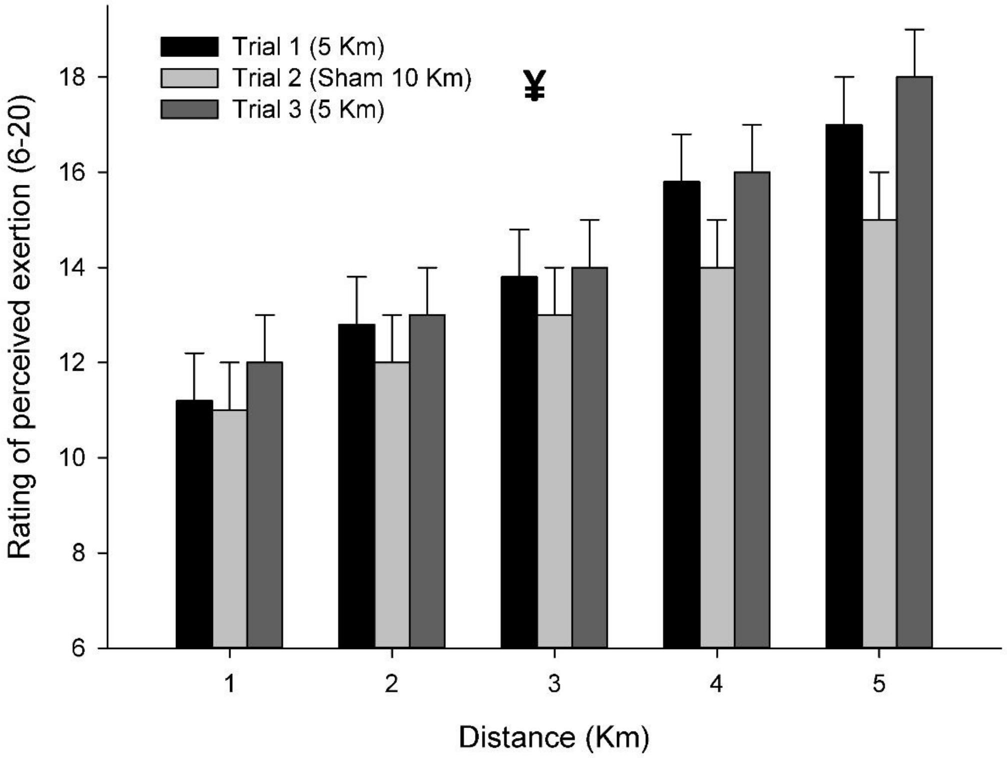


Figure 7

Rating of perceived exertion (6 to 20) per completed kilometre across the three experimental trials. Data are presented as mean ± SD. ¥ represents Trial x Distance interaction.

Distance	Trial 1 (5 km)			Trial 2 (Sham 10 km)			Trial 3 (5 km)		
	HR (bpm)	RPE (6 to 20)	Speed (km/h)	HR (bpm)	RPE (6 to 20)	Speed (km/h)	HR (bpm)	RPE (6 to 20)	Speed (km/h)
1 km	165 ±9	11 ±1	12.4±2	158 ±7	11 ±1	11.4±2	165 ±8	12 ±1	13.3±2
2 km	171 ±9	13 ±1	12.9±2	165 ±9	12 ±1	11.6±2	174 ±10	13 ±1	13.7±2
3 km	175 ±11	14 ±1	13.2±2	168 ±9	13 ±1	11.7±2	177 ±7	14 ±1	13.6±2
4 km	178 ±10	16 ±1	13.2±2	171 ± 8	14 ±1	12.1±2	180 ±9	16 ±1	13.7±2
5 km	182 ±10	17 ±2	14.1±3	174 ±9	15 ±1	12.1±1	184 ±9	18 ±1	15.3±3
TtC (s)	1464 ±223			1617 ±227			1370 ±182		

Table 2

Descriptive statistics (means and SD) for Heart Rate (HR, bpm), Speed (km/h) and Ratings of Perceived Exertion (6-20, Borg’s scale) per completed kilometre, as well as TtC(in seconds) for each trial.

Speed (km/h). Results of the 1 way repeated measures ANOVAs on speed showed a significant Trial x Distance interaction ($p = 0.028$). Data shown in Table 2.Pairwise comparisons showed that speed was significantly lower in the sham 10 km trial than in either of the 5 km trials and that speed increased in the last km in both first and third time trial, but it remains the same in the second sham time trial.

Time to completion (s). Results of the 1 way repeated measures ANOVAs on TtC (s) showed a main effect of Trial ($p < 0.001$). Pairwise comparisons showed that TtC was significantly longer in the sham 10 km time trial than in either of the 5 km trials. The mean difference between the sham 10 km time trial and the first 5 km time trial was 153 s ($p = .001$); and to the second 5 km trial 247 s, ($p < 0.001$). The mean difference in TtC between the two 5 km trials was also statistically significant and 94 seconds longer in the first time trial ($p < 0.001$). Descriptive statistics are reported in Table 2, data is illustrated in figure 8.

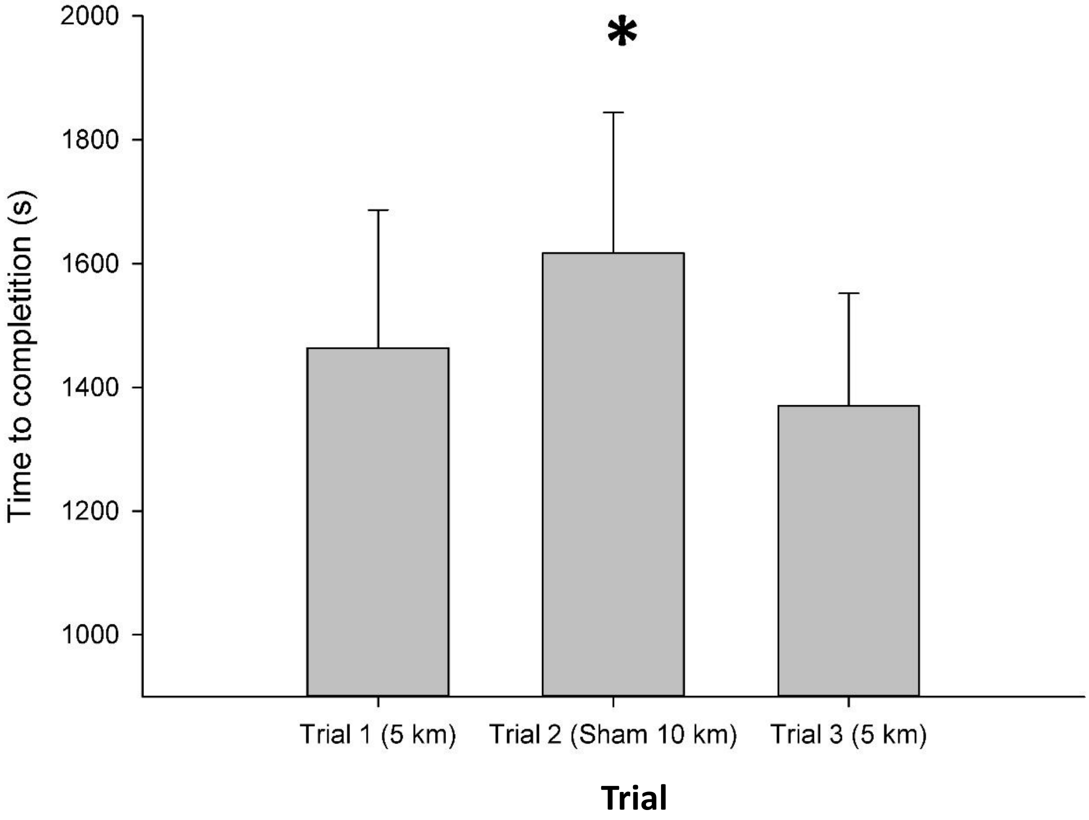


Figure 8

TtC (s) for each of the three experimental trials. Data are presented as mean ± SD.

Discussion

The aim of this study was to look into the effects that the correct knowledge of total distance and learning have upon pacing and performance during endurance running. It was hypothesised that in endurance time trials, participants would choose a faster pace and, as a result, would perform better if provided with correct knowledge of the total distance than they would if they were give incorrect information on the total distance. In addition, we hypostasized that the last 5 km time trial performed in the last session would be affected by the learning factor due to the experience gained from the previous first time trial conducted. The data collected throughout the study provides evidence supporting this hypothesis.

The main outcome of this study is that participants were able to pace themselves more correctly and thus perform better when they were aware of the total distance of the time trial, compared to when they were given the incorrect information. This can be explained by the more conservative pacing strategy employed by the participants, who were expecting to run for 10 km instead of the actual 5 km. Similarly, we might have obtained similar results if the participants had been asked to run 3 km in the second trial and then, towards the end of the race, we had let them continue up until the fifth km. The principle is the same: an incorrect knowledge of the total distance does not allow athletes to identify an adequate pacing strategy for the competition.

As Ulmer (1996) suggests there is a teleoanticipatory subconscious process in the brain that takes into account the distance to cover and previous experience allowing athletes to plan an adequate pace for asset task. In this case, the participants deceived in the second trial adjusted their pace for a 10 km run and not a 5 km. Those results support the psychobiological model for pacing, as knowledge of the total distance is an important factor to produce the self-regulated pacing strategy at which to run the time trial. The more this factor is refined and correct, the better the pacing strategy will be.

As consequence of a more conservative pace in order to complete the virtual 10 km trial, HR resulted significant lower in the second sham 10 km trial compared to the first and third trial where subjects were aware of the correct distance to cover. As shown in Table 1 subjects' HR at the 5th km of the second sham 10 km (which was half away in their belief) was on average similar to the HR during the second and third km during the first and third trial, which correspond as well to half way of the correct 5 km time trials they performed.

In addition, during the 10 km sham time trial, their TtC was significantly lower compared to that in the first and third time trials. Participants were producing higher speed during the correct information trials and ultimately achieved a better performance. The results show an increase in speed during the last km of the first and third time trial, which was absent in the second sham trial. Such an increase in speed can be interpreted as an end-spurt phenomenon. As widely claimed by scientists such as St Clair Gibson and colleagues (2006) and Abiss and Laursen (2008) the end-spurt is a very common phenomenon in various pacing strategies and during several types of competition. It reflects the athletes' conscious decision to accelerate near the end of the race, as competitors know that the distance left to cover before the end of the race is minimal and thus they can maximally exert without worrying about exhausting their energy. Indeed, the absence of the end-spurt in the second time trial suggests that participants were still planning their pacing strategy in order to achieve the 10 km and they were aware to be only half way through the race. As Marcora (2008 and 2009) suggests, during the end-spurt the only conscious awareness and decision for competitors is to accelerate as much as they can, given that the finish line is very near and thus there is no need to employ any other pacing strategy.

The significant interaction (Trial x km) for RPE showed a lower RPE during the sham 10 km time trial as result of the participants' conscious awareness that they would have to run for further 5 km and thus they needed to consciously decide a pacing strategy which would allow them to complete the race without collapsing before reaching the finish line. According to the psychobiological model for pacing, choosing an adequate pacing strategy is necessary to avoid reaching maximal effort and thus premature exhaustion when it is too early in the race. The absence of the end-spurt and critical physiological and perceptual values suggest that the incorrect knowledge of the distance has clearly produced a non-optimal pacing strategy, the performance as consequence was diminished (St Clair Gibson et al., 2006). The incorrect information of knowledge of distance created an unclear situation, which reduced the participants' ability to create a proper pacing strategic plan, as also clarified by Paterson and Marino (2004).

In this specific design, ABA results showed that the third time trial was significantly faster than the first one. Usually this type of design is proposed to explore any possible familiarization/training effect due to the non-randomized method. It has been demonstrated that one familiarization is sufficient to guarantee the high reliability of the physical test used (Abiss et al. 2007). In this specific case we wanted to observe the familiarization and learning effect due to the previous experience of the first 5 km time trial performed. If we consider that subjects were completely inexperienced, the increase in performance during the third time trial suggests that when memory of past experience has been reinforced the ability to pace oneself will increase and, this will be beneficial to the performance (Marcora, 2009; Mauger et al., 2009; Mickle wright et al. 2010). These data are also supported by several studies where the learning effect due to familiarization affected up to 1.2 % of performance in Athletes and up to 5% in non-Athletes (Hopkins et al., 2001).

Further considerations

Whilst this study appears to show that amateur runners pace themselves differently according to their knowledge of distance, we cannot assume that the same can be said for elite performers, as elite athletes may require more or less information. Further studies could look into the effects of knowledge of distance, prior experience and in particular familiarization upon elite endurance runners. An ideal study would therefore consist in testing participants with different levels of fitness.

