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# The effects of fatigue and task knowledge duration on kicking performance and pacing strategies in soccer

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# Abstract

Interest in the topic of fatigue in sports science has a long history and recent research and theories have highlighted the problem of fatigue more broadly. A new perspective seems to have emerged supported by the concept of the brain acting as a central master regulator of exercise performance. This kind of regulation is named “pacing” and nowadays is assumed as an important concept in sport and exercise, supporting this psychophysiological perspective. Having prior knowledge about the activity is a central point on this view of pacing, based on the principle that athletes are then able to self-regulate their own performance through the entirety of the exercise. However, the precise importance of the psychophysiological perspective in context of training (exercises) or competition remains unclear, especially in team sports as a soccer. The general aim of this thesis was to analyze the effects of fatigue and task knowledge duration on kicking performance and pacing strategies in soccer. For the accomplishment of these purposes the following sequence was used: (i) reviewing the available literature; (ii) demonstrating the effects of fatigue on kicking ball velocity in soccer players; (iii) investigating the influence of fatigue upon kicking performance of soccer players and examining the effect of the knowledge of the exercise duration upon these two parameters; (iv) investigating the influence of different exercise intensities on kicking accuracy and velocity in soccer players and analyzing the player pacing strategies from different prescribed intensities; (v) investigating the possible influence of knowledge of exercise duration on player pacing strategies during soccer small-sided games (5 vs 5). The main conclusions drawn were (i) there is potential negative fatigue effect induced by high intensity exercises on kicked-ball velocities in soccer; (ii) the effect of fatigue can be variable; (iii) kicking accuracy is not affected by fatigue considering the accuracy as a secondary aim in relation with kicking velocity; (iv) no effects of knowledge of the exercise duration were found on kicking performance, but in respect of pacing strategies during soccer small-sided games, the findings showed its relevance. In addition, the results support the hypothesis about the involvement of psychophysiological factors and they express the complexity of the fatigue phenomenon and the relevance of the theory of central master regulation of the brain on exercise performance.

# Key words

Fatigue, Kicking, Performance, Pacing, Psychophysiology, Perception of effort, Intermittent exercise, High-intensity exercise, Self-regulation of effort

# Resumo

O interesse pelo tema da fadiga em ciências do desporto tem uma longa história e pesquisas recentes têm realçado o problema da fadiga de forma mais abrangente. Uma nova perspetiva parece ter surgido apoiada pelo conceito de que o cérebro atua como um regulador central do desempenho no exercício. Este tipo de regulação é chamada de "estratégia de ritmo" e hoje assume-se como um conceito importante no desporto e exercício, servindo de suporte a essa perspetiva denominada psicofisiológica. O conhecimento prévio sobre a atividade é um ponto central dessa regulação baseada no princípio de que os atletas são capazes de autorregular o seu próprio desempenho em todo o exercício. No entanto, a importância concreta da perspetiva psicofisiológica no contexto de treino (exercícios) ou competição continua por esclarecer, especialmente em desportos coletivos como o futebol.

O objetivo geral do presente trabalho foi analisar os efeitos da fadiga e do conhecimento prévio da duração da tarefa no desempenho do remate e nas estratégias de ritmo no futebol. Para a concretização desses objetivos foi usada a seguinte sequência: (i) revisão da literatura; (ii) demonstrar os efeitos da fadiga na velocidade da bola na ação de remate; (iii) investigar a influência da fadiga no desempenho do remate dos jogadores de futebol e analisar o efeito do conhecimento da duração do exercício sobre estes dois parâmetros; (iv) investigar acerca da influência de diferentes intensidades de exercício na precisão e velocidade da bola na ação de remate em jogadores de futebol e analisar as estratégias de ritmo dos jogadores de acordo com diferentes intensidades prescritas; (v) investigar a possível influência do conhecimento da duração do exercício nas estratégias de ritmo durante a realização de jogos de futebol reduzidos (5 vs 5). As principais conclusões foram: (i) há um potencial efeito negativo da fadiga induzida por exercícios de alta intensidade na velocidade da bola na ação de remate; (ii) o efeito da fadiga pode ser variável; (iii) a precisão do remate não é afetada pela fadiga, considerando a precisão como um objetivo secundário em relação à velocidade; (iv) não foram encontrados efeitos do conhecimento da duração do exercício na performance de remate, mas em relação às estratégias de ritmo durante jogos de futebol reduzidos, os resultados mostraram a sua relevância. Além disso, os resultados apoiam a hipótese acerca do envolvimento de fatores psicofisiológicos e expressam a complexidade do fenómeno da fadiga e da relevância da teoria da regulação central no desempenho do exercício.

# Palavras-Chave

Fadiga, Futebol, Remate, Desempenho, Estratégia de ritmo, Psicofisiologia, Percepção de esforço, Exercício intermitente, Exercício de intensidade alta, Auto-regulação do esforço

# Resumen

El interés por el tema de la fatiga en las ciencias del deporte, tiene una larga historia e investigaciones recientes han destacado más ampliamente el problema de la fatiga. Una nueva perspectiva parece haber surgido basada en el concepto de que el cerebro actúa como un regulador central del rendimiento en el ejercicio. Este tipo de regulación es llamada "estrategia de ritmo" y hoy en día se acepta como un importante concepto en el deporte y en el ejercicio, apoyando a esta perspectiva psicofisiológica. El conocimiento previo sobre la actividad, es un punto central de esa regulación, basada en el principio de que los atletas son capaces de autorregular su proprio desempeño durante todo el ejercicio. Sin embargo, la importancia concreta de la perspectiva psicofisiológica en el contexto del entrenamiento (ejercicios) o competición, permanece poco claro, especialmente en deportes de equipo, como el fútbol. El objetivo general de esta tesis fue analizar los efectos de la fatiga y del conocimiento previo de la duración de la tarea en el rendimiento del remate en las estrategias de ritmo en el en el fútbol. Para alcanzar estos objetivos se utilizó la siguiente secuencia: (i) revisión de la literatura disponible, (ii) demostrar los efectos de fatiga en la velocidad del balón en la acción de remate; (iii) investigar la influencia de la fatiga en el desempeño del remate de los jugadores de fútbol y analizar el efecto del conocimiento de la duración del ejercicio sobre estos dos parámetros, (iv) investigar la influencia de diferentes intensidades de ejercicios en la precisión y velocidad del balón en la acción de remate de los jugadores de fútbol y analizar las estrategias de ritmo de los jugadores de acuerdo con las diferentes intensidades prescritas; (v) investigar la posible influencia del conocimiento de la duración del ejercicio en las estrategias de ritmo durante la realización de juegos reducidos (5 VS 5). Las principales conclusiones fueron que: (i) hay un efecto negativo en la fatiga inducida por ejercicios de alta intensidad en la velocidad de la bola en la acción del remate, (ii) el efecto de la fatiga puede ser variable; (iii) la precisión del remate no está afectada por la fatiga, considerando la precisión como un objetivo secundario en relación a la velocidad; (iv) no se encontraron efectos del conocimiento de la duración del ejercicio en el rendimiento del remate, pero en relación a las estrategias de ritmo durante los juegos reducidos, los resultados mostraron su importancia. Además, los resultados apoyan la hipótesis sobre la participación de los factores psicofisiológicos y expresan la complejidad del fenómeno de la fatiga y de la importancia de la teoría de la regulación central en el rendimiento del ejercicio.

# Palabras clave

Fatiga, Fútbol, Remate, Rendimiento, Estratégia de ritmo, Psicofisiologia, Esfuerzo percibido, Ejercicio intermitente, Ejercicio de alta intensidad, Autorregulación del esfuerzo

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# List of Abbreviations

| | |
|---|---|
| ATP | Adenosine triphosphate |
| $Ca^{2+}$ | Calcium ion |
| CNS | Central Nervous System |
| GPS | Global Positioning System |
| $H+$ | Hydrogen ion |
| HR | Heart Rate |
| $HR_{max}$ | Maximal heart rate |
| $K+$ | Potassium ion |
| PCr | Phosphocreatine |
| RPE | Rating Perceived Exertion |
| SSG | Small-side soccer games |
| $VO_2$ | Oxygen uptake |
| $VO_2$ max | Maximal oxygen uptake |

# Chapter 1. General Introduction

The process of exercise performance is complex and the phenomenon of fatigue as part of this process is intriguing and challenging to study (Marino et al., 2011; Noakes, 2012; Smith et al., 2014; Tucker, 2009). For these reasons, the study and interest in fatigue, particularly in sports science, has a long history, and has been the subject of many scientific studies (Marino et al., 2011; Noakes, 2012). However, the phenomenon of fatigue is still ambiguous, uncertain and hard to explain comprehensively in all its possible aspects. The number of variables that can influence the fatigue process during exercise along with the integrated functioning of the human body are responsible for this complexity. As a result, there is no scientific consensus behind a single explanation for fatigue during exercise (Marcora, 2008; Noakes & Tucker 2008; Swart et al., 2012; Tucker, 2009) and in fact, there is no single definition of the concept of fatigue in exercise fatigue research.

Classical fatigue theories continue to dominate the discussion on this issue, but in recent years, many studies have pointed out some limitations of these theories and suggested they overlook significant factors (Marino et al., 2011; Noakes, 2012; Tucker, 2009). In fact, recent research and theories have highlighted the concept of fatigue beyond the physiological aspects, although they maintain their importance. The result is not a simplification of the phenomenon, but an understanding of the awareness that it should be interpreted more broadly. The physiological perspective supports and justifies one part of the problem, but other factors affecting the fatigue process should be considered, allowing the opportunity for a new psychophysiological perspective (Edwards & Polman, 2014; Waldron & Highton, 2014; Gabbett et al., 2015).

Regulation of effort is a choice that every athlete must make continuously throughout every workout and competition and it has a profound effect on outcomes (Gabbett et al., 2015). This kind of effort regulation is named “pacing” and nowadays is an important concept in sport and exercise, and supports, as a construct, the psychophysiological perspective. Despite the practical experience of coaches and athletes regarding the importance of pacing, only recently has the concept of pacing received some, yet relatively little, attention from exercise scientists. The principle of a psychophysiological system that controls physical capabilities appears applicable to all types of exercise including team sports (Edwards & Polman, 2014). Despite the fact that it is absolutely connected to sport and exercise, there was a tendency to view pacing as a psychological phenomenon and therefore outside of exercise science, whose focus has been mainly physiological. In other words pacing was studied from a physiological perspective that tended to “explain away” the psychological dimension of the phenomenon.

Recent advances in our knowledge of the brain have led to a recognition that pacing is a phenomenon with both psychological and physiological dimensions that are deeply mutually interpenetrating. The stress of exhaustive exercise may lead to conscious or unconscious inhibition of the athlete's willingness to tolerate further pain, and the central nervous system (CNS) may slow the exercise pace to a tolerable level to protect the athlete. Indeed, researchers generally agree that the perceived discomfort of fatigue precedes the onset of a physiological limitation within the muscles. Nevertheless, the precise mechanisms subjacent to the CNS's role in causing, sensing and even overriding fatigue are not fully understood, and there is a lack of experimental research associated with this phenomenon. This does not diminish the importance of the physiological system. It merely indicates that the ultimate form of performance regulation is performed by the brain, either consciously or unconsciously. In fact, improvements in our understanding of how exercise mechanisms really works are opening up exciting new possibilities for the practice of pacing in sport and exercise (Noakes & Tucker 2008; Swart et al., 2012; Tucker, 2009; Waldron & Highton, 2014). Moreover if pacing is a buffering mechanism that enables athletes to successfully complete tasks, then prior experience and accurate knowledge of the task seems to be crucial to their success.

Having prior information about the activity (e.g., duration, importance, match demands) is a central point in the psychophysiological view of pacing, based on the principle that the athletes are then able to regulate (self-pace) their own performance across the exercise. Information about task duration may lead to modifications in athlete performance, which has been shown in research on continuous sports such as ultra-marathon running (Millet et al, 2011). However, the precise importance of this point in the context of training (exercises) or competition in team sports remains unexplained. The specific context in which fatigue expresses is another important point of analysis and rarely considered. The idiosyncrasies inherent in each sport also determine how we should look and interpret the results and sensations of fatigue (Edwards & Polman, 2014; Waldron & Highton, 2014). For example, the characteristics of the effort required in team sports are different than the characteristics of the effort needed in individual sports, and due to this specificity, different considerations about the mechanisms of fatigue seem to be necessary.

To this purpose, we found that studies on pacing were associated mainly with endurance sports and rarely with team sports (Edwards & Polman, 2014; Waldron & Highton, 2014). The inherent complexity of team sports creates many difficulties and the tendency to study specific variables may lead to an excessively simple model of the problem. Nevertheless, due to the lack of investigation, it seems to be required to assess and better understand the mechanisms and consequences of fatigue not only in endurance sports but also in team sports.

Particularly in soccer, the physical demands of competitive matches may result in some fatigue, inferred by the high-intensity periods involving sprinting and jumping and by the long distances covered (Bradley et al., 2009; Di Salvo et al., 2009; Mohr et al., 2003; Mohr et al., 2005; Krustrup et al., 2006; Vigne et al, 2010). Research showed that running performance declines from the first to the second half of an elite match (Krustrup et al., 2010; Di Salvo et al., 2009) or temporarily after the most intensive periods (Bradley et al., 2009; Di Mascio & Bradley, 2013; Krustrup et al., 2006). All the data confirmed that a soccer player is in a fatigued condition at the end of the match and temporarily fatigued after intensive periods of activity (Mohr et al., 2005). However, our understanding is still limited and more investigation is needed to clarify the responsible mechanisms for this fatigue. Even considering only the physiological responses during the game or the effects of fatigue on soccer skills performance (Paul et al., 2015), these effects and their causes also remain to be explored.

One of the most widely studied soccer abilities (De Proft et al., 1988; Masuda et al., 2005), considered the most determinant (Barfield et al., 2002; Bacvarevic et al., 2012) and the most used in competition (Kellis and Katis 2007; Sedano et al., 2009), is kicking. Maximum kicking velocity and accuracy is a complex skill that depends on technical (Nunome et al., 2006), biomechanical (Young and Rath, 2011), neuromuscular (Dörge et al., 1999; Nunome et al., 2006) and strength factors (Masuda et al., 2005). Several studies have explored the different factors that could affect maximal kicking velocity and accuracy. However, the precise influence of fatigue on soccer kicking has not yet been clarified because the results are discordant and inconclusive. There is some evidence that shows the effect of fatigue on biomechanical and muscular performance but the practical effects upon soccer skills performance and particularly on soccer kicking are still unclear.

Kicking performance is also a consequence of a particular player action that may be conditioned by the transient capacity of the player (Mohr et al., 2003). This kind of capacity could be influenced by the role of the psychophysiological factors (Billaut et al., 2011; Gabbett et al., 2015; Marino, 2009; Millet, 2011; Waldron & Highton, 2014) and further research should be developed to determine the influence of knowing the duration of the task and pacing strategies on kicking performance. Investigations have been scarce on these points and it would be appropriate to analyze the results in accordance with an integrated perspective based on a psychophysiological approach. In addition, the game is characterized by differing levels of intensity, and it would be also pertinent to consider what kinds of exercise intensity may influence kicking performance. Furthermore it should be interesting to observe the player's behavior based on self-application/regulation of prescribed intensities (pacing strategies), considering the ability of the players to choose an appropriate self-intensity according to self-perception of effort (Edwards & Polman, 2014; Gabbett et al., 2015).

It is also pertinent to consider some recent evidence that psychophysiological factors may also justify some of the results of the fatigue effect in the context of game (Edwards & Polman, 2014; Gabbett et al., 2015; Paul et al., 2015). Despite advances on this topic and the recent investigation that might confirm the hypothesis that the brain initiates a pacing strategy at the start of a match, based on both the knowledge of the duration of the game and prior experience, few studies have examined the influence of pacing as an explanation of reduced work outputs in team sports. This is probably because of the difficulties in identifying an appropriate model that represents the complexity of energetic demands and movement in a particular sport (Edwards & Polman, 2014). Additionally, in team sports, due to inherent complexity (Paul et al., 2015) it is difficult to identify the precise factors associated with the pacing concept.

The prior knowledge of exercise duration is also seen in this context as a central aspect of pacing strategies of the players. Waldron & Highton (2014) demonstrated that team-sport athletes that are required to compete for relatively short periods (e.g., substitutes) set a higher initial pacing strategy and exhibited a significantly greater end spurt than athletes required to play the entire match. This suggests that shorter anticipated exercise periods are associated with greater playing intensities. Billaut et al. (2011) examined the influence of prior knowledge of sprint number on repeated-sprint exercise performance and concluded that pacing occurs during repeated-sprint exercises in anticipation of the number of efforts that are expected to be included. Despite these approaches, more studies are needed in order to clarify the importance of prior knowledge of the task on a broader context as a game-based activities. The small-sided games due to its characteristics, use and practical applicability should be used in further investigation.

To our best knowledge, only one study in rugby attempted to investigate the influence of prior knowledge of the task on the pacing strategies employed during game-based activities. The authors concluded that rugby players alter their pacing strategies based on the anticipated endpoint of the exercise period (Gabbett et al., 2015). Nevertheless, it is difficult to generalize the conclusions of this study to all team sports, because each one has its specific idiosyncrasies.

Considering the abovementioned, the general aim of this thesis was to analyze effects of fatigue and knowledge of the task duration on kicking performance and pacing strategies in soccer. To our best knowledge, no studies have tried a broad and paradigmatic approach to respect of the effects of fatigue in the context of soccer.

It was hypothesized that fatigue negatively influences kicking performance in soccer and this influence depends of the exercise intensity. It is also hypothesized that psychophysiological factors are involved in fatigue in soccer activities and knowledge of the task duration influences pacing strategies employed during these activities.

This thesis is organized in the following manner:

Chapter 2 presents a review regarding the complexity of the fatigue concept and its association with soccer.
Chapter 3 shows the experimental studies developed to accomplish the main aim of this thesis:

> Study 1 demonstrates the effects of fatigue on kicking ball velocity in soccer players;
> Study 2 investigates the influence of fatigue on kicking performance of soccer players and examines the effect of knowledge of exercise duration upon these two parameters;
> Study 3 investigates the influence of different exercise intensities on kicking accuracy and velocity in soccer players and analyzes player's pacing strategies from different prescribed intensities;
> Study 4 extends the field of analysis and investigates the possible influence of knowledge of exercise duration on pacing strategies during soccer small-sided games.

Then, a general discussion of the results is obtained on the studies performed (Chapter 4), followed by the main conclusions of the thesis (Chapter 5). Some suggestions for future research are also presented (Chapter 6).

# Chapter 2 – Literature Review

## The complexity of fatigue in Sport and Exercise

The Oxford Dictionary (2010) defines fatigue as “extreme tiredness after exertion; reduction in efficiency of a muscle, organ etc. after prolonged activity”. Research shows that the fatigue phenomenon is more complex and involves too many parameters for such a reductive understanding of the concept. The long history of research in this area has only served to extend the number of available definitions of fatigue.

It is very difficult to establish the development of fatigue as a concept in the exercise sciences (Noakes, 2012). The work of Mosso in the early 20th Century stands as a landmark in the study of fatigue (Mosso, 1904). In “La fatica” (1904), Mosso concluded that there were two phenomena that categorized fatigue: “The first is the reduction of the muscular force. The second is fatigue as a sensation”. Along the years, there has been a wide variation in definitions of fatigue in the exercise sciences including statements such as “the failure to maintain the required or expected force” (Edwards, 1981), “a loss of maximal force generating capacity” (Bigland-Ritchie et al., 1986) or “a reversible state of force depression, including a lower rate of rise of force and a slower relaxation” (Fitts & Holloszy, 1978).

The many definitions highlight the inability to agree on a single definition of fatigue and this inability makes consistent interpretation of and comparison between research findings on fatigue difficult. The many definitions of fatigue cause different interpretations of results but also keep open permanently the debate regarding the usefulness of these results for every sport and exercise fatigue in all of its potential states.

Marino et al. (2011) stated that to prematurely arrive at a definition of fatigue that is only accepted because no better one exists may only serve to confirm the complexity of the reality of the fatigue phenomenon. The present consensus on fatigue is only the conclusion that it is highly complex (Noakes, 2012).

### Peripheral fatigue and central fatigue

Classically, fatigue in sport and exercise can theoretically be categorized into two types: peripheral fatigue and central fatigue.

Peripheral fatigue is associated with a reduction of muscle force production caused by processes distal to the neuromuscular junction (Ament & Verkerke, 2009). The concept of peripheral fatigue originates from the studies of Hill and colleagues in the 1920s (Hill & Lupton, 1923; Hill et al., 1924a; Hill et al., 1924b; Hill et al., 1924c). These studies led to the conclusion that immediately before termination of exercise, the oxygen requirements of the exercising muscles exceed the capacity of the heart to supply that oxygen. This develops an anaerobiosis within the working muscles, causing lactic acid accumulation. Because of this change in the intramuscular environment, continued contraction becomes impossible and the muscles reach a state of failure. In their studies, the authors (Hill & Lupton, 1923; Hill et al., 1924a; Hill et al., 1924b; Hill et al., 1924c) state that fatigue is the result of increased intramuscular lactic acid, which is produced in the body only under anaerobic conditions (Noakes, 2012). These conclusions were also supported by the fact that exercise performance improved when oxygen was inhaled (Hill & Flack, 1910). The authors then concluded that the main factor limiting the exercise tolerance was the heart's ability to pump blood to the active muscles and predicts that fatigue develops as a consequence of heart no longer being able to supply oxygen nor is the cardiovascular system able to remove waste products from the working muscles (Noakes, 2012).

From this perspective, the cardiovascular system restricts performance via exercise-induced deficiencies in the delivery of blood, nutrients and oxygen to the working muscles, by local muscle utilization processes for the regeneration of ATP (energy currency) and by limitations to (pulmonary) blood circulation with the lungs for gas exchange (Bassett & Howley, 2000; Fitts, 1994). Limitations to the pumping capacities of the heart, the density of capillaries supplying skeletal muscle with oxygenated blood and the quantity of mitochondria with which to extract oxygen could all directly restrict performance. This theory, called the anaerobic/cardiovascular/catastrophic model of human performance exercise with the catastrophic term predicting the failure of homeostatic heart function. Despite criticism, this theory remained and possibly still remains the most-cited explanation of exercise-induced fatigue, however some limitations have been pointed out.

Hill and colleagues stated that the maximal cardiac output limit of the heart is attained due to the development of myocardial ischemia because the heart cannot pump any more blood as it has reached the limit of its oxygen consumption rate (Raskoff et al., 1976). The model also showed that the attainment of a maximal cardiac output limits the flow of blood to the working muscles, causing anaerobiosis that limits the oxidative removal of lactic acid. The accumulation of lactic acid directly interferes with the contractile ability of the muscle fibers, causing muscle fatigue. The authors also proposed the possibility that myocardial ischemia as the cause of attainment of the exercise-limiting maximal cardiac output and a threat to the integrity of the cardiac tissue may be avoided due to the existence of a governor, located in either the brain or heart, thereby protecting it from damage.

However, there is a lack of evidence to demonstrate that muscles actually become anaerobic during exercise or that oxygen consumption or cardiac output consistently reaches a maximal point, which would be a requirement for their implication in fatigue during maximal exercise (Noakes, 2012). Moreover, myocardial ischemia does not occur in a healthy heart during even the most severe exercise and the hypothesis about the governor either in the brain or heart did not have much evidentiary support.

The model also suggests that the development of fatigue in the periphery would result in the brain recruiting additional muscle fibers in an attempt to help out those fatiguing fibers and thereby maintain exercise intensity, with this response continuing until all available muscle fibers had been maximally recruited. However, this prediction is contradictory to other aspects of the model, as continued recruitment of muscle should worsen the metabolic crisis that the model predicts to be the cause of exercise termination. The main problem of this theory is that it states that fatigue is indeed a catastrophic event, based on a "all or nothing" response, i.e., resulting in a complete failure of the working muscles to continue producing force. However, catastrophic muscle or organ failure clearly does not occur at exhaustion in healthy individuals during any form of exercise (Noakes, 2012). Moreover, in this model fatigue is shown from the viewpoint of an exhaustion failure system. However, skeletal muscles are never fully recruited during exercise, muscle ATP never falls below 60% of resting levels, and glycogen concentration declines but is not depleted during exercise (Rauch et al., 2005). Moreover, fatigue in many circumstances occurs prior to high concentrations of metabolites such as lactate, $H^+$, extracellular $K^+$, without disturbances to muscle $Ca^{2+}$ kinetics and without high core temperatures or significant hypohydration (Noakes, 2000).