Conclusion

In conclusion, this study demonstrates that knowledge of total distance and familiarization from previous experience play a key role in the pacing and pacing strategy and, consequently, on an athlete's performance in a 5 km time trial running. Athletes appear to consciously identify a pacing plan based on this information. At the beginning of the race, they must also determine a speed they are confident to maintain depending on their present perceived effort and on the effort perceived in previous similar competitions. Towards the end of the time trial, athletes must then decide whether or not they have exerted adequate effort and if they feel they can exert more (depending on the distance remaining), and it can be observed an increase in pace known as the end-spurt phenomenon. Ultimately, according to the psychobiological model knowledge of total distance and memory of previous experiences are two of the five factors that athletes take into account to find the most appropriate pacing strategy for a successful performance. These are also crucial factors competitors consider in order to achieve an optimal performance.

CHAPTER 4

THE DETERMINANT ROLE OF CONSCIOUS TIME/DISTANCE FEEDBACK ON ENDURANCE PERFORMANCE

Introduction

Endurance performance is directly influenced by how the velocity or power output is distributed throughout the exercise, i.e., pacing strategy (Abbiss and Laursen, 2008). A variety of exercise factors can influence this phenomenon, mainly in presence of a known endpoint (closed-loop task), such as previous experience with the task (Mauger et al., 2009, 2010), the knowledge of time or distance endpoint (Chinnasamy et al., 2013), and conscious time/distance feedback provided externally (Koning et al., 2011; Chinnasamy et al., 2013). However, based on the Central Governor model, the conscious time/distance feedback is not essential to develop an appropriate pacing strategy and achieve the best performance (Mauger et al., 2009; Mauger et al., 2010; St Clair Gibson et al., 2006).

According to the Central Governor model, an internal clock in the subconscious brain regulates the muscle recruitment and pacing strategy during closed-loop task, in order to achieve the best performance (St Clair Gibson et al., 2006). Empirically, the athlete would set an appropriate pacing strategy at the start of an event based on the knowledge of the endpoint and the associated duration of the event, an internal clock using scalar timing, and memory of pacing strategy from previous experiences. Furthermore, this pacing strategy would allow athletes to reach the end of the event without catastrophic failure occurring in any physiological system (St Clair Gibson et al., 2006). Then, the conscious time/distance feedback is not necessary to determine pacing strategy and performance (Mauger et al, 2009, 2010).

On the other hand, the Psychobiological model (Marcora, 2010) has based its theory on five cognitive/motivational factors to explain closed-loop task performance: i) the perception of effort, defined as “the conscious sensation of how hard, heavy and strenuous the exercise is” (Marcora, 2009); ii) the potential motivation that represents the athletes ’willingness to exert effort; iii) the distance or time trial duration to cover; iv) the time/distance elapsed/remaining and; v) the previous experience/memory of perceived exertion during exercise of varying intensity and duration. According to this model, athletes choose a slightly conservative pace at the beginning and in middle of the task because they are not be able to consciously predict the effort they will perceive at the end of the task. Close to the endpoint, athletes increase the speed/power as they know that the task is almost complete and changing the pace will not compromise their performance (Marcora, 2010). Therefore, conscious time/distance feedback during endurance exercise is important to determine the pacing strategy and level of performance. In short, Central Governor Model postulates that pacing strategy and endurance performance are not influenced by conscious time/distance feedback due to the subconscious internal clock, while the Psychobiological model postulates that conscious feedback influences pacing and performance.

The aim of the following study is to test the contrasting predictions of the Central Governor and the Psychobiological models of pacing strategy and endurance performance. According to our hypothesis conscious feedback on time (during 30 min cycling trial) and distance (during 5 km running trial), respectively provided by an external clock and odometer, has a significant effect on pacing strategy and performance during closed-loop task.

Methods

Participants

Twenty-seven males, who were asymptomatic of illness, injuries, and performed exercise regularly, participated in the present study. Sixteen participated in the 5 km running experiment (23.7 ± 4.9 yr; 175.4 ± 5.7 cm; 71.6 ± 7.9 kg; 53.8 ± 3.7 ml/kg/min) and eleven participated in the 30 min cycling experiment (26.6 ± 4.1 yr; 173.5 ± 6.9 cm; 68.5 ± 10.1 kg; 47.1 ± 7.6 ml/kg/min). Prior to the experiments, participants read the written informed consent and agreed to take part of the study. All the procedures used in this study were approved by the local university ethics committee and were conducted in accordance with the Declaration of Helsinki.

Design

Two randomized crossover experimental designs were performed: the running experiment consisted of two 5 km trials with distance feedback (control) and without distance feedback (treatment), while the cycling experiment consisted of two 30 min trials with time feedback (control) and without time feedback (treatment). The main dependent variables were performance, pacing, heart rate and rating of perceived exertion measured during the trials.

5 km running experiment

The participants visited the laboratory three times, at intervals of at least 48 h, at the same time of the day (± 2 h) and with a room temperature ranging from 18o to 20o C. They were asked to refrain from vigorous exercise for 24 h before the tests and were not allowed to consume caffeinated drinks for at least four hours before being tested.

In the first visit, the anthropometric characteristics, maximal oxygen consumption and familiarization trial were performed. The maximal oxygen consumption was measured using the single stage sub maximal jogging test (George et al., 1993). Then, the participants performed a 5 km self-paced treadmill (h/p/cosmos mercury 4.0, Nussdorf-Traunstein, Germany), running in the time trial test in order to "calibrate de central governor" of the participants before the two following sessions. In addition, participants were introduced to the RPE scale (6-20 Borg scale; Borg, 1998) and were provided with the following information prior to every session: "While exercising we want you to rate your perceptions of effort, i.e. how hard, heavy and strenuous exercise feels to you". The perception of exercise depends on how hard you are driving your leg or arms, how heavy you are breathing, and the overall sensation of how strenuous exercise is. It does not depend on muscle pain, i.e. the aching and burning sensation in your leg or arm muscles. Look at this rating scale; we want you to use this scale from 6 to 20, where 6 means "no exertion at all" and 20 means "maximal exertion". Nine corresponds to "very light" exercise. For a normal, healthy person it is like walking slowly at his or her own pace for some minutes. Thirteen on the scale is "somewhat hard" exercise, but it still feels well to continue. Seventeen ("very hard") is very strenuous exercise. A healthy person can still go on, but he/she really has to push himself. It feels very heavy, and the person is very tired. Nineteen on the scale is "extremely hard" exercise. For most people this is the most strenuous exercise they have ever experienced. Try to appraise your feelings of exertion as honestly as possible, without thinking about what the actual physical load is (heart rate, speed, power output, intensity level on the exercise machine). Do not underestimate your perception of exertion, but do not overestimate it either. It is your own feeling of effort that is important, not how it compares to other people. What other people think is not important either. Look carefully at scale and expressions, and then give a number. Any questions?"

During the familiarization participants were able to receive feedback on the time and distance remaining

In the second and third sessions, participants performed randomly the feedback and non-feedback 5 km trials. The heart rate monitor (FS1, Polar Electro, Kemple, Finland) was set in the participant followed by rating of perceived exertion instructions. Then, participants warm themselves up running during 6 min at 70% of their maximal heart rate. Thereafter, a blood sample was collected to determine blood lactate concentration (Lactate Pro, Arkray, Shiga). Before the beginning of the tests, the participants were informed of the total running distance (5 km), the possibility to change the speed at any time and run as faster as they could. A cash prize was promised to the best runner, i.e., the participant completing the test in the shortest time considering both feedback and non-feedback sessions (endurance performance).

During the feedback session participants were allowed to see the distance covered/elapsed on the panel of the treadmill. Any other external sources of feedback, such as heart rate, speed, time and clock were removed from the participant's view. During the non-feedback session, all possible external sources, including distance, were removed from the participant's view. During both trials, speed and heart rate were measured every 0.5 km. The RPE was measured every 0.5 km during the feedback session, whereas in the non-feedback session, it was measured at 1 km, between 1.1 and 2.4 km, at 2.5 km, between 2.6 and 4.9 km, and at 5 km. The exact instant of the RPE recorded among the different ranges was randomly assigned. It was performed a linear regression between RPE and distance to compare the same 10 scores of RPE recorded during the feedback session (i.e., from 0.5 to 5 km). No words of encouragement were given to the participants during both sessions. Immediately after every trial, blood lactate concentration was measured again.

30 min cycling experiment

The participants visited the laboratory four times, at intervals of at least 48 h, at the same time of the day (± 2 h) and room temperature ranging from 18o to 20o C. They were asked to refrain from vigorous exercise for 24 h before the tests and were not allowed to consume caffeinated drinks for at least four hours before testing.

In the first visit, it was determined the anthropometric characteristics and peak oxygen consumption. The peak oxygen consumption was measured (Cortex Metalyzer 3B, Germany) during incremental test in a cycling ergometer (SRM, Germany). The participants' ergometer set-up was saved for the three sessions to follow. Before the cycling session, participants were provided with the same RPE instructions described in the running experiment section above. Thereafter, they warmed-up by cycling at 50 W for 2 min, and this was immediately followed by 25 W of increment per minute until exhaustion. The RPE was recorded for every minute of the test.

The second session was performed to "calibrate de central governor" of the participants to the 30 min cycling trials. During the first 5 min, participants warmed-up by cycling at 70% of their peak power output determined in the peak oxygen consumption test. After a 5 min rest, a heart rate monitor (FS1, Polar Electro, Kemple, Finland) was set-up with the computer screen being positioned in front of the participant, only displaying the time covered/elapsed. Any other external sources of feedback, such as heart rate, power output, distance and clock were removed from the participant's viewing. Then, participants were asked to push as hard as they could for 30 min. The power output, RPE and heart rate were recorded at the 1st min, 5th min and every 5 min until the end of the trial (i.e., 30 min). At the end of the trial, the distance (i.e., endurance performance) was recorded.

In the 3rd and 4th sessions, similar procedures to the 2nd session were followed excepting the non-feedback session in which all the external sources of feedback were removed from the participant’s view, including time. Moreover, before starting the tests, the participants were informed of the total cycling time (30 min), and that a cash prize would be given to the 1st (£ 70), 2nd (£ 50) and 3rd (£ 30) best performer, i.e., the greatest distance covered considering both sessions.

In addition, the electromyography (EMG) activity of vastus lateralis (VL) and biceps femoris (BF) were measured during the 30 min trials. The EMG signals were collected using delsys Bagnoli 16-channel electromyography system and EMG works system 3.5 software (Delsys Inc.; sampling rate = 2000 Hz), through bipolar single differential surface EMG sensors (99.9% Ag, 10 x 1 mm, 10 mm spaced apart; Delsys DE-2.1; Delsys Inc.). The electrodes sites were identified according to the SENIAM recommendations (Hermens et al., 2000), marked with indelible ink and prepared by the same experimenter in both sessions. Before the placing the electrode, the participant’s skin was shaved, lightly rubbed with abrasive gel and cleaned with alcohol swabs. Reference electrode was placed over the 5th cervical spine protuberance. The electrodes were covered with straps of adhesive tape to prevent disconnection and reduce motion artefact.

The raw EMG signals were smoothed using a fourth-order band-pass Butterworth digital filter with a frequency range set between 20 and 500Hz. The onset and offset of EMG activity were obtained by a mathematical method (Hodges and Bui, 1996), where the onset of muscle activation was determined when signal amplitude was two standard deviations above mean baseline (period between each EMG burst). This procedure was adopted as threshold criterion for determination of the muscle activation–deactivation dynamics (Diefenthaeler et al., 2012). The root mean square

(RMS) values were used as an index of the total muscle activation, and these values from each muscle were normalized by the average muscle activity at the first 30 s of the test. Using custom-made code written in Matlab software (MathWorks Inc., Natick, MA, USA), it was determined the RMS from VL and BF muscles during 30 s before the 1st min, 5th min and every 5 min.

Statistical analysis

Normal distribution and sphericity of the data were checked. The Greenhouse-Geisser adjustment was made to the degrees of freedom when violations of sphericity occurred. In the 5 km running experiment, two-way ANOVAs for repeated measures, having condition (feedback and non-feedback) and distance factors (0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0 km), were performed to the speed, heart rate and RPE dependent variables. A two-way ANOVA for repeated measures, having condition (feedback and non-feedback) and time factors (pre- and post-5 km trial), was performed to the blood lactate concentration variable. In the 30 min cycling experiment, two-way ANOVAs for repeated measures, having condition (feedback and non-feedback) and time factors (1, 5, 10, 15, 20, 25, 30 min), were performed to the speed, heart rate, EMG activity and RPE dependent variables. The performance for both running (time) and cycling (distance) experiments was compared using dependent-sample t-tests. The significance level was set at $P < 0.05$. Power analyses have been conducted based on a two-way repeated measure ANOVA with two groups, an alpha error probability of 0.05 and a power of 0.80.