All of these observations contradict the prediction of the peripheral linear catastrophic model that some form of homeostatic failure has to occur in order to cause fatigue. However, the importance of the model peripheral component remained. In the Hill model (1924a—c), the physiological aspect is accepted but revealed to be unable to respond to the complexity of the fatigue phenomenon in a broader scope. Despite considering a refutable role of the brain in order to prevent myocardial ischemia, the model ignores the role of neural control over all physiological systems (Noakes, 2012).

Whereas peripheral fatigue occurs via processes outside of the CNS, in central fatigue, it is proposed that the origin of fatigue is located within the CNS, with a loss of muscle force occurring through processes proximal to the neuromuscular junction. Specifically, this refers to locations within the brain, spinal nerves and motor neurons. It is associated with instances where the CNS has a diminished neural drive to muscle (Noakes et al., 2005). Central fatigue is known as the failure of the central nervous system to maximally drive the muscle resulting some loss of force (Taylor et al., 2006). The source or diminished force output/performance

(Merton, 1954) is justified broadly, either within the central nervous system (brain and spine - central) as anywhere outside the central nervous system (e.g., muscle peripheral).

Comparatively, little research was made on the role of the CNS in fatigue until recent decades (Davis & Bailey, 1997), which is curious (Noakes, 2012) considering for how long the possibility of a central component of fatigue has been suspected. The impact of peripheral fatigue research findings and the limitations of the ability to measure central fatigue due to the lack of objective and tools contribute to this lack. The central fatigue is sometimes only accepted when experimental findings do not support any peripheral causes of fatigue (Davis & Bailey, 1997).

The central nervous system plays a crucial role in the maintenance of homeostasis (Lambert, et al., 2005), and the motor cortex of the brain is responsible for the generation of the motor drive and recruitment of motor units during exercise (Lambert et al., 2005). The brain assumes the control of cognition and recognition of physical sensations that are perceived as fatigue. The perceived fatigue caused by exercise is felt as a "sensation" and is common during exercise. The workload may create such an intense sensation that is perceived as necessary to reduce force to successfully complete the activity (i.e., pacing) or even cease exercise entirely if the sensations are too severe (Noakes, 2011). For this reason the different paces of athletes during exercise are indicative that physiological mechanisms are not solely responsible for the regulation of exercise intensity and that humans display an anticipatory aspect of exercise regulation possibly related to factors including perception of task effort and motivation (Noakes, 2012). The physical and biochemical changes during exercise are physiological aspects that naturally should be considered, but the perceived fatigue also should be considered because they induce changes in behavior/performance and therefore should be studied with the same importance (Noakes, 2012). When these are taken together, conditions are created for the appearance of the psychophysiological model in which catastrophic system failure does not occur.

## Central regulation of exercise performance: a psychophysiological approach

The inability of peripheral and central fatigue processes to convincingly explain sport and exercise fatigue has required exercise scientists to widen their focus in order to clarify the fatigue phenomenon. An interesting perspective that has recently arisen is the concept of the brain acting as a central master regulator of exercise performance (Tucker, 2009).

The cardiovascular/anaerobic/catastrophic model of exercise performance already suggested the presence of a governor either in the heart or brain. However, it was only justified by its responsibility for reducing the pumping capacity of the heart, thereby protecting it from damage due to myocardial ischaemia that was pointed out as the main cause of fatigue during exercise (Hill et al., 1924a; Hill et al., 1924b; Hill et al., 1924c). As noted by Noakes (2012), the governor component of Hill´s peripheral model of exercise fatigue had been omitted because the research established that the healthy individual does not become ischaemic during even maximal exercise. This fact discredit the role of this governor as proposed by Hill et al. (1924), but the peripheral catastrophic model remained the dominate model.

This dominance was due to modifications of the Hill model, such as the incorporation of factors such as energy supply and energy depletion (Costill et al., 2001). In the energy-supply variation of the model, fatigue during high-intensity exercise has been suggested to occur as a consequence of inability to supply adenosine triphosphate (ATP) at rates sufficiently fast to sustain exercise (Costill et al., 2001). In this model, training and diet induces an increase in storage capacity (e.g., glycogen), and an improved ability to utilize metabolic substrates during exercise may provide a greater capacity to produce ATP. In the energy-depletion variation of the model, it has been argued that carbohydrate stores are the limiting (depleting) factor (Costill et al., 2001). This is probably due to the observation that fatigue in prolonged exercise is associated with significant reductions in liver and muscle glycogen (Fitts, 1994; Coggan & Coyle, 1987). Improvements tolerance in exercise-induced hypoglycemia enables exercise to continue (Coggan & Coyle, 1987).

However, neither the energy-supply nor energy-depletion models have general acceptance. In the energy-supply model, exercise ought to terminate when depletion of muscle ATP occurs. However ATP concentration, even in muscles forced to contract under ischemic conditions, does not fall to extreme levels below (Fitts, 1994). In the energy-depletion model, pre-exercise carbohydrate loading ought to produce an ergogenic effect (Hawley et al., 1997). However, although carbohydrate supplementation may improve exercise outcomes in some cases, studies have also shown that post-exercise concentrations of muscle glycogen are similar between normal and supplemented conditions (Rauch et al., 1995; Rauch et al., 2005).

Ulmer (1994) re-introduced the concept of a central governor that regulates muscle metabolic activity and performance through afferent peripheral feedback. He suggested that this central programmer/governor takes into account the finishing point of an exercise period by using previous exercise experience or knowledge of the current exercise period and regulates metabolic demand from the onset of exercise to achieve successful completion of exercise without catastrophic physiological failure. This maintenance of an appropriate metabolic demand by the brain is termed “teleoanticipation”. The central governor described by Ulmer (1994) was developed and explained in a series of articles (Lambert et al., 2005; Noakes, 2000; Noakes et al., 2001; Noakes et al., 2005; St Clair Gibson & Noakes, 2004) culminating in a full description of a model termed the “anticipatory feedback model” of exercise regulation by Tucker (2009) constituting itself as an psychophysiological approach to the phenomenon of fatigue.

This model states that the exercise is regulated from the outset by self-pace of the athletes according to previous exercise experience, knowledge of the expected distance or duration of the current exercise period, and afferent physiological feedback regarding variables such as muscle glycogen levels, skin, and core body temperature. The synthesis of this information allows the brain to predict the most appropriate exercise intensity that will enable optimal performance without causing a severe disruption to homeostasis.

This prediction manifests itself as a rating of perceived exertion (RPE) template. Moreover physical, mechanical and biomechanical variables during exercise are continuously monitored by the brain and this afferent feedback is used to generate the athlete’s conscious RPE. During exercise the conscious RPE is continually compared to the template RPE and will progressively rise and reaches its desired maximum at the predicted termination of exercise. Exercise intensity is modulated according an acceptable level that the brain interprets can be tolerated, taking into account the permanent comparison between template RPE and the actual conscious RPE.

The anticipatory feedback model therefore holds that fatigue, rather than a physical state, is a conscious sensation generated from interpretation of subconscious regulatory processes (Noakes et al., 2005; Crewe et al., 2008). It also suggests that RPE rather than simply a direct manifestation of afferent physiological feedback plays a significant role in preventing excessive exercise duration intensity by acting as the motivator behind an athlete’s decision to stop exercise or to adjust intensity to ensure exercise completion without significant physical damage (Tucker, 2009). Despite the lack of experimental research regarding this topic, some phenomena support this model.

## Pacing strategies

Pacing has been defined as the goal-directed distribution and management of effort across the duration of an exercise period (Edwards & Polman, 2013). To this extent, it also supports the anticipatory feedback model. The concept of pacing in sport and exercise cannot be investigated from a purely physiological perspective (Edwards & Polman, 2013). The distribution of effort is an integral part of racing, for instance, allowing the suggestion that a voluntary behavior (effort) may limit performance rather than absolute capacity of a single physiological system (Noakes, 2011). The role of a central process must be considered in the development of a pacing strategy and how this strategy is carried out.

The presence of pacing strategies is important from the perspective of the proposed anticipatory regulation of exercise performance. It seems that athletes perform exercise less well when an exercise is unfamiliar to them and the demands of the exercise are unclear (Paterson & Marino, 2004). Furthermore, athletes voluntarily reduce their exercise intensity when confronted with factors such as high ambient temperature or humidity but this reduction in intensity is in advance of any actual physical need to do so (e.g., before significant increases in body heat storage) and before impairment of performance occurs as a result of any physical system failure (Dugas et al., 2009; Marcora et al., 2009).

Alterations in exercise intensity during endurance exercise have been reported in the first few minutes of exercise, before any peripheral physiological cause of fatigue could be present. These findings suggest that the modification of exercise intensity (pacing) during self-paced exercise is conducted in anticipation of, rather than as a result of, physiological system stress/failure (Edwards & Polman, 2013; Marino, 2004). As Edwards and Polman (2013) state, if pacing strategies are used as a way of enabling successful exercise completion without physical damage, then previous experience along with accurate knowledge of exercise demands is critical. The use of pacing strategies in sport and exercise may provide support for aspects of the anticipatory feedback model but also refutes aspects of the peripheral linear catastrophic model. During self-paced exercise, a pacing strategy is observed that is dependent on the environment, exercise demands and goals and afferent physiological feedback, which is in line with the anticipatory feedback model. If an athlete’s pacing strategy is determined by the accumulation of metabolic products, or depletion of energy stores as predicted by the peripheral linear catastrophic model, athletes would always begin exercise at an unsustainable pace and gradually slow due to the negative effect of the peripheral variables (Noakes, 2012), which is not supported in practice. The peripheral linear catastrophic model states that the only pacing strategy it is possible to follow in sport and exercise is linear. The model simply does not allow for the existence of other strategies, but the evidence for these other strategies is plentiful.

The prior knowledge/experience of the exercise may be important information that the brain uses to select an appropriate exercise intensity. Research into the use of pacing strategies in exercise has confirmed that ability to pace accurately is improved with training and experience (Mauger et al., 2009; Micklewright et al., 2010).

## The end spurt phenomenon

The end spurt phenomenon supports the anticipatory feedback model (Millet, 2011). This phenomenon is characterized by a significant increase in exercise intensity near the end of race, regardless of how hard the athlete was pushing throughout the event. During exercise, there is often a degree of uncertainty about the precise end point of the exercise period and the type of effort that will need to be expended. These factors would influence the pace of the athlete at any given time and could necessitate alterations to pace that could not be anticipated prior to the exercise. This uncertainty may result in the maintenance of a motor unit and metabolic reserve through exercise (Tucker, 2009), because the athlete cannot be certain of what may occur in the remainder of the exercise period and (subconsciously) holds something back to enable them to respond to any potential physical challenges and to complete the exercise period without significant homeostatic disruption. When the endpoint of exercise draws near the uncertainty decreases and the reserve is no longer required, so the athlete can significantly increase metabolic demand due to the increase of speed/power output. This is possible evidence that fatigue is not caused by inability of muscles to produce force (Millet, 2011).

## Influence of knowledge duration of the task

The importance of knowledge of exercise duration as a regulator of exercise performance is supported in research studies about the knowledge (or lack) of the task duration. These studies are commonly named "deception." In these studies participants believe they are exercising for a given time period, but almost at the completion of this time are asked to continue exercise for longer.