Results

Endurance performance

The duration of the 5 km running trial at non-feedback condition (1,373 ± 192 min) was greater ($p < 0.001$) than at feedback condition (1,287 ± 137 min). In addition, the distance covered during the 30 min cycling trial at feedback condition (15,270 ± 900 m) was greater ($p < 0.001$) than non-feedback condition (14,549 ± 943 m).

The 5 km running experiment

There was condition x distance interaction for the speed ($p < 0.001$) and RPE ($p < 0.001$). The heart rate increased throughout the running (main distance effect: $p < 0.001$). These variables are illustrated by figure 9. There was condition x time interaction for the blood lactate concentration ($p < 0.001$). The blood lactate concentration increased ($P < 0.001$) from pre- to post-running feedback (1.54 ± 0.53 vs. 9.34 ± 2.66 mmol) and non-feedback conditions (1.68 ± 0.71 vs. 6.33 ± 2.45 mmol). In addition, the blood lactate concentration at post-feedback condition was greater (32%) than at post-non-feedback condition ($p < 0.001$).

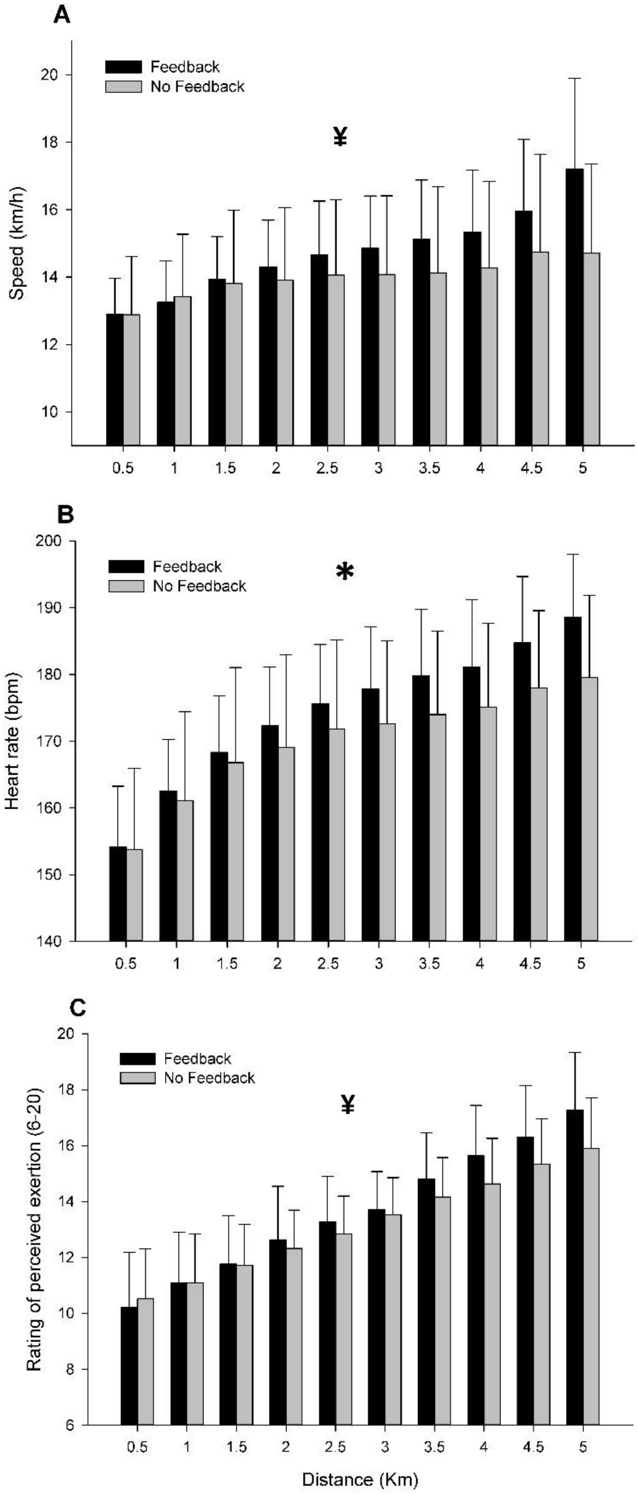


Figure 9

Mean and standard deviation of the speed (A), heart rate (B) and rating of perceived exertion (C) during the 5 km running trials at feedback and non-feedback conditions.¥ Significant condition x distance interaction; *significant main distance effect.

The 30 min cycling experiment

There was condition x time interaction for power output ($p < 0.001$), heart rate ($p = 0.003$) and RPE ($p = 0.01$). The results of these variables are presented on figure 10. In addition, there was condition x time interaction for the RMS of the VL ($p = 0.007$) and BF muscles ($p = 0.01$) (figure 10).

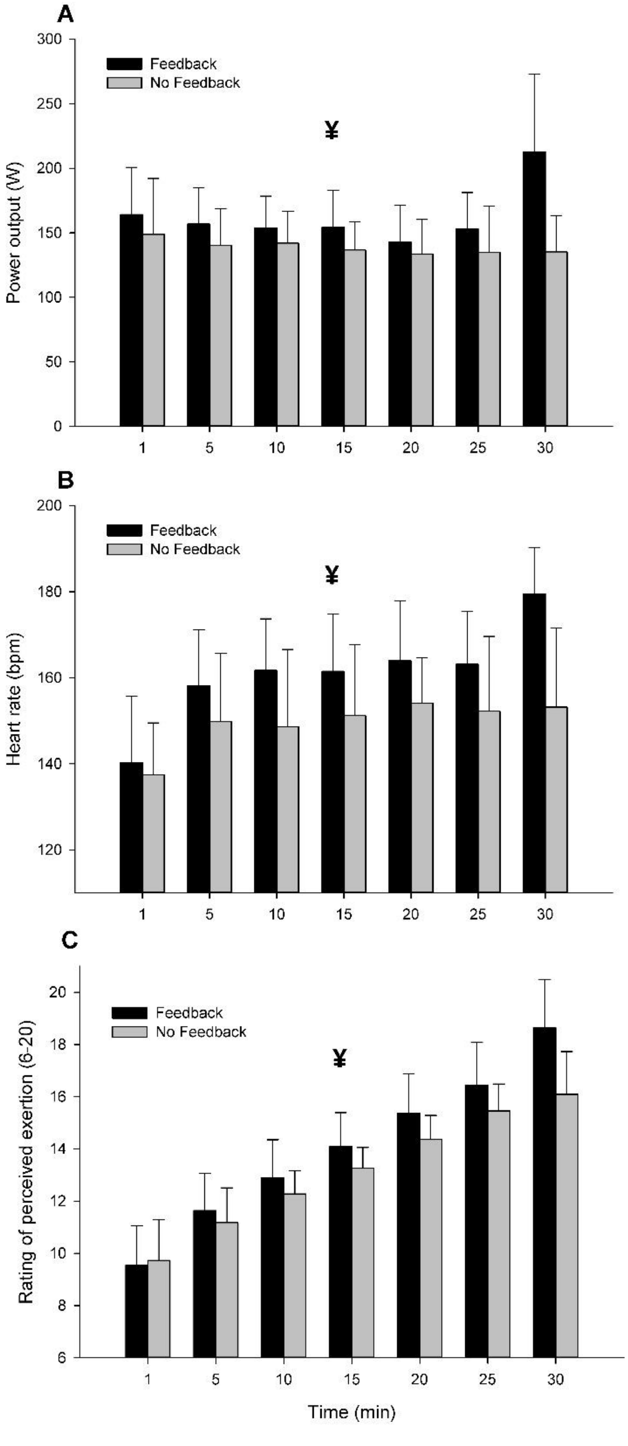


Figure 10

Mean and standard deviation of the power output (A), heart rate (B) and rating of perceived exertion (C) during the 30 min trials at feedback and non-feedback conditions. ¥ Significant condition x time interaction.

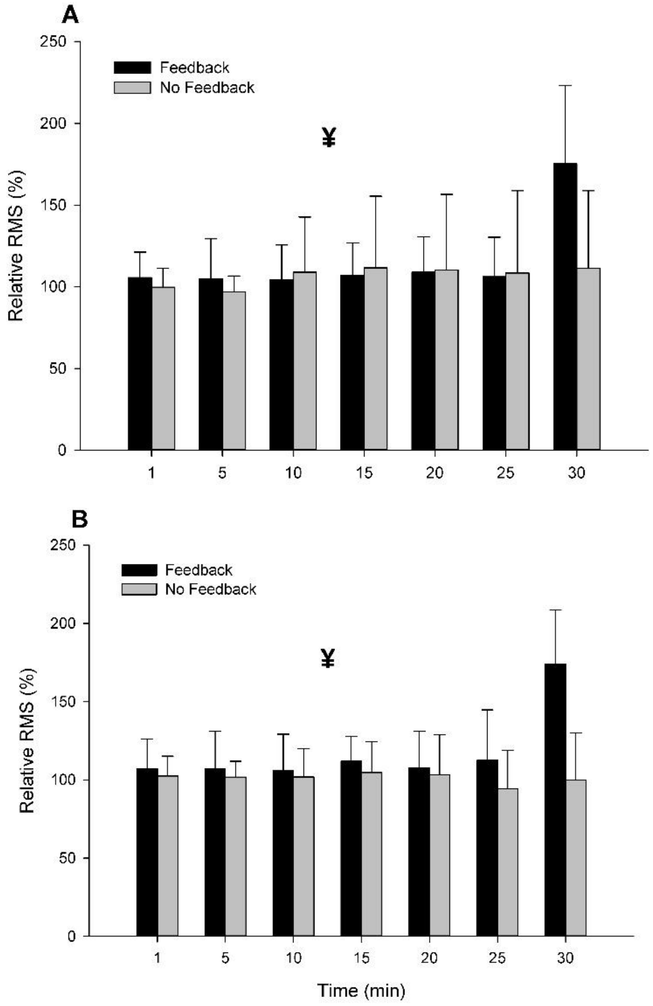


Figure 11

Mean and standard deviation of the root mean square relative to the first 30 s of exercise for vastus lateralis (A) and biceps femoris (B) during the 30 min cycling trials at feedback and non-feedback conditions. ¥ Significant condition x time interaction.

Discussion

It was hypothesized that conscious feedback about time and distance has a significant effect on pacing strategy and performance during closed-loop task. Both experiments (5 km running and 30 min cycling trials) confirmed the validity of this hypothesis on the basis of the end-spurt occurrence at the final stages of the exercise with conscious feedback, with end-spurt absence in non-feedback condition, and in view of the greater performance in feedback condition compared with non-feedback.

The pacing strategy chosen by the participant during the exercise influences the performance success (Abbiss and Laursen, 2008). Most participants choose a slightly conservative pace because it is difficult to accurately predict at the beginning of the race how perception of effort will develop during a closed-loop task (Marcora, 2010). Such a conservative pace could be observed in both 5 km running and 30 min cycling experiments. On the other hand, differences in pacing strategies were influenced by the presence or absence of conscious feedback, despite the exercise mode. Receiving conscious feedback, the participants ran faster after reaching 70% of the completion time. In similar conditions, participants cycled faster during the whole trial compared with the non-feedback one. In both experiments, end-spurt phenomena could be observed, i.e., great acceleration, in the presence of conscious feedback only, during the closing stages of the race (Koning, 2011). Furthermore, the performance with conscious feedback was greater than in non-feedback condition in both 5 km running (6%) and 30 min cycling (5%) experiments. These results clearly show the key role of the conscious feedback in the pacing strategy and endurance performance.

One may ask why the conscious feedback had changed the pacing strategy. The answer is straightforward: as the participants adopted a conservative pace in the early stages of the trial, when they approach the end of the trial and predictions become more reliable, athletes know they can increase velocity/power output without risking premature exhaustion (Marcora, 2010). The participants knew that the end of the trial was near because of the conscious feedback, thereby performing the end-spurt. However, if they did not know that the end of the trial was near (non-feedback condition), the participants maintained the conservative pacing strategy adopted in the early stages of the trial until the end of the exercise. These results refute the Central Governor theory that postulates the existence of an internal clock in the subconscious brain regulating the muscle recruitment and pacing strategy during closed-loop task (St Clair Gibson, 2006). If such an internal clock did exist as postulated by St Clair, the participants in our experiment should have adopted similar pacing strategies with similar performances in both feedback and non-feedback conditions. This, however, was not observed in the experiments.

Recent studies have proposed that conscious feedback is not necessary to determine the pacing strategy and performance (Mauger et al., 2009; 2012). However, these studies were not properly designed to check the influence of conscious feedback on these parameters. The non-feedback trials were accompanied by the absence of a known endpoint. As known endpoint is another important parameter to determine pacing strategy (Chinnasamy et al., 2013; Marcora, 2010), its absence could interfere in the pacing strategy and performance. In addition, Albertus et al. (2005) have suggested that inaccurate distance feedback during 20 km time trials did not affect pacing strategy and performance when compared with accurate distance feedback trial. However, it is not possible to infer that conscious feedback is not required for pacing, because there was distance feedback throughout the whole exercise, although inaccurate.

However, in a recent study, school children that received time feedback, after performing a control 750 m running trial in a track, obtained overall lower performance compared with the group that received distance feedback (Chinnasamy et al., 2013). Different performance between groups was attributed to the end-spurt suppression at the final 20% of the time trial feedback, i.e., lower running speed. These results can be explained by the necessity of a conscious feedback and perception of effort during the exercise. Koning et al. (2011) integrated the velocity and perception of effort data of nine separate experiments, in which either cyclists or runners completed competitive simulations in the laboratory, in events that required from 4 to 60 minutes. The results indicated that the pacing strategy during high-intensity exercise performance is actively regulated, and this accounts for conscious feedback and perception of effort (Koning et al., 2011).

Perception of effort, potential motivation, knowledge of the endpoint, conscious feedback and previous experience with the motor task are five main cognitive/motivational factors that determine endurance performance (Marcora, 2010). In the present study, the participants were familiarised with the motor task prior to the feedback manipulation. In addition, they were advised about the endpoint prior to every trial. Finally, we have artificially increased the motivation of each participants by offering monetary reward for the best cycling and running performance, which depended on both feedback and non-feedback trials.

Then, such manipulation allowed checking the influence of conscious feedback on pacing strategy and performance. The participants used a conservative pace to produce overall lower velocity and power output, which lead to a lower performance in a non-feedback trial if compared with feedback trials. Participants in the non-feedback trial had a lower heart rate, muscle activity and perception of effort. However, according to the Central Governor theory, such results should not have occurred due to the fact that participants had set an appropriate pacing strategy at the start of the event. This strategy would allow them to achieve optimal performance, and to reach the end of the event without catastrophic failures occurring in any physiological system, regardless of conscious feedback (St Clair Gibson et al., 2006). Therefore, the worst pacing strategy and endurance performance in the non-feedback trial compared with the feedback trial may lead the reader to choose one of the following conclusions about the internal clock: its inexistence or its inefficiency to control pacing strategy and endurance performance. Furthermore, the reader may accept that conscious feedback is required to optimize the endurance performance, as previously postulated by the psychobiological model.

The end-spurt is considered by the psychobiological model as an effort-based decision-making process of performance. Indeed, in any task the effort required to complete may increase if subjects know that the task is about to finish. The psychological mechanism behind this behaviour could suggest that the pacing strategy is no longer needed toward the completion of the task, so that participants may decide to switch to an all-out strategy approaching the end of the race (Marcora, 2008; 2013).

Further studies may look at the effect of time/distance feedback on Elite Athletes. It may be possible that high skilled Athletes may have an increased time/distance perception and be able to pace themselves better than untrained subjects even without feedback and probably they would produce also an end-spurt at the end of test. However, feedback may still produce better outcomes compared to non-feedback even in elite Athletes. If we asked untrained participants to do an end-spurt during a non-feedback time trial test they would probably burn themselves by increasing speed too early, and their performance would result too conservative as previously shown in this chapter.

Conclusion

In conclusion, this study demonstrated that conscious feedback about time (during 30 min cycling trial) and distance (during 5 km running trials) has a key role in pacing strategy and performance during closed-loop task. These findings validate the psychobiological model by Marcora and colleagues (2008, 2009 and 2010), which postulates that feedback of time and distance is one of the five factors that athletes use to find the effective pacing strategy and which has been shown to be a crucial factor for competitors to achieve an optimal performance. On the contrary, the lack of end-spurt and the perceptual and physiological results in this study invalidate the central governor model proposed by Noakes and colleagues (2012), which, instead, postulates the existence of an internal clock regulating the pacing strategy. The lack of end-spurt in the non-feedback trial disproves the existence of such clock.

CHAPTER 5

THE RIGHT TIME TO ENCOURAGE: THE EFFECTS OF VERBAL ENCOURAGEMENT DURING DIFFERENT PHASES OF A 30 MIN CYCLING TIME TRIAL

Introduction

Endurance performance and its determinants has always been of interests for sport scientists, in particular for aspects related to musculo-energetic factors which have dominated the research in this field for many years (Joyner and Coyle, 2008). However, recently, an increased interest in psychological and psychobiological factors affecting endurance performance has moved the attention of sport scientists towards central and psychobiological mechanisms of fatigue (Marcora et al., 2009; Noakes, 2012).

Marcora and colleagues (2008, 2009, and 2010) have recently proposed a new model of endurance performance: The psychobiological model. This model is based on the idea that exhaustion is caused by the conscious decision of the individual to terminate the exercise and not directly by cardiorespiratory and musculo-energetic variables. An individual will terminate endurance exercise either when the effort required to complete the task exceeds the highest amount of effort that the individual is willing to exert during the task (potential motivation), or when the effort is considered maximal and the continuation of the task is perceived as impossible (Marcora et al., 2008, 2009; Marcora and Staiano, 2010).

According to this psychobiological model, effort, defined as conscious sensation of how hard, heavy and strenuous exercise is (Marcora, 2010) is the key determinant of prolonged physical performance and as such, any intervention affecting perception of effort will lead to a change in performance either positively or negatively. Potential motivation instead is the maximum effort an individual would be willing to exert in a physical task. Manipulations of potential motivation have involved social facilitation (Corbett et al. 2012), monetary reward (Cabanac, 1986) and verbal encouragement (McNair et all., 1996) in order to change performance.

Verbal encouragement refers to the use of encouraging words as extrinsic motivation during physical exercise in order to motivate subjects to push as much as they can. The importance of verbal encouragements is widely recognized and encouragements are always used during competitions. In addition, encouraging has always been a method by which researchers to could push their participants to perform at their best during maximal exercise testing. Maximal exercise testing is a standardised procedure and a key component in the research of exercise performance and allows scientists to measure the positive and negative effects of a determined treatment on physical exercise (Andreacci et al., 2002). Therefore, it is of crucial importance that such measurement is as accurate as possible and reflects the maximal performance of the participants involved in the physical exercise.

Many Researchers often provide verbal encouragement during maximal tests such as VO_{2max} tests, time trials and TTE tasks to encourage their participants to exert as much as they can. Research has supported this decision and has demonstrated that offering verbal encouragement can lead to higher oxygen uptake, time to exhaustion and peak power output values in untrained runners (Chitwood et al., 1997; Moffatt et al., 1994; Andreacci et al., 2002). Moreover, in a recent study, Blanchfield and colleagues (2013) they demonstrated the efficacy of motivational self-talk strategy (i.e. internal motivating speech) in improving a time to exhaustion (TTE) task by reducing rating of perception of effort (RPE). It is unclear the mechanisms of verbal encouragement in increasing motivation, however Blanchfiled and colleagues (2013) showed a significant effect on performance by altering RPE.

A possible mechanism to explain this may that verbal encouragements distract athletes from unpleasant discomfort due primarily to high levels of effort (Scott, 1999). It can be suggested that encouragement acts as a dissociative strategy such as listening to music or watching a video (Scott, 1999). Moreover, the statements used to encourage can be interpreted as positive reinforcement to keep high levels of effort and may affect the perceived ability of the subjects engaging in a physical task (Blanchfield et al. 2013).

Andreacci et al. (2002) recognised that earlier studies (Chitwood et al., 1997; Moffatt et al., 1994) did not provide details about the type, duration, or temporal distribution of the encouraging statements and described a replicable procedure for offering verbal encouragement. In this study, Andreacci and colleagues (2002) compared the effect of providing participants with either no verbal encouragement or five seconds of verbal encouragement and clapping that was delivered every 20, 60, or 180 s. Verbal encouragement that was delivered frequently (every 20 s or every 60 s) lead to significantly higher VO_{2max} values than when either no encouragement was given or when the encouragement was infrequent (i.e. every 180 s). Although Andreacci provides a valid procedure describing the frequency of the encouraging words to be used, there is no study up to date researching the effect of encouraging words provided at different phases of a physical task (i.e. beginning or near the end of exercise).

Based on the results of Blanchfield and colleagues (2013), the aim of this study was to test the hypothesis that using verbal encouragement in different phases of a 30 min time trial performance will produce significant effect on RPE. We tested how encouraging manipulation affects RPE in four different scenarios: during the first 15 min and in the last 15 min of the time trial, throughout the entire time trial or in cases where encouragements were not provided at all. We hypostasized that verbal encouraging would decrease participant’s RPE during the 30 min time trial if this occurred during the last 15 min of the time trial, and that it would produce a negative effect on RPE and pace if delivered in the first 15 min.

Methods

Subjects and Ethical Issues

Ten eligible subjects [8 men and 2 women; mean ± SD, age 28 ± 2 yr, height 173 ± 8 cm, weight 72 ± 9 kg, peak power output 228 ± 50 W, peak oxygen uptake ($\dot{V}$O2peak) 42 ± 7 ml·kg−1·min^{-1}] signed an informed consent form describing the study protocol, which was approved by the Ethics Committee of the School of Sport and Exercise Sciences (University of Kent) according to the standards set by the Declaration of Helsinki. Eligibility criteria were being between 18 and 44 yr old, being involved in regular physical activity, being free of any known illness, and not taking any medication with the exception of contraceptives.

Study Design and Procedures

For this study, we employed a single-blind, randomized, crossover experimental design. Subjects visited laboratory 6 times. During the first visit, a preliminary incremental exercise test (2 min at 50 W + 50 W increments every 2 min) was performed until exhaustion [operationally defined as a pedal frequency of less than 60 revolutions/min (RPM) for more than 5 s despite strong verbal encouragement] on an electromagnetically braked cycle ergometer (Corival, Lode, Groningen, The Netherlands) to measure $\dot{V}O_{2peak}$. The cycle ergometer was set in hyperbolic mode, which allowed the power output to be set independently of pedal frequency over the range of 30–120 RPM. Subjects were also given standard instructions for overall rating of perceived exertion (RPE) using the 15-point scale developed by Borg (1998).

During the second visit, a familiarization time trial was performed by subjects in order to avoid any learning effect. The visit 3, 4, 5 and 6 were the main visits in which participants completed a 30 min time trial.

All subjects were given written instructions to drink 35 ml of water per kilogram of body weight, sleep for at least 7 h, refrain from the consumption of alcohol, and avoid any vigorous exercise the day before each visit. Participants were also instructed to avoid any caffeine and nicotine for at least 3 h before testing. Environmental conditions in the laboratory were kept between 18 and 22°C for temperature and 45 and 60% for humidity.

Time Trial

All time trials (TT) were performed on the Velotron Racermate™ cycle ergometer (USA). Participants completed a standardised warm up of 5 minutes cycling at 40% of the peak power output calculated from the first visit. After the warm-up they completed 30 min of self-paced cycling where the aim was to achieve the greatest distance possible. Participants completed this on 5 separate occasions. The first was a familiarization session while the remaining 4 were the main visits. Distance covered was kept secret to participants who were only informed of the time remaining.

Treatment

During the 4 main visits the treatment, which consisted in verbally encouraging the participants, was applied. In a randomized order, participants to the TT received no verbal encouragement at all (NoVE), verbal encouragement throughout the time trial (AllVE), during the first 15 min of the TT (VE0-15) and during the last 15 min of the TT (VE15-30). Verbal encouragement consisted in a set of encouraging statements read from a prepared sheet, such as “Come on!”, “Keep pushing!”, “Keep it up!”, “Let’s go!” The volume of encouragement was kept as constant as possible and hand clapping was also performed during the encouragement. Each verbal encouragement lasted 5 s and the frequency of the verbal encouragement was every 20 s. As Andreacci et al. (2002) suggest, this frequency guarantees the most effective encouragement.

The motivator responsible of providing verbal encouragement was completely blind to the purpose of the study.