One of the first studies was conducted by Baden et al. (2005) where participants were asked to run on a treadmill at 75% of their peak speed. On one occasion, they were asked to run for 20 minutes and were stopped at 20 minutes. On a second occasion they were asked to run for 10 minutes, but at 10 minutes were asked to run for a further 10 minutes. On a third occasion, they were asked to run but were not told for how long (they were stopped after 20 minutes). All of the trials were conducted at the same running speed and all lasted for 20 minutes. Participants´ RPE increased significantly between 10 and 11 minutes in the 10-minute deception trial, which was immediately after the deception was revealed that participants were required to continue exercising. These changes to the perception of effort and pleasure occurred despite no changes in running speed in physiological responses to the exercise period. The significant increase in RPE when participants were required to exercise for longer than originally thought has also been found by other researchers using very similar protocols (Eston et al., 2012).

The study of Eston et al. (2012) found the effect also increased in the last few minutes of exercise, perhaps due to the participants being aware that the exercise was almost over. These findings relate to the end-spurt phenomenon: an increase in pleasurable feelings towards the end of exercise may play a role in allowing the end spurt to occur. Also Eston et al. (2012) found no increase in effect in the trial when participants did not know how long they were to exercise for and the effect continued to decrease throughout this trial.

It seems that knowledge of exercise duration is crucial for appropriate regulation of exercise performance, as suggested by the anticipatory feedback model. The increase in RPE when deception is revealed may reflect a disruption to the feed-forward/feedback mechanism, which is crucial for RPE and is also suggested by other studies (Billaut et al., 2011; Tucker, 2009).

Other important data revealed is that both RPE and physiological responses (oxygen consumption, heart rate) are lower during exercise with an unknown duration compared to know duration, despite no difference in exercise intensity (Baden et al., 2005; Eston et al., 2012). These responses may reflect a subsconscious improvement in exercise economy in effort in order to conserve energy due to unknow duration of exercise bout. This again highlights that knowledge of the endpoint of exercise plays a large role in the perceptual and physiological responses to that exercise period (Morton, 2009). This is further evidenced by the observation that RPE responses to exercise are robust when the exercise duration is known, even when no information is provided to the participant about how much distance has been covered or duration is remaining (Faulkner et al., 2011).

Research findings from prior-knowledge studies, provide further evidence for some process by which athletes can hold back a physiological reserve during exercise of an uncertain duration (Eston et al., 2012). These findings also provide support for a key role of CNS in the regulation of exercise performance (Meeusen et al., 2006), perhaps to ensure the maintenance of homeostasis and the presence of an emergency "reserve" of energy/physical ability (Eston et al., 2012; Swart et al., 2012).

## The relationship between rate of rise in RPE and performance

The principles of self-regulation suggest that RPE methods of monitoring training are effective across all types of exercise. The American College of Sports Medicine position statement recognizes RPE as a valid and reliable indicator of level of physical exertion. RPE represents a conscious perception of effort experienced during exercise and consequently has considerable practical value to the athlete. In addition, exercise corresponding to higher levels of energy expenditure and physiologic strain consistently produces higher RPE. Moreover, studies showing a relationship between changes in RPE during exercise and exercise duration shed further light on the anticipatory feedback model, as they suggest that RPE is a crucial regulator of exercise performance. Also, the suggestion that RPE can be modified from the onset of exercise by changes in ambient temperature and exercise intensity (Crewe et al., 2008; Tucker at al., 2009) in advance of actual physiological changes and that this change in

RPE also alters exercise intensity provides support for a role of RPE in the anticipatory regulation of exercise.

This also leads to the suggestion that RPE may not be a direct reflection of an exercising athlete's physiological state but may instead be an anticipatory sensory regulator of exercise performance. RPE may change during the exercise in anticipation of physiological changes occurring, not as a result of those physiological changes. This suggestion also requires us to consider the nature of fatigue itself as pointed out by Baden et al. (2005).

## Criticisms

An interesting alternative to the brain regulation model was proposed by Marcora (2008) who, while appearing to accept that the brain regulates muscle recruitment and limits performance also questioned whether there is a need for a central regulatory governor. This perspective suggest that the search of a central governor in the subconscious brain could be similar to that currently pursued by reductionists searching for a singular cause of fatigue.

The anticipatory feedback model states that a central regulator in the brain holds subconscious control over skeletal muscle recruitment during exercise. However, the presence of a single region of the brain that is dedicated to regulating exercise performance is highly unlikely, as the suggestion goes against all we know of how the brain functions, namely as an incredibly complex integrated organ where each region contributes to overall brain function (Edwards & Polman, 2013). This may also explain why the specific brain region thought to be the central governor has not been located. The model also states that the perception of effort is crucial in deterring the individual from continuing on to dangerous levels of exercise. However, Marcora (2008) points out that if a subconscious central regulator has control over skeletal muscle recruitment, then the conscious perception of effort is in theory redundant, as the subconscious regulator will stop the individual from exercising to a dangerous level regardless of how much motivation there is continue. Marcora (2008) states that the anticipatory feedback model could exist without the inclusion of effort perception and propose an alternative, simplified model to explain some of the findings attributed to the anticipatory feedback model. This model states that exercise termination occurs when the effort required to continue exercise is equal to the maximum effort that the individual is willing to provide, or when the individual believes that they have provided a true maximal effort and therefore perceives the continuation of exercise to be impossible (Marcora, 2008). Increasing the effort that the individual is willing to put into exercise will improve exercise tolerance provided it does not exceed what the individual perceives to be their maximal effort (Marcora, 2008). Effort perception remains important but the existence of a central governor in the brain is not required. It also been suggested that the progressive increase in RPE over time and at different rates in response to changes in exercise intensity and ambient temperature can be explained by factors other than a central regulator that uses effort perception as a safety brake. Marcora (2008) contends that RPE is generated via signals leaving CNS specifically referred to prolongated submaximal exercise at a constant workload. This is limited and highlighted in a rebuttal to the paper of Marcora (2008) by Noakes & Tucker (2008).

These authors discuss that RPE has been shown to alter almost from the onset of exercise as a result of differences in exercise intensity and ambient temperature and that this is finding is not well explained by Marcora's suggestion that RPE increases due to requirements for a progressive increase in CNS discharge. Also Noakes & Tucker (2008) argue that increased motor commands from CNS could not happen without some form of afferent feedbacks and thus, the model proposed cannot work without afferent sensory feedback, which makes similar to the anticipatory feedback model (Noakes & Tucker, 2008).

# Fatigue and Soccer Performance

## Features and capabilities of the soccer players

Soccer is a high intermittent sport, in which the player performs different activities in different intensities, distributed acyclically over a prolonged period (Bangsbo et al., 2006). During the game, the players make 1000-1400 short duration actions that change every 3-5 seconds involving actions with and without the ball, such as running at different velocities, dribbles, tackles, direction changes, accelerations, decelerations, jumps, kicks, running backwards and sideways, disputes, etc. … (Laia et al., 2009; Mohr et al., 2003) presented according to game circumstances (Drust et al., 2007).

The mean of the maximal oxygen consumption of soccer players ($VO_2$ max) varies between 55-70 mL/kg min$^{-1}$, with individual values above of 70 mL/Kg min$^{-1}$ (Reily et al., 2000; Wisloff et al., 1998). The anaerobic threshold of the top players is set between 80-85% of $VO_2$ max and 80–90% of the maximum heart rate (Helgeurd et al., 2001; Stolen et al., 2005). In relation to anthropometric values, the height of the players present values between 167–180 cm. The body mass of the players present values between 75–80 kg with 10% body fat (Reily et al., 2000; Sheppard, 1999). These values are not predictive of performance, however (Bangsbo, 1994).

## Physiological demands of soccer

A soccer game usually has a duration of 90 min, played in two halves of 45 min with a 15 min halftime break. The effective time of the game is nearly 50 min or 55% of the total duration of the game (Castellano et al., 2011). In this time, top-level players covered between 10 and 13 km (Bangsbo et al., 2006) of medium intensity effort near the anaerobic threshold (80%-90% $HR_{max}$) with an 2.2/18 seg of an intermittent effort profile corresponding an 1:8 ratio of work/rest (Vigne et al., 2010), though these distances may vary somewhat depending on the system game presented by the team (Bradley et al., 2011).

A soccer game requires a great capacity to make intense and repeated efforts supported by capabilities such as speed, muscle strength, anaerobic power, agility or maximal aerobic power (Rampinini et al., 2009). At the same time, the game requires a large number of technical and tactical decision-making skills, and all of these capabilities are used in the context of pressure and fatigue (Gabbett et al., 2009). The ball time possession per game per player is 44.6–74.3 sec and the number of touches on the ball by individual possession is 1.9–2.2, revealing the importance of the game without the ball and speed actions (Dellal et al., 2004).

In respect of heart rate as a physiological demand indicator, Ali & Farraly (1991) determined an average value of 172 beats/min in semi-professional soccer players during the game. Mohr et al., (2004) found an average value of 160 beat/min in professional players corroborating with the Bangsbo (1994) study that found the same results. Based in these results we can concluded that the mean heart rate during a soccer game present values between 160–175 bpm varying at times up to 190 bpm during extreme activity (Bangsbo, 1994). Therefore, the aerobic metabolism is the most required during the game, corresponding to 90% of the energy demand. Previous studies also found 98% and 85% of the maximum values percentages of maximal and average heart rate (Bangsbo et al., 2006; Krustrup et al., 2005), indicative of a high physiologic demand. This high physiologic demand is also supported by some recent studies that show strong oxidative stress in players during a game, increasing the oxidant component of their blood (Andersson et al., 2009; Ascensão et al., 2009) and an increase in the inflammatory response, as expressed by an increase in leukocytes, more specifically neutrophils, after a soccer game (Ispirlidis et al., 2008; Rowsell et al., 2009).

Regarding the energy expended, the value found in the literature is around 5700 KJ (Reily et al., 2000) mainly from muscle glycogen, blood glucose (from the hepatic reserves) and free fatty acids (Bangsbo, 1994). Recently, some studies reported that after a game, some biochemical markers such as creatine kinase, urea, uric acid, myoglobin and C-reactive protein are changed (Anderson et al, 2008), confirming the existence of metabolic and mechanical stress, cycle activation of purines and amino acid degradation (Brancaccio et al., 2007).

Considering the total time of the game, the energy expended is almost all derived from aerobic metabolism (Bangsbo, 1994), although the decisive actions such as sprints, jumps, changes of direction, and kicks, were more dependent on anaerobic metabolism (Stolen et al., 2005). Indeed the participation of different energy systems should be looked at in an integrative perspective. For example, it is estimated that a top-level player performs 150–250 short intense actions during a game (Mohr et al., 2003) with a high ratio of phosphocreatine degradation during different parts of the game indicative of the fact that the phosphocreatine was used in ATP resynthesis. However is also known that aerobic metabolism is critical for renewal of phosphocreatine levels (Hof & Helgerud. 2004).

In order to better determine the importance of anaerobic metabolism some studies measured blood lactate concentrations before, during and after a game. The results shows values of lactate concentrations between 2–10 mmol $L^{-1}$ during the game with individual values above 12 mmol $L^{-1}$ (Bangsbo et al., 1991; Krustrup et al., 2006) showing that anaerobic metabolism has a decisive importance during different periods of the game (Mohr et al., 2005).

## Physical requirements in soccer

During a soccer game, the player runs intermittently over the total distance (10-13 km), using either aerobic or anaerobic metabolism. In a study of elite players, Vigne et al. (2010) observed that during the competition, players move at a rate of 121.82 ± 9.57 m $min^{-1}$, of which 38.9% is spent walking (3477 ± 1433 m), 29.5% running at low intensity (2631 ± 1097 m), 13.3% running between 13 and 16 km/h (1192 ± 487 m), and 8.4% running between 16 and 19 km/h (750 ± 314 m) and 9.8% sprinting (878 ± 433 m). Regarding the sprint demands, the literature indicates an overall related distance of 16 m with sprint durations between 2 and 4 seconds and this action is repeated approximately every 70–90 seconds of the game, which corresponds to 0.5% –3% of effective playing time.

## Fatigue during a soccer game

Regarding the demands on the players there are a number of aspects that can influence their physical performance that have been studied. Although there is a pattern of movement and physical performance, variables such as place of the game, the type of competition, the positions of the players, the density of the game, the opponent's level and even play style of the team may have direct influence on performance.