Physiological and Perceptual Response to Exercise

Distance covered (m), cadence (rpm) and Heart rate (beats·min-1) were recorded at the first minute, at the end of minute 5, 10, 15, 20, 25 and finally at the end of minute 30.Speed was recorded as average of every 5 minutes at 5, 10, 15, 20, 25 and 30. At rest, at minute 15 and at the end of minute 30 a 5-μl sample of blood was taken from the finger on the right hand and analysed for lactate concentration (mmol/l) using a portable analyzer (Lactate Pro LT-1710, Arkray, Shiga, Japan). During the final 15 s of min1, 5, 10, 15, 20, 25 and 30 of the TT, participants were asked to rate how heavy and strenuous the exercise felt on a large RPE scale displayed in front of them throughout the cycling test. This scale ranges from 6 (no exertion at all) through 13 (somewhat hard) to 20 (maximal exertion).

Psychological Questionnaires

Mood

The Brunel Mood Scale (BRUMS) was used to assess mood before each time trial. This profile of mood states has been validated by Terry and colleagues (2003). This mood questionnaire includes six subscales (anger, confusion, depression, fatigue, tension, and vigour) with four items per subscale. Items were answered on a 5-point Likert type scale (0 = not at all, 1 = a little, 2 = moderately, 3 = quite a bit, 4 = extremely). Participants filled up the questionnaire upon arrival in the laboratory before commencing the time trial session.

Motivation.

Motivation related to the time trial tests was measured using the success motivation and intrinsic motivation scales developed and validated by Matthews et al. (2001). Each scale consists of 7 items (e.g., “I want to succeed on the task” and “I am concerned about not doing as well as I can”) scored on a 5-point Likert scale (0 = not at all, 1 = a little bit, 2 = somewhat, 3 = very much, 4 = extremely). Participants filled up the questionnaire upon arrival in the laboratory before commencing the time trial session. A cash prize of £ 50 was offered for the best performance in order to keep participants motivated to do their best.

Statistical Analysis

All data are presented as means ± SD. Normal distribution and sphericity of the data were checked. The Greenhouse-Geisser adjustment was made to the degrees of freedom when violations of sphericity occurred. In the 30 min cycling TT, two-way (4x6) ANOVAs for repeated measures, having condition (verbal encouragement) and time factors (5, 10, 15, 20, 25, 30 min), were performed to speed and heart rate. Two-way (4x5) ANOVAs for repeated measures, having condition (verbal encouragement) and time factors (5, 10, 15, 20, 25 min), were performed for RPE dependent variable. A two-way (4x3) ANOVA for repeated measures, having condition (verbal encouragement) and time factors (pre-test, at min 15 and post exercise), was performed to the blood lactate concentration variable. A one-way ANOVA for repeated measures was using to assess motivation, speed, HR at the first minute and RPE at the first minute and at exhaustion at the 30th minute. Significance was set at 0.05 (2-tailed) for all analyses, which were conducted using the Statistical Package for the Social Sciences, version 18. Power analyses have been conducted based on a two-way repeated measure ANOVA with 4 groups, with an alpha error probability of .05 and a power of 0.80.

Results

Manipulation Check

Success motivation (*p* = 0.724) and intrinsic motivation (*p* = 0.431) did not differ significantly among all trials. Such results suggest that participants were similarly motivated before commencing every time trial. Similar non-significant results have been found for all mood subscales of the BRUMS questionnaire, which demonstrates that participants showed a similar mood state before each TT.

Physiological measures

Results of the 4 x 3 repeated measures ANOVA for blood lactate concentration showed a significant interaction condition by time (*p*= 0.036). As shown in figure 12 blood lactate concentration does not differ at baseline and at the end of the TT, however simple main effects of condition showed a significant difference (p= 0.03) among conditions at min 15, where subjects in the VE0-15 showed an higher lactate concentration compared to the other 3 conditions.

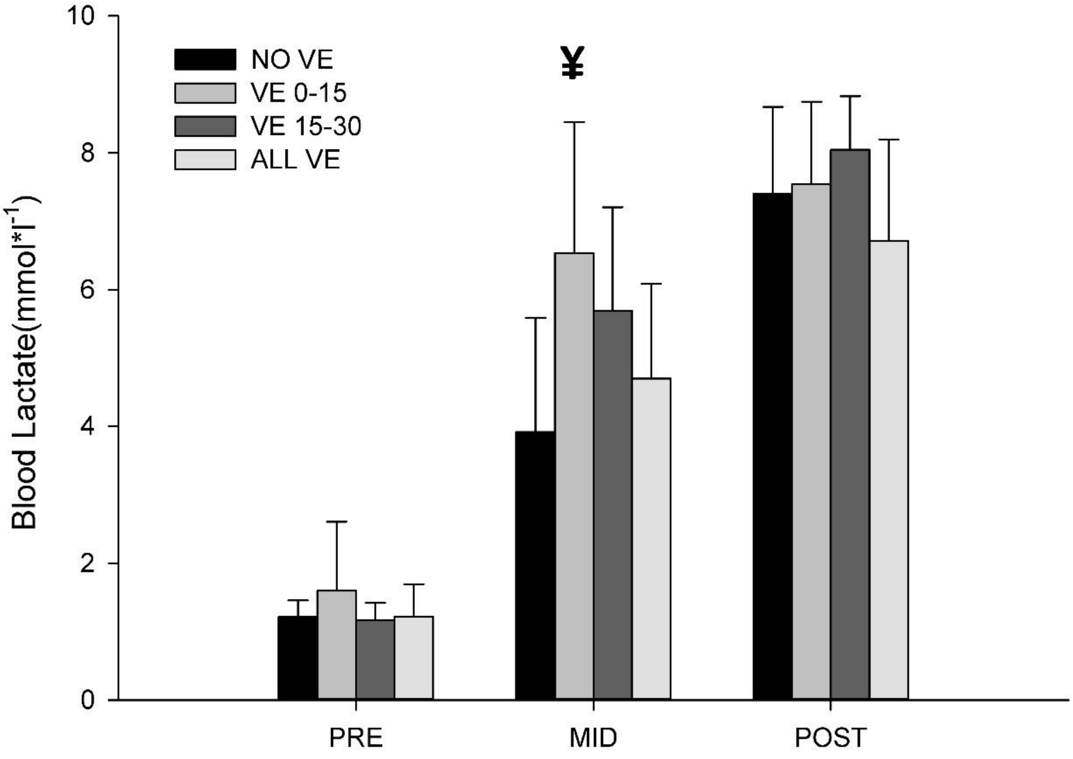


Figure 12

Blood Lactate concentration measured at pre, at the end of the 15 min and at exhaustion during the 30 min time trial for the four conditions: no verbal encouragement (NoVE), Verbal encouragement in the first 15 min (VE 0-15), Verbal encouragement in the last 15 min (VE 15-30) and verbal encouragement all over (AllVE). Data are presented as mean ± SD. ¥ represents Trial x Distance interaction.

Two-way repeated measures ANOVA for HR showed a significant interaction Condition by Time (p= 0.032). Data in Figure 13 showed that HR increased over time, however simple main effects of condition showed that HR in the NoVE condition is significant lower than in the other conditions. NoVE and AllVE showed a similar trend although AllVE presented higher values for each time point. VE 0-15 instead showed an increased HR in the first 15 min, which consequently dropped in the second half the TT, while VE15-30 showed an opposite trend with an increase in the second half of the TT. Simple main effects of time in all conditions showed an increase in HR towards the end of the TT during the last 5 min as result of the end-spurt phenomenon.

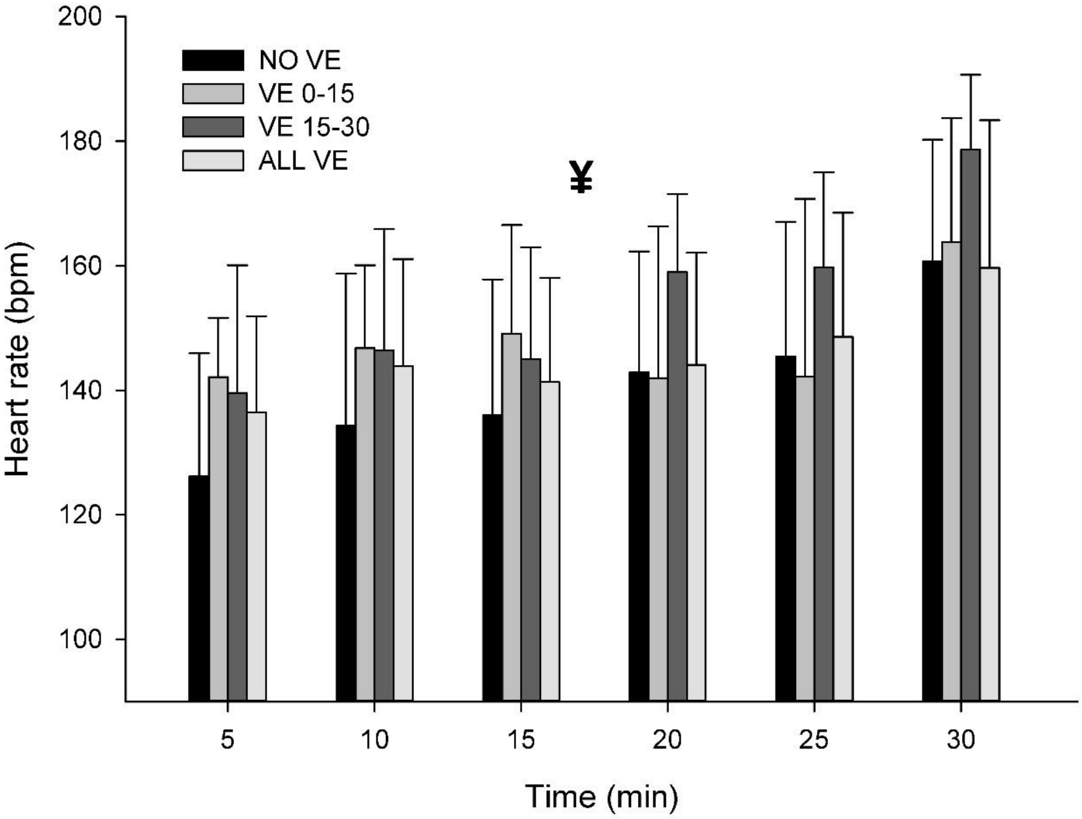


Figure 13

Heart rate measured in the last 15 s of min 5, 10, 15, 20, 25 and 30 during the 30 min time trial for the four conditions: no verbal encouragement (NoVE), Verbal encouragement in the first 15 min (VE 0-15), Verbal encouragement in the last 15 min (VE 15-30) and verbal encouragement all over (AllVE). Data are presented as mean ± SD. ¥ represents Condition x Time interaction.

Two-way repeated measures ANOVA for speed Figure 14 showed a significant interaction Condition x Time (p= 0.012). Simple main effects of condition showed that speed seems to follow a similar trend between the NoVE and the AllVE, while an opposite trend is observed when comparing the VE0-15 to the VE15-30. Speed increased in the second half of the TT in the VE15-30 phase and decreased in the VE0-15 during the second half of the TT probably as result of cessation of verbal encouragement.

One-way repeated ANOVA for speed, HR showed no significant difference among conditions. (p= 0.141 and p= 0.110 respectively).