However, independent of these aspects, the performance of the players seems to follow a different physical pattern between the first and second half of the game. According to the literature, there is a reduction of the total distance and activity at high intensity from the first to the second half (Di Salvo et al, 2009; Mohr et al., 2003; Vigne et al., 2010) with less lactate concentration, indicative of this effort profile (Stolen et al., 2005). However Rampinini et al. (2007) found that players who traveled a less distance than average in first half, in the second half traveled more distance in high intensity. A recent study (Andrzejewski et al., 2012) also showed that the distance traveled during the second part of the game was significantly higher. The authors explained this difference was due to the players, during the first half, trying to identify and adjust their capacities to their opponent.

The literature also mentions an important reduction (20–40%) in the amount of running at high intensity specifically in the last 15 minutes of the match compared with the initial 15 minutes (Bradley et al, 2009; Mohr et al., 2003). The studies also show that 5 min of greater intensity at the beginning of the game are followed a decrease of 12% of the distance covered at high intensity in the 5 min following, compared to the average of the values encountered during the game (Mohr et al., 2003), with increased recovery times between high intensity efforts (Bradley et al., 2009) and reduction of the actions by 11% in the second half. These results indicate that soccer players present two fatigue patterns: a long fatigue pattern associated with long durations (from start of play toward the final); and a short fatigue pattern (temporary fatigue), which takes place according to the different circumstances of the game (Mohr et al., 2003) with consequent reduction of the ability to perform repeated sprints (Krustrup et al., 2006) and conditioning some abilities. This is also referred to as transient fatigue.

After implementation of fatigue protocols during or after games, some studies observed a diminution of the performance of the sprint, countermovement jump, peak isokinetic strength in knee flexion-extension (Ascenção et al., 2008; Fatouros et al., 2009), a decrease of 13% at full strength (Rahnama et al., 2003), deterioration of kicking performance and changes in the cinematic of the knee. These aspects suggest a fatigue situation felt by player during the game. Some mechanisms that are suggested are depletion of energetics substrates, dehydration, fever, lactate accumulation, hydrogenous accumulation, changes in intramuscular pH, interstitial potassium accumulation, and decrease of PCr and ATP (Mohr et al., 2004; Mohr et al., 2005; Krustrup et al., 2006). In addition, the physiological mechanisms responsible for fatigue appear to change at different stages of the game (Mohr et al., 2005). The temporal fatigue that the player feels at different times during the game is due to factors such as accumulation of lactate, a decrease in muscle pH, decreased deposits PCr, decreased ATP deposits and consequent accumulation of inosine monophosphate and ammonium accumulation inorganic phosphate, and potassium accumulation in muscle interstices (Alghannam, 2012; Bangsbo et al, 2006; Mohr et al., 2005).

Of all these factors, the accumulation of interstitial potassium seems to be the main causative mechanism. Accordingly, it has been suggested that at the point of exhaustion, the concentration of interstitial potassium rises to values of 12 mmol/L (Mohr et al., 2004; Nielsen et al., 2004). These levels are high but also required for the depolarization of potential in the muscle membrane and reduction of the strength of discharge (Cairnes and Dulhuntry, 1995). The extracellular potassium accumulation and associated electrical disturbances are also identified as important causes (Mohr et al., 2005).

With respect to the accumulated fatigue during the game until its end (long-term fatigue duration), depletion of energy deposits, especially glycogen, under thermal stress conditions dehydration and hyperthermia are also considered to be factors (Bangsbo et al., 2006; Mohr et al., 2005; Rahnama et al., 2003).

Regarding the decrease in performance observed at the beginning of the second half, it may be due to a loss of muscle temperature, which happened during the interval (Mohr, 2004), although in this case, this is a factor that can be minimized with a team strategies during the break.

## The influence of fatigue on kicking performance

Kicking is the most widely studied soccer skill (Katis & Kellis, 2007). Is defined as the ability of a player to consciously hit the ball with their foot and is considered a fundamental skill for soccer player performance (Kellis & Katis, 2007; Masuda et al., 2005) because it is a determinant factor for scoring goals (Kellis & Katis, 2007). In biomechanical terms, the soccer kicking action can be described as a movement pattern in which the distal segments of the leg are allowed to lag behind the proximal segments as they move forward (Dörge et al., 2002). Kicking can also be described as a set of forces in which the foot is the last and fastest segment to intervene in the open kinetic chain (Young & Rath, 2011). Therefore, the foot velocity at the initial instant of the impact correlates with the ball velocity (De Witt & Hinrichs, 2012; Levanon & Dapena, 1998).

Due to its inherent importance, the study of kicking in soccer has raised scientific interest, which has resulted mainly in studies from the point of view of biomechanics, technical analysis, muscular involvement in the kicking action and even footwear studies (Forestier and Nougier, 1998; Madigan and Pidcoe, 2003; Sterzing, 2010). These studies show that there are many factors that can determine the results of a soccer kick, such as body posture, technical approach, footwear, muscle strength and power output and fatigue.

The performance of soccer kicking depends on the kicked ball velocity and accuracy (Lees et al., 2010; Lees & Nolan, 1998). Although accuracy is an important factor, kicking performance has been evaluated predominantly by the maximum ball velocity (Giagazoglou, et al., 2011; Katis et al., 2013; Markovic et al., 2006). The role of ball velocity in soccer has been investigated by several studies that have investigate various factors that contribute to the maximal kicking velocity. These factors include the effect of gender (Barfield et al., 2002; Shan, 2009), limb dominance (Barfield et al., 2002; Nunome et al., 2006), practice time (Shan, 2009), competition level (Cometti et al., 2001), and playing position (Khorasani et al., 2010). Other studies have explored the relationship between the ball velocity and the ability to strike a target (kicking accuracy) (Lees et al., 2003), as well as different kicking techniques such as the different contact surfaces of the foot with the ball (Katis & Kellis, 2010; Levanon & Dapena, 1998; (Nunome et al., 2006) and kicking with or without a previous run-up (Kellis et al., 2004; Masuda et al., 2005; Scurr & Hall, 2009).

Kicking accuracy is also considered to be an important factor of success in soccer, and it can be defined as the ability to kick the ball at a specified area (Finnoff et al., 2002). However, this factor has been relatively understudied compared with velocity (Kellis & Katis, 2007) and there is no standard procedure for the evaluation of accuracy of a soccer kick. Despite several studies that have evaluated the relationship between different kinematic parameters and the accuracy of a soccer kick (Lees et al., 2003; Teixeira, 1999), the complex requirements involved in the performance of an accurate kick limit their validity because they do not replicate real game situation in which there are dynamic changes of context. Nevertheless, maximal ball velocities for kicks under accuracy demands are significantly lower in comparison with kicks that are performed without accuracy requirements (Andersen & Dorge, 2011; Teixeira, 1999).

The velocity and accuracy of a soccer kick are the main factors that contribute to a successful outcome. However, few studies have explored the relationship between velocity and accuracy (Kellis & Katis, 2007). According to the Fitts law (Fitts, 1954), an inverse relationship exists between speed and accuracy, which can be determined by a logarithmic equation.
Recently, the notion of a speed-accuracy tradeoff has received renewed interest in several fields such as verbal instructional (Van den Tillaar, 2014) and cognitive neuroscience (Heitz, 2014). It could be of interest to apply this approach to soccer to reach a better understanding of the relationship between speed and accuracy of a soccer kick.

Van den Tillaar and Ulvik (2014), considering the influence of instruction, showed that kicking accuracy was only affected when the main priority was hitting the target. According to the same authors (2014) when the main focus is upon velocity and the secondary aim is accuracy or the opposite, no difference in velocity or accuracy is found. Only when the sole aim is accuracy does the velocity decrease and the accuracy increase.

Protocols measuring soccer kick performance vary across studies with regard to the different variables that are evaluated such as the angle, distance, and/or the number of steps in the previous run-up (Kellis et al., 2004).

Some studies include a stationary-ball kicking procedure, and a few studies also used a rolling ball procedure, either on the ground (Mario et al., 2011) or after a drop (Markovic et al., 2006). The run-up in kicking testing procedures has, in some cases, been left to the free choice of the players (Scurr & Hall, 2009), whereas in other studies, players were given instructions regarding the number of steps, distance, and/or the approach angles. This disparity in protocols does not allow for reliable comparisons across different studies.

In respect to the influence of fatigue, it is considered an important factor in soccer and in soccer skills ability (Mohr et al., 2005; Stone and Oliver, 2009), although few studies have examined the effect of fatigue on soccer kicking performance and especially in the analysis of ball velocity. Some studies have tried to explain the effect of fatigue on physical conditioning variables related to biomechanical and muscular analysis in the lower limbs based on the effects of prolonged intermittent specific soccer exercises. It was found that after fatigue, an increased electro-mechanical delay and knee joint laxity and a significant decline of maximum isokinetic moment of force of both knee extensors and flexors occurs. (Drust et al., 2000; Rahnama et al., 2003). It was also found that fatigue developed during a match after relatively intense intermittent activities negatively affected short-passing performance ability as shown by the increased number of errors made during the test and the time required to perform the test (Rampinini et al., 2008).

With respect to the studies considering soccer kicking performance, most of them occur in conditions of no fatigue (Lees and Davies, 1988). Only three studies have investigated the effect of fatigue on kicking following intermittent exercise protocols. Kellis et al. (2006) found a decline in kicking ball velocity following a fatigue protocol. However, Currell et al. (2009) reported that kicking ball velocity performance did not change during simulated match play and Russell et al. (2011) also found no evidence that fatigue affects the average ball velocity. However, Russell et al. (2011) did conclude that peak kicking velocity tends to reduce in the second half of a soccer match simulation protocol (including passing, dribbling and shooting skills). For all three studies, the results are conflicting and inconclusive. There is evidence that shows the effect of fatigue on biomechanical and muscular performance, but the practical effect upon soccer skills performance and kicking is still unclear. In our view, the protocols used may limit the validity of the results, as they were based on few measurements of ball velocity. Kellis et al. (2006) took measurements at three intervals (before induction of fatigue; during the protocol; and at the end) and Russell et al. (2011) took measurements before and after the first and second half. For a proper understanding of the temporal changes, it seems essential to provide a longer test period to know what really happens to ball velocity under the influence of fatigue.

## The psychophysiological approach to soccer

It is difficult to characterize the physical demands of soccer such as the reductions in running performance in the second half or temporarily after the most intense period of games and due to this fact the precise fatigue mechanisms in soccer continue to be clarified (Edwards & Polman, 2014; Paul et al., 2015). Besides what can be attributed to physical and physiological reasons, it seems reductions in performance could be attributed to causes such as pacing strategies, contextual factors, prior experience/knowledge or a combination of mutually inclusive factors (Paul et al., 2015). This should force a more comprehensive and integrated investigation of these factors based on a psychophysiological approach.

### The concept of pacing in soccer

An important point related to the psychophysiological approach is the pacing strategies of the soccer players. The concept of pacing, adjusted to team sports, is defined by Gabbett et al. (2015) as the management and strain distribution during an exercise in which the player, consciously and unconsciously, tries to complete the activity in a reasonable physiological state, controlling the onset of fatigue. Afferent sensations are sent from the musculoskeletal and cardiovascular systems to the central nervous system, where the pacing strategy is altered based on the brain’s interpretation of the perceived exertion (Edwards & Noakes, 2009; Gabbett et al., 2015). This concept of pacing takes into account previous topics of temporary fatigue during team sports matches but suggests and adds alternative mechanisms for the observed fluctuations in running performance in matches based on the psychophysiological system (Edwards & Polman, 2014; Waldron & Highton, 2014). This view does not diminish the importance of physiological factors, but it specifies and enhances the crucial role of the brain in the regulation of physical effort.

Various pacing profiles seem to characterize running performance in matches among soccer players (Waldron & Highton, 2014). Whole-match players supposedly adopt a “slow positive” pacing profile, characterized by a gradual decline in total and high-intensity running. In contrast, part-match players are thought to select either “all-out” or “reserve” strategies, depending on their role in the match, although this all-out end spurt may not be a common event. Perhaps the most logical way of viewing pacing is to consider it as a neural buffering process to prevent premature physical exhaustion. This buffering process may avoid the necessity to conclude an exercise period prior to its scheduled finish, or attain an unnecessarily high peak power output prior to the specific point where it is most required. If pacing is a buffering mechanism that enables athletes to successfully complete tasks, then the prior experience and accurate knowledge of the task are crucial to success.