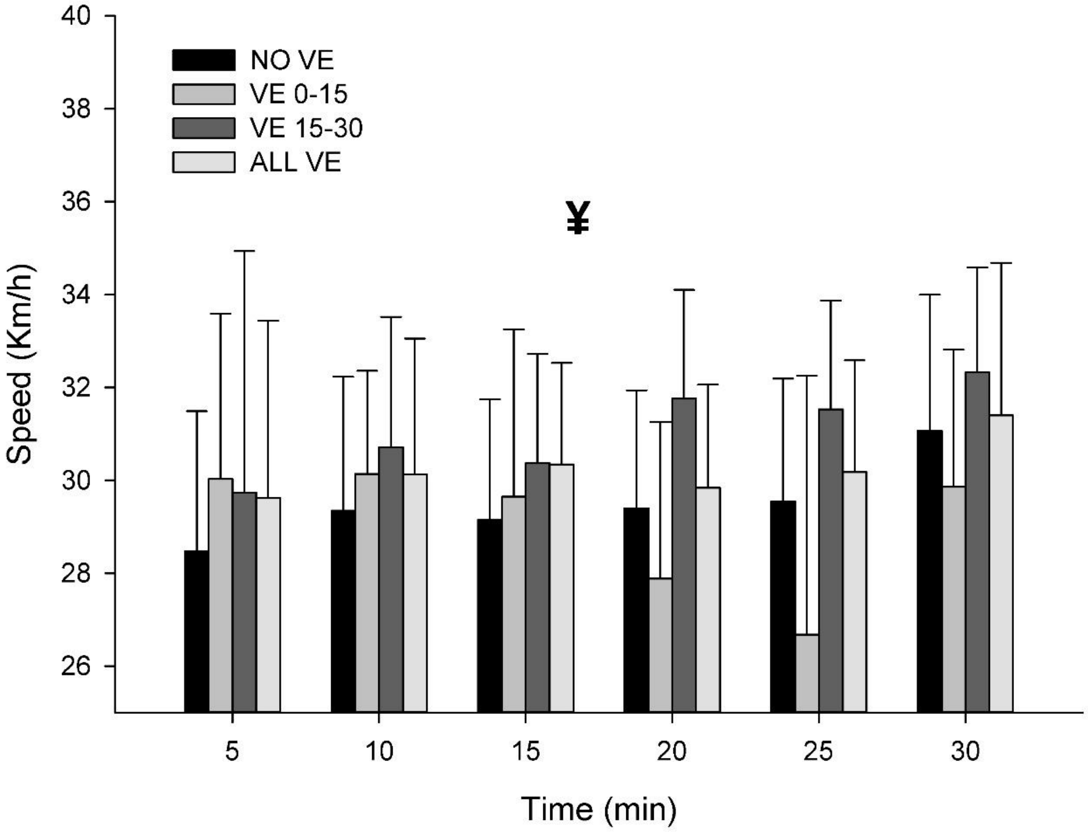


Figure 14

Speed measured as average of minutes 0 to 5, 6 to 10, 11 to15, 16 to 20, 21 to 25 and 26 to 30 during the 30 min time trial for the four conditions: no verbal encouragement (NoVE), Verbal encouragement in the first 15 min (VE 0-15), Verbal encouragement in the last 15 min (VE 15-30) and verbal encouragement all over (AllVE). Data are presented as mean ± SD. ¥ represents Condition x Time interaction.

One-way repeated measure ANOVA for total distance showed a significant difference for conditions (*p*= 0.004). Participants during the VE15-30 trial covered more distance compared to the rest of the trials. When encouraged during the first 15 min, participants covered the shortest distance (Table 3).

Condition	Distance (m)	SD
1 NoVE*	14638	1241
2 VE0-15a	14343	1010
3 VE15-30b	15433	1150
4 AllVEAc	14997	1272
P= 0.004 *= trend in the difference from condition 2 a= significant different from condition 3 and 4 b= significant different from condition 2 c= significant different from condition 2		

Table 3

Total distance covered by participants for every single condition. Data are presented as mean ± SD. P-value represents significant difference among conditions.

RPE measure

Two-way repeated measures ANOVA for RPE showed a significant interaction Condition x Time (*p*= 0.042). RPE increased over time; however, it showed significant single main effects of condition. It increased constantly in the No VE condition. An opposite trend is observed in the VE15-30 in which RPE increased in the second half of the TT. In the VE 0-15 phase and in the AllVE, a decreased in RPE is observed from the first haf to the second half of the TT (Fig. 15).

One-way repeated ANOVA for RPE at exhaustion showed no significant difference among trials (*p* = 0.103).

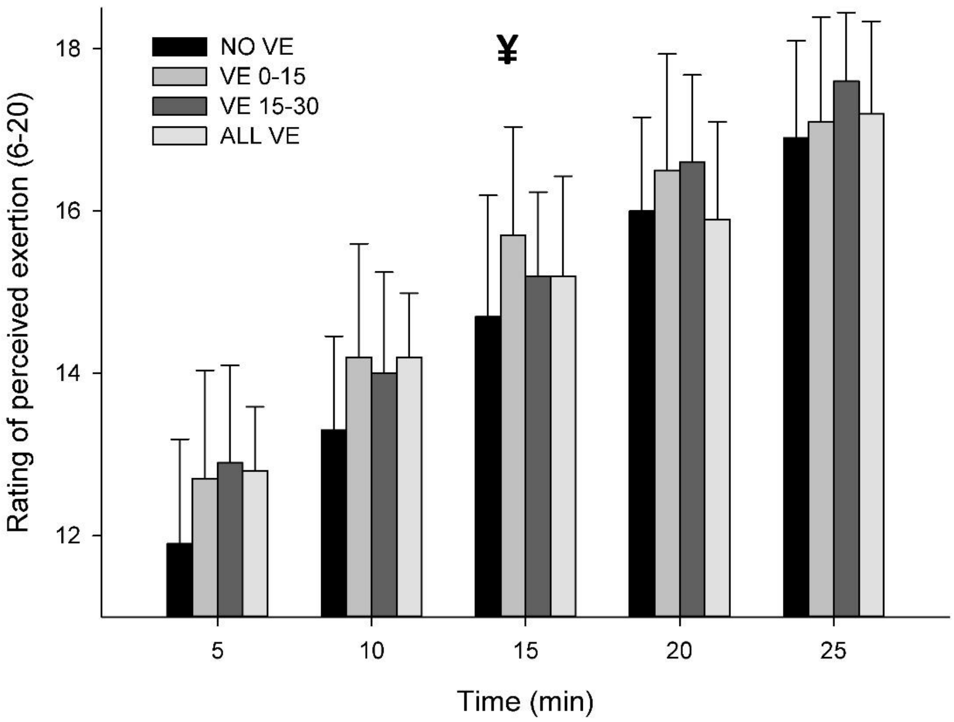


Figure 15

RPE measured in the last 15 s of minute 5, 10, 15, 20 and 25 during the 30 min time trial for the four conditions: no verbal encouragement (NoVE), Verbal encouragement in the first 15 min (VE 0-15), Verbal encouragement in the last 15 min (VE 15-30) and verbal encouragement all over (AllVE). Data are presented as mean ± SD. ¥ represents Condition x Time interaction.

Discussion

This study investigated the effect of verbal encouragement given during different phases of a 30 min TT performance on pacing and pacing strategy. As we hypothesized that verbal encouraging alters the pace of participants if provided in different moments of the competition. Specifically, we have demonstrated that verbal encouragement given in the first 15 min of a TT will lead to a positive pacing strategy, which consists in starting fast and gradually decreasing speed. On the contrary, when verbal encouragement was provided during the last 15 min a more negative pacing was employed with a slow start and increasing speed over the duration of the event. When verbal encouragement was provided throughout the duration of the TT or not provided at all, a more even pacing strategy was used by participants. In all conditions it has been reported a change in speed during the last 5 min which can be due to the end-spurt phenomenon. Changes observed in pacing strategy lead to a significant variation of other parameters, such as speed, HR, Blood lactate concentration, RPE and more importantly distance covered. This study is the first to demonstrate that verbal encouragement provided in different moments in a competition may produce alteration in pacing strategies and thus in performance.

Blood lactate concentration measured in the middle of the test at minute 15 showed higher concentration in the VE0-15 trial compared to the remaining 3 trials. This is in line with previous studies showing that individuals using a positive pacing strategy (i.e. fast start and slow decrease through the race) will result in an increased VO_2, increased RPE and greater accumulation of fatigue related metabolites during the early stages of an exercise task (Abbiss and Laursen, 2008). Similar results were reported for HR as well. When verbal encouragement was provided in the first 15 min (VE 0-15) a higher HR has been observed compared to the VE 15-30 condition, which instead reported a higher HR during the last 15 min of the time trial.

Speed has shown a similar trend. When verbal encouragement was provided in the first 15 min (VE 0-15) a higher speed was observed compared to the VE 15-30 condition, where, instead, a higher speed was reported during the last 15 min of the time trial. Pacing strategy remained the same during the NoVE and AllVE conditions, although the AllVE condition showed a significant greater pace compared to NoVE.

These results suggest that verbal encouraging in the first half of the trial, and in particular in the VE 0-15 condition, may have caused an accentuated muscle fatigue with subsequent accumulation of metabolites. They may also have caused the increase of RPE in the first 15 min of the trial and a drop in the observed speed in the second half of the trial. As a psychological explanation for these results, stopping the verbal encouragement in the second half may have caused a deterioration of the performance. Indeed, when we compare the VE 0-15 condition with the AllVE one there is a significant difference in the distance covered, as the AllVE condition is higher. Such result may suggest how encouraging athletes throughout the competition had a more positive effect than when encouragements stopped at minute 15.

The distance covered resulted higher in the trial where encouragements were provided in the last 15 min compared to the trial where encouragements were used during the first 15 min. No difference has been detected between the AllVE and the VE 15-30 although a trend is present (p= 0.07). Such findings suggest that encouraging throughout a competition or only at the end can be more effective than encouraging at the beginning or not at all.

It can be speculated that potential motivation has been affected by verbal encouragement in VE 0-15 condition to drop as soon as the verbal encouragement was interrupted. However, motivation has been measured prior to exercise only, we do not possess any retroactive measure, such as a questionnaire, to assess the motivation and perception of participants in terms of effectiveness of verbal encouragement and to know in which time trial they perceived themselves more effective or motivated in completing the TT. Indeed, previous psychophysiological studies have demonstrated how by altering perceived ability it is possible to alter the effort exerted (Silvestrini & Gendolla, 2007; Wright, 2008). In particular, if individuals perceive themselves more able and skilled in completing a task they will be willing to exert more effort to successfully complete the task. Therefore it may be plausible that verbal encouragements provided at the right time of a physical task may increase the self-efficacy and the perceived ability as Blanchfield and colleagues (2013) suggest as well.

Another explanation for the shortest performance shown in the time trial where verbal encouragement was provided in the first 15 min may be due to the ability of the subjects to pace themselves properly over 30 min. In this case performance may have been affected by the encouragement in the first half of the trial, which pushed subjects to go too fast in the first half. This fast start produced an anticipated exhaustion and thus a negative effect on the overall performance. A trend between the No VE and VE 0-15 suggests that encouraging in the first 15 min produced a higher negative impact compared to no verbal encouragement at all. A possible explanation can be that encouraging participants in the first half disrupted the ability of subjects to properly pace themselves and it drastically decreased the performance in the second half of the time trial. Blood lactate, HR and Lactate were significantly higher at min 15 compared with the other time trials, which would support such a theory.

Although we were unable to measure potential motivation, a significant difference has been found in RPE, which was altered when verbal encouraging was provided in either the first 15 min or at the end. Those results are in line with the ones obtained by Blanchfield and colleagues (2013), who found a significant difference in RPE in subjects using motivational self-talk compared to the control group that did not.

Changing in distance covered and thus in performance shown in the present study, in addition to the end-spurt phenomenon observed in all trials due to a rapid change in speed, HR and RPE cannot be explained using traditional muscle and cardiorespiratory mechanisms. Moreover, even more prominent models such as the central governor model (Noakes, 2000, 2012; Noakes et al. 2005) that emphasize the importance of central mechanisms based of an afferent feedback system subconsciously limiting performance, could not explain such difference in performance as found in our results and due to a solely psychological intervention such as verbal encouragement. Verbal encouragement would very unlikely cause alteration in the periphery to produce a change in the afferent feedback.

However the psychobiological model proposed by Marcora and colleagues (2008, 2009 and 2010) can provide a valid explanation to the change of speed and thus of performance. Self-regulation of speed-power during a TT is determined mainly by 5 psychological factors: RPE, potential motivation, memory of perception of effort during previous exercise of different intensities and durations, knowledge of total distance/duration to cover, knowledge of the distance/duration covered remaining. Because verbal encouragement has shown to alter RPE, individuals will adjust their pace (i.e. speed/power) based on the RPE in order to complete the TT without reaching premature exhaustion.

It is noteworthy to discuss some limitation of this study. The significant alterations of physiological measures such as HR and blood lactate concentration due to verbal encouragement were expected as we used a pool of participants who were not highly trained. Those findings are supported by a previous study by Mofatt et al. (1994) that compared trained vs. non-trained subjects and showed a higher variation of physiological variables due to verbal encouragement in the not well trained individuals compared to trained athletes. Although at first glance results in this study may suggest that verbal encouragement seems to be more effective when delivered near the end of the competition, there are some confounding effects due to the level of experience in doing TT of the participants. It is plausible that inexperienced cyclists may have been misled by the encouragement in the early stages of the TT pushing themselves at an unrealistically pace in the first half of the race and drastically reducing the speed in the second half, as also reported by our results of speed and HR. Nevertheless, most of the subjects reported an inability to focus on the task and the pacing strategy to use if encouragement was given during the first minutes of the trial. It may be interesting for future research to test the effect of verbal encouragement using subjects with different level of training or previous experience of this type of task.

Another major limitation regards the inability to measure potential motivation in this study. Indeed, all the time trials ended with maximal RPE so we may expect potential motivation to have been really high in all tests, despite our inability to measure it.

Conclusion

In conclusion this study was the first study to investigate the impact of verbal encouragement provided at different phases during a 30 min TT. We have provided new insights in the role of verbal encouragement in relation with RPE and we suggested the most suitable time when this should be employed. Moreover, we further proved the psychobiological model of endurance performance (Marcora, 2010) as valid model to explain alterations in self-regulating speed/power due to psychological interventions such as verbal encouragement. Any psychological and physiological intervention influencing RPE will lead to a change in physical performance expressed as changing in pacing and/or increased of speed/power during the TT.

CHAPTER 6

GENERAL DISCUSSION

The aim of this general discussion is to summarize and compare the main findings across all four studies with reference to both the psychobiological model and the central governor model of pacing regulation. We will also discuss the limitations of the present research program and suggest directions for future research.

Psychobiological model

As previously stated, according to the psychobiological model of exercise performance, self-regulation of speed/power output during time trials is conscious and determined principally by five psychological factors: (1) perception of effort; (2) potential motivation; (3) knowledge of the distance/duration to cover; (4) knowledge of the distance/duration covered/remaining, and (5) previous experience/memory of perceived exertion during exercise of varying intensity and duration (Marcora, 2010). In Chapter 2 we elucidated the influence of $VO_{2\ max}$ on perception of effort (defined as the psychophysical relationship between speed and RPE), pace and pacing strategy during a 30 min running time trial. In Chapter 3 we discussed the effect of knowledge of the distance to cover and memory of previous experience on pacing, pacing strategy and thus on performance during a 5 km running time trial. In Chapter 4 we assessed the effect of the knowledge of distance/time remaining on pacing strategy by using a 5 km time trial to account for knowledge of distance and a 30 min cycling time trial to account for knowledge of time remaining. Finally, in Chapter 5 we analysed the effect of motivational verbal encouragement provided at different times during a 30 min cycling time trial.

The outcomes of the studies conducted in each single chapter are in line with the predictions of the psychobiological model for the regulation of speed/power in a time trial exercise. The studies' results suggest that perception of effort, knowledge of the distance/duration to cover; knowledge of the distance/duration covered/ remaining, and previous experience are determinant of pacing and endurance performance during time trials. The role of potential motivation is less clear as our motivational manipulation seems to have reduced RPE rather than increase the maximum amount of effort the participants were willing to exert. Each psychological factor is discussed in the detail below.

Perception of effort and potential motivation

Studies in Chapters 2 and 5 support the hypothesis that perception of effort is an important factor in pace and performance. The results discussed in Chapter 2 showed that the VO_{2max} determine the RPE-Speed ratio which refers to the ability to run at a certain pace given a certain RPE. The lack of significant difference in RPE measured across VO2max levels supports the proposal that individuals choose their pace based on the RPE they perceived, so that, despite difference in cardiorespiratory fitness, every individual can complete the time trial without premature exhaustion. More importantly, in this particular study no differences in pacing strategy have been detected, suggesting that VO_{2max} is a determinant of perception of effort and pace, but not of pacing strategy in the experimental setting and population we investigated.

Further support to the proposal that perception of effort is an important determinant of pacing is the finding that verbal encouragement has an effect of RPE and clearly affected the pace at which subjects where cycling as well as their pacing strategy. Indeed, a comparison of two tests where verbal encouragement was offered in the first 15 min and in the last 15 min has showed a completely different profile of pacing strategy. A positive strategy was employed when encouragement was given in the first 15 min and a negative one when encouragement was given at the end of the time trial. Importantly, contrary to the effects of VO2max on pacing, the effects of verbal encouragement on pacing cannot be explained using traditional physiological mechanisms such as changes in oxygen delivery. Therefore, the results presented in Chapter 5 support the postulation in the psychobiological model according to which perception of effort is not just an epiphenomenon but that it is a direct determinant of pacing and endurance performance.

As anticipated in the introduction, very few studies have been conducted to explore the effect of potential motivation on performance and, in particular, during a physical task (Nakamura et al., 2010; Andreacci et al., 2002; Blanchfield et al., 2013; Viru et al., 2010; Corbett et al. 2012). A major issue with this variable is that it is quite complex to assess potential motivation with a questionnaire, especially during exercise. As documented in Chapter 5 this was one of the limitations of our study. Furthermore, interventions aimed at increasing potential motivation may also have other effects. Some of those studies (Nakamura et al., 2010; Blanchfield et al., 2013) reported a change in performance through a change of perception of effort, which are in line with the results of the fifth study, in Chapter 5, discussed in this thesis. Such results suggest that, with the exception of monetary rewards, it may be very difficult to isolate the effects of potential motivation on pacing and endurance performance.

In addition to the psychological arguments provided above, a link between RPE and effort-based decision-making processes can be explored and supported from a neurophysiological perspective. Several studies suggest these may share similar brain areas. Previous results by Fontes et al. (2013) and Williamson, and colleagues (2006) suggest that the activation of the anterior cingulate cortex (ACC) towards the end of a physical task, when the RPE is reaching consistently high values (above 15 or 6-20 Borg`s Scale) shows the implication of this area in the development of RPE. As stated by Williamson et al. (2006, 2002, 2001), this particular area along with the insular cortex is not only responsible for the higher regulation of decision processes related to the effort/reword relationship but is also involved in the emotion modulation and in response to an increase of perceived exertion during active exercise when heart rate and blood pressure are elevated.

A number of recent studies on animals have shown that the involvement of the ACC as major area of effort-related motivated behaviours (Walton et al. 2006). In such studies scientists collected data on particular neurotransmitters in different area the mouse brain, revealing how levels of dopamine in the cingulate cortex and nucleus accumbens are important for commencing a behaviour, motivation for action, effort-related choices and exertion (Salamone et al. 2003, 2007; Correa and Salamone, 2002). In particular the level of dopamine in those areas determines behavioural changes in rats engaging in rewarded task (Schweimer and Huber, 2006).

As proposed by Salamone and colleagues (2002, 2003, 2007), rats will disengage in a simple task to run for food by choosing the shortest way with less food (reward) compared to the longest run with an higher reward when level of dopamine in the cingulate cortex and nuclei accumbens are low. Although this research was purely limited to rats, its results are quite consistent and in support of the theory that low level of neurotransmitters such as dopamine in determined area of the brain may alter the conscious decision to engage in specific tasks. If translated in the human world and, more in particular, in exercise performance, this may explain an athlete’s decision to slow down by changing pace or gear if on a bicycle. These studies may help understand the link between potential motivation and perceived effort in order to shed some light on the key role and influence of one variable on the other.

Knowledge of the distance/duration to cover; knowledge of the distance/duration covered/ remaining, and previous experience/memory of perceived exertion

In chapter 3, the false information of the end point produced a different pace: participants were made to believe that they would be running 10 km in the second trial but were then stopped after just 5 km. This also affected the subject's pacing strategy, defined as the distribution of speed over time through the exercise. Subjects in the second trial showed an even pacing strategy with no end-spurt phenomenon as a result of the incorrect information on the distance to cover.

The importance of knowing the end-point is also supported by the results presented in Chapter 4 which show that feedback during a competition about the time/distance left is a determinant of pace and pacing strategy. Subjects produced a better performance in both cycling and running performance when they were provided with feedback related to the remaining time and distance. Several studies, however, proposed that this variable does not play an important role and that participants may simply be relying on knowledge of previous experience and knowledge of end-point to set an optimal pacing strategy (Albertus et al., 2005; Mauger et al., 2009, 2011; Wilson et al., 2012). Yet, the typology of manipulation used in our study does not allow drawing such a conclusion as previous studies proved that incorrect feedback (not greater than 15% from the correct one) did not affect the performance, but did not prove that feedback does not play a crucial role in pace and pacing strategy. Indeed, the lack of end-spurt and the more conservative pace observed in the fourth study, in Chapter 4, validates this hypothesis. As Albertus et al. (2005) stated, it seems that feedback does not affect performance as long as the mismatch of the incorrect information of time/distance compared to the correct one is sufficiently small. In this case, the subject is not able to consciously detect the difference between the correct and incorrect information. Indeed, as the psychobiological model suggest, pacing is a “conscious” self-regulated behaviour based on five factors which affect the pace and pacing strategy and therefore the use of non-conscious manipulations such as that of Albertus et al. (2005) to asses effectiveness of one or more of those pacing factors may result in misleading results and interpretations. When differences in external feedback about distance/time are large (e.g., present vs absent as in our studies), then significant effects on pacing and performance are evident with subjects pacing themselves more effectively when external feedback is given. This is not surprising because without external feedback subjects have to rely on their conscious perception of time, which is not very accurate especially over periods of more than a few minutes (Matthews and Meck, 2014)

Many studies reported the importance of memory of previous experience, in particular in combination with the knowledge of the end-point (Albertus et al., 2005; Mauger et al., 2009). However, it is important to underline that knowledge of the end-point has indeed an effect on the pace as athletes not knowing how long or how far they will be running for, find it difficult to decide the optimal pace in order to reach the end of the race without developing early exhaustion. In this frame, knowledge of distance to cover/time remaining has also an effect on the pacing strategy as it is difficult to plan a strategy in advance and/or during the race if athletes do not know when the race will be over.

On the other hand, results in Chapter 3 suggest that memory of previous experience has a significant effect on pace adopted during the time trial; however, memory seemed not to affect the pacing strategy adopted which, instead, remained the same. In the second study, in Chapter 3, even though the third trial was faster, it showed a similar profile in terms of the strategy adopted. These results demonstrate the importance of memory of previous experience on pace but not necessarily on the pacing strategy. Other factors such as the type of race and the length, for example, may dictate the choice of an appropriate pacing strategy. Short-time trial such as 4000 m track cycling race benefits more from an all-out start strategy (positive pacing strategy) (de Konig et al., 1999), while for longer distance such as 30 min time trial an even steady pace followed by an acceleration seems to be the optimal strategy to adopt (Marcora, 2010).

Feedback on elapsed time/distance is an important information that regulate both pacing strategy and pace, as demonstrated by the lack of end-spurt and the more conservative speed chosen by the participant in the results discussed in Chapter 4. It can be argued that in elite athletes who have an increased awareness of time/distance covered and elapsed time, and in particular for distances they are used to race, the difference between having the feedback or not may often be smaller. Nevertheless, having the feedback of the distance left can, indeed, let the athlete plan a more optimal strategy (i.e. choosing the right time to accelerate during the end-spurt).

Comparing the central governor model and the psychobiological model of pacing regulation

The main aim of this thesis was to analyse the effects of the factors proposed by the psychobiological model and demonstrate that they are determinants in explaining pacing and pacing strategy mechanisms. The second aim was to analyse and compare the outcomes of the studies in this thesis with reference to the central governor model (Noakes and colleagues, 2004; 2005). This is because only experiments can ultimately determine which the most valid model of pacing regulation is.

Central governor model is the hypothesis that exercise duration or intensity (depending upon the type of performance test) is set in anticipation by a subconscious intelligent system in order to avoid failure of homeostasis. Moreover, this central governor in the brain controls pacing strategy in response to afferent feedback from different physiological systems and the end-point. This is a feed-forward homeostatic mechanism because the extent of locomotor muscle recruitment is controlled in order to complete the exercise task within the physiological limits of the body, i.e. to avoid catastrophic homeostatic failure (Noakes, 2012).

Studies in Chapters 2 and 3 are in line with both central governor and psychobiological models. Although differences exist between the two models on whether learning occurs at conscious or subconscious level, both models predict a significant effect of previous experience on pacing regulation and performance. As demonstrated in previous study by Noakes and colleagues (2005) the effect of prior experience plays an important role in the change of the pacing produced by the participants. As we demonstrated in Chapter 3, previous experience reinforced the ability of subjects to pace themselves more efficiently and thus to perform better. The increase in performance in the third trial compared to the first one demonstrated that inexperienced runners, such as the participants in that study, were able to run faster and pace themselves faster after having experienced the first time trial. Very interestingly, this learning/experience effect did not affect pacing strategy that remained unvaried.

Results in Chapter 3 with regard to knowledge of the distance/duration to cover are also in line with both models. According to Noakes and colleagues (2004, 2005 and 2012) the feed-forward mechanism requires the subject to know the end-point in order to produce the appropriate pace for completing the race without any homeostatic failure. Similarly, the psychobiological model predicts that different conscious information about the endpoint would affect pacing regulation.