## The importance of the knowledge duration of the task in soccer

It seems that the brain initiates a strategy at the start of a match, based on both the knowledge of the duration of the game and prior experience. Recently, Waldron & Highton (2014) demonstrated that team-sport athletes that are required to compete for relatively short periods (e.g., substitutes) set a higher initial pacing strategy and exhibit a significantly greater end spurt than athletes required to play the entire match. This suggests that shorter anticipated exercise periods are associated with greater playing intensities. In a more controlled approach, Billaut et al. (2011) examined the influence of prior knowledge of sprint number on repeated-sprint exercise performance. The authors concluded that pacing occurs during repeated-sprint exercises in anticipation of the number of efforts that are expected to be included in the exercise period.

In fact, the knowledge of the duration initially employed in continuous sports is known as a significant factor in developing a pacing strategy and has been demonstrated to be a major factor in the allocation of physiological and psychological resources during continuous exercise, and has also been recently investigated in intermittent exercise (St Clair Gibson & Noakes, 2004; St Clair Gibson et al., 2006).

Despite advances on this topic, few studies have examined the influence of pacing as an explanation of the reduced work output in team sports. This is probably because of the difficulties in identifying an appropriate model that represents the complexity of the energetic demands and movement (Edwards & Polman, 2014). Additionally, in team sports it is difficult to isolate effects from the factors associated with the pacing concept. One study in rugby attempted to investigate its influence on the pacing strategies employed during game-based activities and the authors conclude that rugby players alter their pacing strategies based on the anticipated endpoint of the exercise period (Gabbett et al. 2015).

## The influence of prior knowledge on pacing strategies in small-side games

Small-sided games (SSG) are applied externally as part of the training (Hill-Haas et al., 2011) and in recent years have become a central part of soccer training methodology (Hill-Haas et al., 2011). Structured collective duels (collaboration/opposition) develop in a common space with simultaneous participation. SSGs are performed in confined spaces, with rules modifications, and involve fewer players than full soccer matches (Hill-Haas et al., 2011; Little, 2009).

SSG use is based on the premise that team performance improves when players are encouraged to concentrate on the game situations replicating the specific demands of the sport (Owen et al., 2004). Their use appears to result in effective and specific methodology (Gabbett & Mulvey, 2008) in which the player feels more motivated (Flanagan & Merrick, 2002). In addition, SSGs also allow training in decision-making, optimizing the training time and the construction of the team game idea (Hill-Haas et al., 2011).

In SSGs as in full matches, it appears that information about the duration of the task may condition the performance of players and their self-regulation of effort. In the only study performed to date for team sports (rugby; Gabbett et al., 2015), the authors found greater amounts of high-speed running during the initial phases of game-based activities of an anticipated shorter duration and more low-speed activity during the game-based activities of anticipated longer duration. They conclude that during rugby game-based activities, players alter their pacing strategy based on the anticipated endpoint of the exercise period.

## Mental Fatigue

It is evident that the performance of soccer activities does not depend only on energy systems. Mental fatigue, in addition to the physiological fatigue is a factor that has received some attention recently, although overall has been little studied. Mental fatigue has been defined as a psychobiological state caused by prolonged periods of demanding cognitive activity and is characterized by subjective feelings of tiredness and impaired attention and decision making (Marcora et al., 2009; Knicker et al., 2011). The decline in running performance during matches is often attributed to a player’s physical capacity but it is possible that mental fatigue interacts with the processes that limit physical ability. Smith et al. (2014) recently examined the effect of experimentally induced mental fatigue on performance during a 45-minute self-paced, intermittent team-sport simulation test. The objective was to identify potential physiological and psychological mechanisms underpinning any change in performance. The findings demonstrated that mental fatigue increases the perception of effort and reduces overall and low-intensity running during intermittent running.

In fact, it seems that mental fatigue is understood as a multifaceted paradigm: dependent of actions as game unfolds, expectations integrate with contextual factors (e.g., score or time in a match), phase of play (e.g., team in possession), and the athlete (e.g., age, fitness, and skill level), opponent (e.g., position), or environmental characteristics (e.g., temperature) to provide a confirmation or modification of the anticipated response (Macgarry et al., 2002). This dynamic seems to be very dependent on the perception of effort/reward. For example, if the perception of effort does not follow expectations, the associated motivation is weakened.

Similarly if the player feels very pressured by an opponent, they may display signs of fatigue, a decrease in performance that is not due to a physiological but a mental cause. Despite this evidence, further studies seem to be required to develop this paradigm.

## Measuring fatigue in soccer: indicators of physiological demands

Although there is a wide variety of methods used to assess internal load training, heart rate (HR), blood lactate levels and rated perceived exertion (RPE) are still considered valid and objective methods to evaluate exercise load (Dellal et al., 2012). Technologies such as GPS (accelerometry integrated), and lactate analyzers have allowed the affordable monitoring and evaluation of game/training performance (Carling et al., 2008; Eniseler, 2005).

### Heart Rate

Specifically, HR has been one of the physiological indicators used in monitoring exercise intensity in soccer because of its ease of use and adaptability to any situation (Achten & Jeukendrop, 2003). With respect to the intensity of the game, heart rate is pointed to as a strength indicator for players of different levels, age and gender (Helgerud et al., 2001; Stroyer et al, 2004). Moreover the heart rate is linked to $VO_2$ max, which is itself also a measure of exercise intensity (Coutts et al., 2009; Espósito et al., 2004; Gamble et al., 2004; Impellizzeri et al., 2004). Espósito et al. (2004) analyzed the relationship between HR and $VO_2$ in young soccer players during a specific protocol on the soccer field and compared these values with laboratory testing on treadmills and confirmed that HR is an effective indicator of the specific metabolic stresses in soccer. Drust et al. (2000) developed an intermittent protocol that simulates the physical demands of soccer and showing the relationship between HR and $VO_2$ concluded about the accuracy in the use of HR to estimate the physiological demands of soccer game. Also Hoff et al. (2002) studied whether the heart rate is a valid indicator for measuring exercise intensity during soccer small-side games (SSG) and an specific circuit based on the dribble and found that during SSG, the intensity achieved was 91.3% HR max and was 93.5% for the circuit, concluding that HR is a valid indicator of exercise intensity.

### Blood lactate concentration

Exercise intensity may also be expressed as a function of the blood lactate concentration measured by various portable models (Mujika, 2006; Swart & Jennings, 2004). In soccer games, the concentration of lactate in the blood is a result of anaerobic glycolysis and has been widely used as an indicator of exercise intensity (Bangsbo et al, 1991; Capranica et al., 2001; Eklebom, 1986; Krustrup et al, 2006).

However, it is necessary to consider factors such as error rate of portable analyzers, depletion and individual reserves of glycogen, the type of exercise, temperature at which the analysis is conducted, and the training status (Swart & Jennings, 2004), all factors which require a careful analysis of the results. For theses reasons, knowledge of lactate values does not provide immediate information on the impact of load and its use in isolation limits the analysis of internal load. Although it is a valid indicator, its use should be accompanied by other indicators for a more accurate analysis of the data (Hill-Haas et al., 2011; Impellizeri et al., 2005).

### Rate of perceived exertion applied in soccer

The perceived exertion, based on Borg Scale (1982), is a handy tool and shown to control the intensity of the soccer tasks (Impellizzeri et al., 2004). The scale is based on the perception of effort by allowing players to adjust and control the intensity of the workout (Robinson et al., 1991).

The RPE scales have been related to physiological parameters such as lactate, heart rate, $VO_2$ max (Chen et al., 2002), and although initially were proposed for individual endurance disciplines (Foster et al., 1995) recent research shows that they are useful to quantify the training load in team sports (Foster et al., 2001; Scott et al, 2013; Impellizeri et al., 2004) and particularly in soccer.
Impellizzeri et al. (2004) applied the RPE method to quantify the training load in junior soccer players and assessed the correlation of RPE with different load quantification methods based on HR, finding significant correlations between RPE and HR-based load quantification methods between the methodologies based on RPE. Alexiou & Coutts (2008) replicated the study with elite soccer players and also concluded that the RPE method can be considered a good internal load indicator since it significantly correlated with HR.

Coutts et al. (2009) also evaluated the relationship between heart rate, RPE and lactate in different soccer training exercises and concluded that the RPE method is a more valid indicator of the overall exercise intensity than any of the other indicators alone. Also Gabbet & Domrow (2007) found significant correlations with HR and blood lactate concentration suggesting the use of RPE method.

To provide more robustness to this method, Haddad et al. (2013) showed that the use of RPE method is a valuable method to quantify the training load although we must always take into account the possibility that there are players who overestimate or underestimate the training load (Borresen & Lambert, 2008). Haddad et al (2013) also recommended that individual comparisons between players should be avoided and that results should be interpreted to give an overall perspective of the training or the task.

As part of a practical application in soccer drills, studies such as Hill-Haas et al. (2009) and Dellal et al. (2011) used RPE scales for determining the intensity of exercise and confirmed that it was a valid tool for quantifying the training load.

## Global positioning system technology

Recently, global positioning system (GPS) technology has been used in soccer to quantify the movement demands of players during training and competition (Carling et al., 2008). GPS allows direct tracking of a single player (Aughey & Fallon, 2010; Edgecomb & Norton, 2006; Macleod et al., 2009) and provides information on characteristics the movement of the players (frequencies, durations and distances and impacts, velocities and accelerations). This technology offers the possibility to gather information about the physical demands of the players in real time via an antenna connected to a computer, enabling the transmission of position data and displacement from devices that the players carry. The correlation is high ($r > 0.93$) when comparing the distances at a soccer game using traditional video analysis, but with differences up to 24 % in high intensity distance traveled (Aughey & Fallon, 2010). The limitation of GPS in that it can record only the linear aspects of displacement can be supplemented with other information that enriches the description of the physical demands as tackles, contacts, impacts, and directionality of displacement (Macload et al., 2009).

The application of this technology to sports performance and research has recently been made in studies that analyze the physical demands on players during different game-based activities. These studies attempt to analyze the importance of variables that affect physical demands such as the number of players participating per team (Brandes et al., 2011; Hill-Haas et al., 2009); workout regimen (Hill-Haas et al., 2010); manipulation rules (Hill-Haas et al., 2009); changing the number of team mates and opponents (Torres-Ronda et al., 2015); different competitive level players (Dellay et al, 2011); different number of contacts allowed with the ball by individual possession (Dellal et al., 2011; San Román-Quintana et al., 2013); repetitions performed during training (Dellal et al., 2011;. Dellal et al, 2012) and field dimension and skill level (Silva et al., 2014). Other studies using GPS technology analyzed how to develop teams (Koklu et al., 2011); spatial orientation (Castellano et al., 2012); small-sided games in comparison with formal game (Dellal et al, 2012); positional status, time-motion variables, heart rate and tactical behavior (Sampaio et al., 2014).

Accelerometers have also been included in GPS devices, and this type of system has been validated to measure the physical demands of team sports (Boyd et al., 2001), allowing the analysis of characteristics shared by intermittent-activity sports, such as jumps, tackles and other different activities besides linear movement. These aspects are particularly important in soccer to analyze high-intensity demands, because these could be underestimated, if not analyzed as accelerations performed (Varley et al., 2011).

Some investigations have used accelerometry in the context of team sports (Johnston et al., 2012; Cunnife et al., 2009; Montgomery et al., 2010), presenting it as an aspect that is sensitive to changing game situations or training tasks. Moreover, it has a high correlation with physiological indicators such as HR or blood lactate (Montgomery et al., 2010). Confirming the validity of this system, Casamichana et al. (2012), using a GPS model that allows the quantification of training load through accelerometry, tried to describe the physical profile of semiprofessional players and the difference between soccer positions (e.g., forwards, defenders etc.) and found differences between positions, confirming that the system was sensitive to the variable load demands of each position. Furthermore, the authors found a positive correlation between the amount of the player load and RPE methods concluding that the value of the player load obtained by accelerometry can be considered a good indicator to measure the load on training sessions.

# Chapter 3 – Experimental studies

## Study 1

### The Effect of Fatigue on Kicking Velocity in Soccer Players

### Abstract

Soccer is a game in which fatigue can negatively influence players' performance. Few studies have examined the practical effects of fatigue on soccer performance skills. Thus, the aim of the present study was to evaluate the effect of fatigue, acutely induced by means of a soccer specific circuit on ball velocity. Ten amateur soccer players (age 27.3 ± 5.25 yr; experience 16,8 ± 6.05 yr; level secondary division; body height 1,80 m ± 0,06; body mass 75,7 kg ± 5,78), participated in this study and performed maximal instep kicks before and after the implementation of an intensive, intermittent and repeated exercise protocol. Analysis of variance with repeated measures indicated a significant decrease ($p<0.05$) in ball velocity after just one round of the fatigue circuit. However, after the third circuit ball velocity increased and after the fifth circuit maximal ball velocity increased yet again (compared to the second circuit) and was not significantly different from before commencement of the fatigue protocol. The results partly confirmed the hypothesis of the negative influence of fatigue upon ball velocity in soccer kicking, demonstrating also some variability in the presented values of ball velocity perhaps theoretically accounted for by the general governor model.

Key words: kicking velocity, soccer, fatigue, general governor model

## Introduction

The game of soccer requires intermittent efforts with activity changes every 3-5 seconds, characterised by alternating moments of high intensity and of almost complete rest (Bangsbo, 1994).High intensity moments are those which normally correspond to decisive actions, i.e., scoring a goal. Kicking performance is perhaps the most important action in soccer since it supports a key objective of the game: scoring goals by kicking the ball.

Due to this inherent importance, the study of kicking in soccer has raised scientific interest, which has resulted mainly in studies from the point of view of biomechanics, technical analysis, muscular involvement in the kicking action and even studies in footwear (Forestier and Nougier, 1998; Madigan and Pidcoe, 2003; Sterzing, 2010). These studies show that there are many factors that can determine the action of soccer kicking, such as body posture, technical approach, footwear, muscle strength and power output and fatigue. However, the precise influence of fatigue on soccer kicking has not yet been clarified.

Fatigue is manifested by a reduction of maximal force or power that is associated with sustained exercise and is reflected in a decline of performance (Mohr et al., 2002). It has been noted that players experience fatigue both towards the end of a game and temporarily over its duration (Kellis et al., 2006). Fatigue experienced during a soccer game is manifested by a reduced capacity to perform the critical actions of high intensity mentioned above, along with a progressive reduction of muscle strength. Thus, the ability to resist the negative effects of fatigue is a key factor for a soccer player. Fatigue can be considered as a performance constraint that affects the motor processing and perceptual processing that is linked to the performing skills required in game situations (McMorris & Graydon, 1997). The negative effect of fatigue may be due to a neuromuscular decrease in performance induced by acute and immediate effort. This is probably caused by changes in muscle strength and coordination due to physiological causes and inherent metabolic changes (Kellis et al., 2006; Mohr et al., 2005). Some studies have found significant effects of local muscle fatigue protocols on the performance of complex discrete movements as in handball throwing (Forestier & Nougier, 1998) and vertical jumping (Rodacki et al., 2001).Others, using fatigue protocols related to long-distance running, have reported a significant decline in leg power, maximum isometric force and activity of the quadriceps (Nicol et al., 1991) as well as alterations in circuit reaction force (GRF) and joint kinematics of running (Madigan & Pidcoe, 2003; Mizrahi et al., 2000). Although fatigue is considered an important factor in soccer as well as in soccer skills proficiency (Mohr et al., 2005; Stone & Oliver, 2009) and despite the fact that player kicking ability is seen as one of the most important determinants of soccer performance (Rampinini et al., 2009; Russell et al., 2011), few studies have examined the effect of fatigue on ball velocity in the soccer kicking performance. Some studies have tried to explain the effect of fatigue on physical conditioning variables related to biomechanical and muscular analysis in the lower limbs based on the effects of prolonged intermittent specific soccer exercises. It was found that after fatigue an increased electro-mechanical delay and knee joint laxity occurs together with a significant decline of maximum isokinetic moment of force of both knee extensors and flexors (Drust et al., 2000; Rahnama et al., 2003). It was also found that fatigue developed during a match after relatively intense intermittent activities negatively affected the short-passing performance ability as shown by the increased number of errors made during the test and the time required to perform the test (Rampinini et al., 2008). With respect to the studies considering the soccer kicking performance most of them occur in conditions with no fatigue as a variable (Lees and Davies, 1988). Only three studies have investigated the effect of fatigue on kicking following intermittent exercise protocols. Kellis et al. (2006) found a decline in kicking ball velocity following a fatigue protocol. However, Currell et al. (2009) reported that ball velocity performance in soccer kicking did not change during simulated match play and Russell et al. (2011) also found no evidence that fatigue affects average ball velocity in soccer kicking. However, Russell et al. (2011) did conclude that peak kicking velocity tends to reduce in the second half of a soccer match simulation protocol (including passing, dribbling and shooting skills). For all three studies, the results are variable and inconclusive. There is evidence which shows the effect of fatigue on biomechanical and muscular performance but the practical effects on soccer skills performance and soccer kicking are still unclear. In our view, the protocols used may limit the validity of the results as they were based on few measurements of ball velocity. Kellis et al. (2006) took measurements at three intervals (before induction of fatigue; through the protocol; and at the end of the induced fatigue protocol) and Russell et al. (2011) took measurements before and after the first and second part. For a proper understanding of the temporal changes, a longer test period seems essential to understand what really happens to kicking ball velocity under the influence of fatigue.

The aim of this study was therefore to investigate the influence of fatigue upon maximal ball velocity in soccer kicking. It was hypothesized that acutely induced fatigue has a negative influence on ball velocity i.e. that peak ball velocity decreases with increasing levels of induced fatigue. It is also important to understand how this influence is expressed over the period of an intermittent and specific exercise protocol application and whether or not the effect is progressive.

# Material and Methods

## Experimental Approach to the Problem

A repeated-measures design with one group of amateur soccer players was used to determine the influence of acutely induced fatigue on ball velocity in kicking. Fatigue was induced by a soccer specific circuit performed for 90 s five times.

## Subjects

Ten amateur soccer players (age 27.3 ± 5.25 yr; experience 16,8 ± 6.05 yr; level secondary division; body height 1,80 m ± 0,06; body mass 75,7 kg ± 5,78), participated in this study. Participants were fully informed about the protocol before the experiment. Informed consent was obtained prior to testing from all subjects, according to the approval of the local ethics committee and current ethical standards governing sports and exercise research.

## Procedure

After a general warm-up of 15 minutes which included jogging and kicking drills, ball velocity was tested from 7 m ("penalty kick"). A standard soccer ball (mass approximately 30 g, circumference 70 cm) was used. The instruction was to kick a regular ball with maximum force and attempt to hit a target from seven meters distance, aiming at a 1 by 1 m circled target at 2 m height located in the middle of a goal (3 x 2 meters). Three attempts in each case were made. Immediately afterwards, the subjects performed the soccer specific circuit (Figure 1) involving high intensity activities. The circuit consisted of a set of specific and explosive exercises including jumps, skipping, multiple changes of direction, dribbling the ball, passing, bursts of sprinting and jogging (Figure 1). After following the circuit for 90 seconds, the participants had to kick the ball a further three times, followed by 90 seconds of rest before the start of the next 90 s circuit. Subjects repeated the circuit 5 times. If a given participant completed the circuit in under 90 seconds, he continued to follow it until the set time was reached.

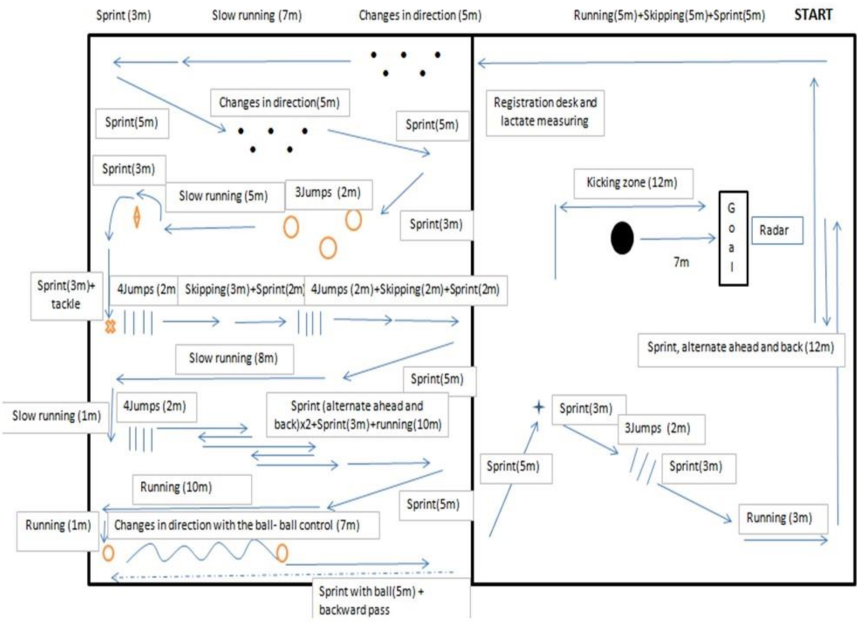

**Figure 1**. Circuit Design

## Measurements

Maximal ball velocity was determined using a Doppler radar gun (Sports Radar 3300, Sports Electronics Inc.), with ± 0.028 m·s-1 accuracy within a field of 10 degrees from the gun. The radar gun was located 1 m behind the goal at ball height. The highest ball velocity of all three attempts after each 90 seconds circuit was used for further analysis together with average ball velocity and standard deviation to discover whether variability in ball velocity increased. The total distance covered during the 90 seconds of the circuit was also measured. This measurement represented the sum of the meters previously marked along the circuit rounded up to the nearest meter. Participants wore a heart rate monitor (Polar, RS300x) for the duration of the experiment. Heart rate was measured immediately following the completion of each circuit and just before the start of the next, together with the rating of perceived exertion (RPE) on a 20 points Borg scale (Borg, 1973). Lactate was measured after the warm up and directly after the three kicks following each circuit. Blood was taken from the fingertip and lactate measurement was performed using a portable apparatus (Roche Accutrend Lactate Test Strips, Basel, Swiss).

## Statistical analyses

To assess differences in maximal ball velocity, heart rate, lactate, RPE and total meters covered after completion of the circuits, a repeated analysis of variance (ANOVA) design was used. Least significant differences (LSD) analyses were conducted to locate differences. All results are presented as mean ± SD. Where sphericity assumption was violated, the

Greenhouse-Geisser adjustments of the p-values were reported. The criterion level for significance was set at p<0.05. Effect size was evaluated with η2p (Eta partial squared) where 0.01< η2 <0.06 constitutes as a small effect, a medium effect and when 0.06< η2 <0.14 and a large effect when η2>0.14. Statistical analysis was performed in SPSS version 18.0 (SPSS, Inc., Chicago, IL).

## Results

The Oneway ANOVA showed that the maximal ball velocity was affected significantly after completion of the circuit (F = 7.6, p<.001, η2 = .46). Post hoc comparisons showed that the ball velocity decreased significantly after just one circuit of the fatigue protocol compared with the ball velocity before the start of the circuit. However, after circuit 3, ball velocity increased (compared to circuit 2) and after circuit 5, maximal ball velocity increased yet again (compared to circuit 2) and was not significantly different from before the start protocol (Figure 2). When average ball velocity was measured, a significant decrease was found after circuit 1 and after circuit 2. From circuits 2 to 3 an increase was found, and again after circuit 5 (F = 4.3, p=.003, □2 = .32; Figure 3).