Both models of performance support the idea that RPE is a major determinant for exercise performance, although the central governor model proposed RPE to be calculated by the central governor based on the end point and peripheral afferent feedback (Hampson et al., 2001) while the psychobiological model suggest that the sensory signals for RPE are corollary discharges of central motor command, not afferent signals about the physiological condition of the body (Marcora, 2009). The effects of VO2max on perception of effort and pacing described in Chapter 2 are compatible with both models as cardiorespiratory fitness affects both the physiological responses to exercise and RPE. Importantly, however, it is hard to reconcile the effect of verbal encouragement as described in Chapter 5 with the central governor idea that perception of effort is generated by afferent feedback about the physiological condition of the body and subconscious teleoanticipatory calculations (Hampson et al., 2001). It would be very dangerous to consciously override the subconsciously generated pacing strategy as threats to homeostasis may occur (Noakes, 2000). On the contrary, the psychobiological model considers perception of effort to represent primarily the magnitude of central motor command (de Morree et al., 2012) and that, as any other perception, it can be influenced by cognitive factors such as self-talk (Blanchfield et al. 2013). Therefore, the results described in Chapter 5, i.e. that verbal encouragement can reduce perception of effort and improve self-paced endurance performance, provide evidence against one of the very core hypotheses of the central governor model, suggesting that the psychobiological model may provide a better explanation for the effects of cognitive manipulations on endurance performance.

Furthermore, the central governor model cannot account for our finding that subjects performed better when given external feedback than when not given external feedback. Such results, indeed, contest the hypothesis that the central governor regulates pacing and endurance performance based on subconscious calculations and an internal clock (Lambert et al., 2003). According to this interpretation, the presence or absence of external feedback on time (or distance in the case of distance-based time trials) should not have any effect on pacing regulation. According to the psychobiological model, instead, pacing regulation is conscious. Because conscious perception of time in humans is not precise, providing precise external feedback should improve performance and modify pacing. Given the importance of these predictions with regard to both the central governor model and the psychobiological model, they were tested in two separate studies presented in Chapter 4. In both occasions, the results obtained supported the prediction of the psychobiological model as opposed to the central governor model.

The findings described in Chapter 2 and 5 together with those of other psychological interventions such as verbal encouraging (Andreacci et al., 2002), the effect of music (Nakamura et al., 2010) or the presence of a competitor (Corbett et al., 2012) and their effect on pace, pacing strategy and performance cannot be explained using the central governor model. The reason for this is that it is very unlikely that a psychological intervention may have an effect in the afferent feedback from the periphery in order to subconsciously generate an alternative pacing plan. However, even if this were plausible it has not been demonstrated yet and, thus, cannot be taken as scientific evidence but only as pure speculation. On the contrary, the psychobiological model does predict significant effects of psychological interventions.

Limitations

The research programme described in this thesis is strengthened by a two folded theory-driven and experimental approach. However, we have to acknowledge two main limitations to this approach, which have been already pointed out. Firstly, in the study in chapter 5 the design we used failed to measure potential motivation so that we have only shown effect of verbal encouragement on RPE and we could only speculate on the possible mechanisms and effects of verbal encouragement on the subject’s motivation. In all studies, it emerged that high levels of RPE above 17-18 demonstrate that potential motivation was always very high although we could not measure it directly. We searched for validated measures of “motivation quantity” (i.e. potential motivation) as opposed to the many measures of motivation quality, which have already been investigated by previous studies (Masters et al., 1993). Therefore, future research programmes may benefit from the preliminary development of a measure of potential motivation that could be used during exercise.

Secondly, the sample used in our study are all participants with a low or moderate level of fitness and this limits the external validity of our findings with regard to elite endurance athletes and other populations. Although we do not expect that the five basic psychological determinants of pacing regulation to be different in elite athletes, further research in this population is required to fully test the validity of the psychobiological model of endurance performance.

Direction for future research

From a psychological perspective, it is necessary to produce new valid measurements of potential motivation during exercise so that effects of reward, needs, contingency and other factors known to affect potential motivation can be evaluated. It is also important to use an experimental approach to determine the influence of many more psychological factors on pacing regulation and endurance performance. Examples include mood/emotion and perceived ability. This research may identify psychological factors that can affect endurance performance independently from the five factors currently thought to be the basis of the psychological level of explanation of the psychobiological model. Therefore, further research would be necessary to further refine the model. It is also important to assess the efficacy of psychological strategies in improving performance during self-paced endurance exercise. We have provided initial evidence about the best timing for verbal encouragement: this is an under researched area that should be explored in depth as it may lead to significant improvements in endurance performance by helping athletes achieve their physiological potential.

The focus of the present research programme was on the psychological level of explanation of the psychobiological model. However, the biological level of explanation is equally important and should be the focus of future research. As exemplified by the previous discussion on the possible neural bases of the link between perception of effort and effort-based decision-making, neurobiological studies can provide concurrent and converging evidence that strengthen the causal relationships proposed on the basis of psychological theory – for example, the link between perception of effort and self-regulation of pacing during endurance exercise. Furthermore, by better understanding the neurophysiology underlying perception of effort and potential motivation we may discover potential neural targets for training, psychological interventions and nutritional strategies. Fresh studies measuring the cortical substrates of perception of effort and blockade studies measuring precisely various perceptions (e.g. pain and effort) would be particularly helpful. By these means, the debate about the role of efferent vs afferent sensory signals in the generation of perception of effort might be settled.

Finally, more studies testing elite athletes in specific disciplines may help to translate this type of research in the elite performance field and to better understand pacing mechanisms and its determinants in sport competitions where the subject usually interacts with competitors and/or team mates. This research would have to draw from social psychology to provide a new understanding of the complex relationships between individual behaviours and teams.

CONCLUSION

This research program demonstrated that the psychobiological models of endurance performance for pacing proposed by Marcora and colleagues in recent years (2008,2009, 2013) is, indeed, a valid model to explain human performance and provides new insights in the study of pacing and pacing strategies. At the same time, some of our findings challenge the central governor model based on the subconscious control of pacing and performance based on afferent feedback, knowledge of the end point and an internal clock.

With the exception of the effect of potential motivation, the predictions based the psychobiological model has been investigated in detail using an experimental or quasi-experimental approach. Altogether, these studies confirmed that perception of effort, knowledge of the distance/duration to cover; knowledge of the distance/duration covered/ remaining, and previous exercise are important determinants of pace and performance during time trials as predicted by Marcora (2010). On the other hand, our results do not support the concept that pacing and pacing strategies may reflect a subconscious system which controls pacing strategy in response to afferent feedback from different physiological systems through a homeostatic mechanism that guarantees completion of the exercise task within the physiological limits of the body, as proposed in the central governor model by Noakes (2012).

The results of these studies may also have practical implications in exercise science and sport performance. Although the psychobiological model postulates that pacing and performance are directly affected only by psychological factors, we demonstrated that the genetic and training factors that determine VO2max are also important. Our proposal is that VO2max and its underlying factors influence self-paced endurance performance by determining the psychophysical relationship between speed/power and RPE, i.e. perception of effort. Therefore, the current approaches to talent identification, physiological testing, physical training and nutrition are still valid and not superseded by the psychobiological model of endurance performance. This model simply provides a different explanation on how these factors affect endurance performance. However, our proposal that perception of effort is a determinant, rather than a correlate, of endurance performance is not just of academic interest. The realization that perception of effort is a causal factor in the determination of endurance performance justifies the use and further development of novel strategies to reduce perception of effort over and above the reduction induced by physical training. These strategies include psychological interventions during training and before competitions, brain training, prevention of mental fatigue before competitions, and nutritional strategies with natural psychoactive substances like caffeine. The addition of these novel interventions may provide additional ways to get closer to the real physiological and biomechanical limits of human endurance.

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Appendix I

This appendix contains an example of the scales for rating of perceived exertion (used in all studies). An example of scale and instruction used for rating of perceived exertion during whole-body exercise (Borg, 1998).

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

Borg’s RPE Scale Instructions

While exercising we want you to rate your perception of effort, i.e how hard, heavy and strenuous exercise feels to you. The perception of exertion depends on how hard driving your legs or arms, how heavy is your breathing, and the overall sensation of how strenuous exercise is. It does NOT depend on muscle pain, i.e. the aching and burning sensation in your leg or arm muscles.

Look at this rating scale; we want you to use this scale from 6 to 20, where 6 means “not exertion at all ”and 20 means “maximal exertion”.

9 corresponds to “very light” exercise. For a normal, healthy person it is like walking slowly at his or her own pace for some minutes.

13 on the scale is “somewhat hard” exercise, but it still feels OK to continue.

17 “very hard” is very strenuous exercise. A healthy person can still go on, but he or she really has to push him--or herself. It feels very heavy, and the person is very tired.

19 on the scale is “extremely hard “exercise. For most people this is the most strenuous exercise they have ever experienced.

Try to appraise your feeling sofexertionash one style as possible, without thinking about what actual physical load is(heart rate, speed, power output ,intensity level on the exercise machine).Don’t underestimate your perception of exertion, but don’t overestimate it either. It is your own feeling of effort that’s important, not how it compares to other people’s. What other people think is not important either. Look carefully at scale and expressions, and then give a number.

Any question

Appendix II

This appendix contains an example of BRUMS Mood questionnaire (Terry et al, 2003) and Matthew’s Motivation questionnaire (Matthews, 2001) which were used in the studies constituting this thesis.

Subject ID: ______ Name:____

Gender: F M DOB: ____ / ____ / ____ Date: ____ / ____ / ____ Time: ____ : ____ Condition: ____

PSYCHOLOGICAL QUESTIONNAIRES

General Instructions.These two questionnaires are concerned with your feelings and thoughts at the moment. Please answer **every** question, even if you find it difficult. Answer, as honestly as you can, what is true of **you**. Please do not choose a reply just because it seems like the 'right thing to say'. Your answers will be kept entirely confidential. Also, be sure to answer according to how you feel **AT THE MOMENT**. Don't just put down how you usually feel. You should try and work quite quickly: there is no need to think very hard about the answers. The first answer you think of is usually the best.

MOOD

Below is a list of words that describe feelings. Please read each one carefully. Then circle one of the following answers that best describes HOW YOU FEEL RIGHT NOW. Make sure you answer every question.

0 = not at all 1 = a little 2 = moderately 3 = quite a bit 4 = extremely

1. Panicky	0	1	2	3	4
2. Lively	0	1	2	3	4
3. Confused	0	1	2	3	4
4. Worn out	0	1	2	3	4
5. Depressed	0	1	2	3	4
6. Downhearted	0	1	2	3	4

7. Annoyed	0	1	2	3	4
8. Exhausted	0	1	2	3	4
9. Mixed-up	0	1	2	3	4
10 .Sleepy	0	1	2	3	4
11 .Bitter	0	1	2	3	4
12. Unhappy	0	1	2	3	4
13. Anxious	0	1	2	3	4
14.Worried	0	1	2	3	4
15 .Energetic	0	1	2	3	4
16 .Miserable	0	1	2	3	4
17 .Muddled	0	1	2	3	4
18.Nervous	0	1	2	3	4
19 Angry	0	1	2	3	4
20. Active	0	1	2	3	4
21. Tired	0	1	2	3	4
22. Bad tempered	0	1	2	3	4
23. Alert	0	1	2	3	4
24. Uncertain	0	1	2	3	4

MOTIVATION

Please answer some questions about your attitude to the task you are about to do (ENDURANCE TEST ON A CYCLE ERGOMETER). Rate your agreement with the following statements by circling one of the following answers. Make sure you answer every question.

0 = not at all 1 = a little bit 2 = somewhat 3 = very much 4 = extremely

1. I expect the content of the task will be interesting……………………	0	1	2	3	4
2. The only reason to do the task is to get an external reward (e.g. payment)	0	1	2	3	4
3. I would rather spend the time doing the task on something else………	0	1	2	3	4
4. I am concerned about not doing as well as I can……………………...	0	1	2	3	4
5. I want to perform better than most people do…………………………	0	1	2	3	4
6. I will become fed up with the task…………………………………….	0	1	2	3	4
7. I am eager to do well………………………………………………….	0	1	2	3	4
8. I would be disappointed if I failed to do well on the task……………..	0	1	2	3	4
9. I am committed to attaining my performance goals…………………..	0	1	2	3	4
10. Doing the task is worthwhile……………………………………….	0	1	2	3	4
11. I expect to find the task boring……………………………………...	0	1	2	3	4
12. I feel apathetic about my performance………………………………..	0	1	2	3	4
13. I want to succeed on the task……………………………………….	0	1	2	3	4
14. The task will bring out my competitive drives………………………..	0	1	2	3	4
15. I am motivated to do the task………………………………………	0	1	2	3	4