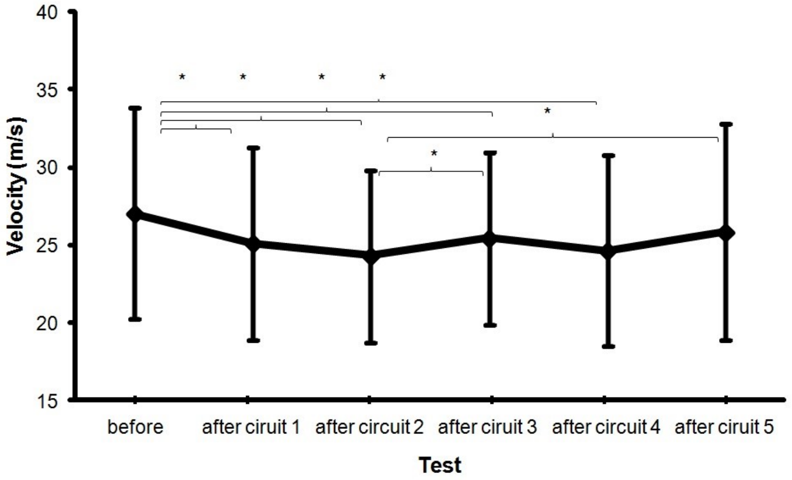

**Figure 2**
Maximal ball velocity (±SD) before and after conducting each circuit (m/s). * indicates a significant difference between these two ball velocities on a .05 level.

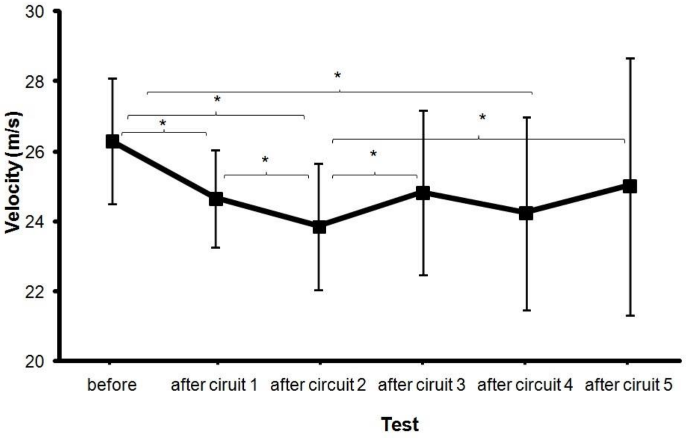

**Figure 3**

Average ball velocity (±SD over the three attempts averaged per subject) before and after conducting each circuit (m/s). * indicates a significant difference between these two ball velocities on a .05 level.

Heart rate as measured before the start of each fatigue circuit (*F* = 57.5, p<.001, $\eta^2$ = .87) increased significantly over the exercise period, but not significantly after each circuit (*F* = 2.0, p=.120, $\eta^2$ = .18). This was accompanied by an increase in the rate of perceived exertion (*F* ≥ 45.8, p<.001, $\eta^2$ ≥ .73; Figure 4 and 5). Post hoc comparison revealed that the heart rate before the start of each fatigue circuit significantly increased only until the start of circuit 3, while heart rate after each circuit significantly increased from circuits 2 to 3 and after the last circuit significantly (Figure 4). The rate of perceived exertion (RPE) before the start of each circuit also increased significantly only up to the start of circuit 4, while the RPE after each circuit significantly increased from 1 to 2, 2 to 4 and from 3 to 5 (Figure 5).

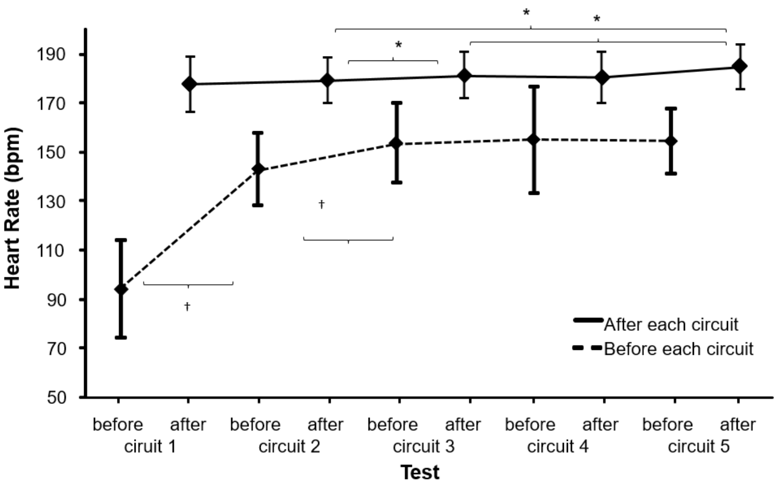

**Figure 4**

Mean (±SD) heart rates before the start of each circuit and after each circuit. * indicates a significant difference on a .05 level between these two conditions. † indicates a significant difference on a .05 level between these two conditions and all right for this.

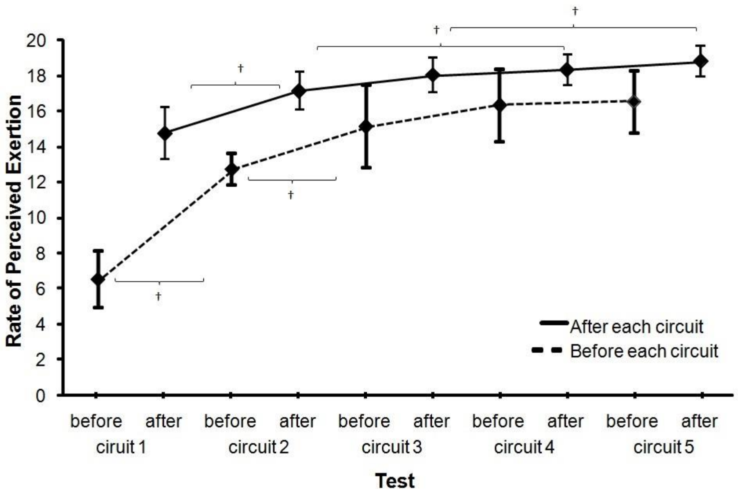

**Figure 5**

Mean (±SD) rate of perceived exhaustion before and after each circuit. * indicates a significant difference on a .05 level between these two conditions. † indicates a significant difference between these two conditions and all right for that.

However, the fatigue associated with the completion of the circuit was not shown in measures of meters covered during the ninety seconds of the circuit. Distance covered was almost the same after each circuit (F = 0.1, p = .83, $\eta^2$ = .006, Figure 6). Lactate concentration changed significantly during the protocol (F = 4.9, p = .002, $\eta^2$ = .41). Post hoc comparison showed that lactate concentration only increased significantly after completion of the second 90 s fatigue circuit. Also a significant increase in lactate concentration after the first circuit compared to the third and fourth circuit was found (Figure 7).

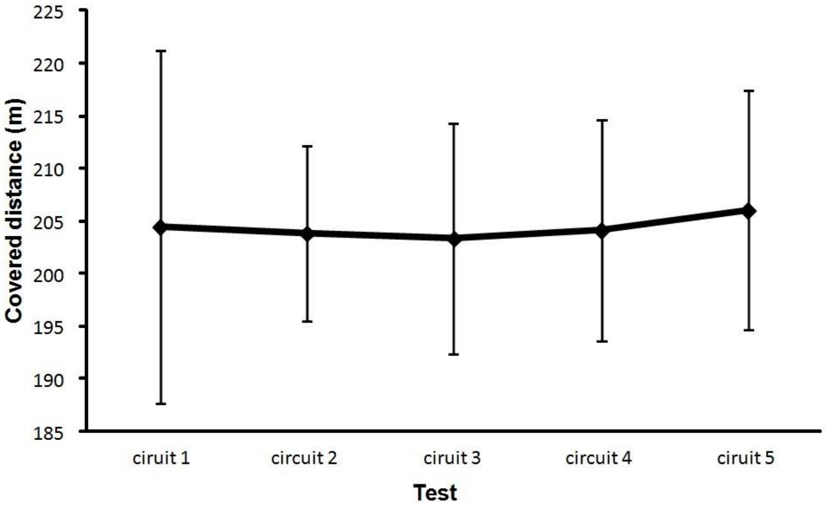

**Figure 6 .** Mean (±SD) distance covered after ending each circuit.

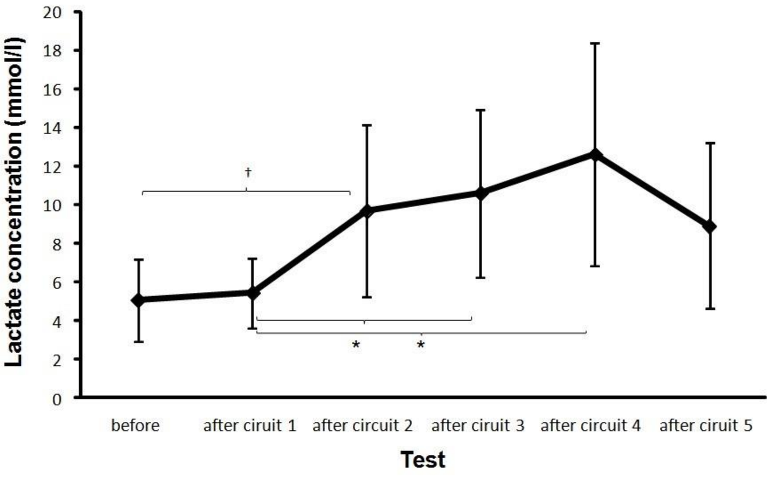

**Figure 7**

Mean (±SD) initial lactate concentration and measured after each circuit.

* indicates a significant difference on a .05 level between these two conditions.

†indicates a significant difference between these two conditions and all right for these conditions

## Discussion

The main finding was that the maximal and average ball velocity decreased after completion of a fatigue protocol. However, after just two circuits of this protocol ball velocity showed no further decline (Figure 1 and 2), while heart rate, RPE and lactate concentration as measures of fatigue continued to rise after the second circuit. The results confirm, in part, the hypothesis of the negative influence of fatigue upon ball velocity in soccer kicking, demonstrating also some variability in the presented values of ball velocity. The decrease in ball velocity at the termination of all repeated circuits with the one before the start of the first circuit (with exception of the last one) is consistent with results found in other studies (Kellis et al., 2006; Russell et al., 2011). In these studies it was confirmed that fatigue had a negative influence on ball velocity in soccer kicking (Kellis et al., 2006).

Possible explanations can be used from a broad range of biomechanical and physiological analyses such as: decreased neuromuscular performance; changes in the pattern of muscle strength; changes in coordination due to inherent physiological causes (Ismail et al., 2010; Seyed et al., 2010) changes in the moment of force (as shown in velocity) of the leg before ball contact; and consequent decrease in strength of the muscles involved in kicking. Other explanations such as approach speed and a skill level (Lees & Nolan, 1998) have been suggested in previous studies as responsible causes for the lower velocity as transferred to the ball (Kellis et al., 2006).Along with those already cited, Ekblom (1986) showed that the blood lactate level and decreased muscle glycogen are connected to impaired neuromuscular performance affecting coordination and consequently soccer performance skills. However, the results of the present study following completion of the third circuit show that these explanations are inadequate.

These results need to be treated with some caution. Taking into account the related literature, it was expected that ball velocity would reduce progressively down to a given limit. However, the results show that after three circuits, ball velocity started to increase again (Figure 2 and 3), even though heart rate, RPE and lactate concentration continued to increase. After completion of the last repetition of the circuit (circuit 5) there was, in fact, no significant difference in maximal ball velocity as compared to the initial ball velocity measured before the start of the first circuit (Figure 2). Even when the player started and finished each circuit considerably more fatigued, as shown by the increased RPE and heart rate (Figure 4 and 5), he was able to attain a similar distance in meters covered (Figure 6) and after two circuits the ball velocity in soccer kicking started to increase again (Figure 2). These findings seem counterintuitive and no real explanation for them exists in any related study. However, we consider that the phenomenon may best be explained by the central governor model and the concept of “pacing” (Lambert et al., 2005; Noakes et al., 2004; Noakes et al., 2005; St Clair Gibson & Noakes, 2004).

The central governor model is a theory developed by Noakes (Lambert et al., 2005; Noakes et al., 2004; Noakes et al., 2005; St Clair Gibson & Noakes, 2004) which explains the phenomenon of fatigue. It proposes that physical activity is controlled by a central governor in the brain and that the human body functions as a complex system during exercise. The subconscious brain regulates power output - pacing strategy - by modulating motor unit recruitment to preserve whole body homoeostasis and prevent catastrophic physiological failure (Lambert et al., 2005; Noakes et al., 2004; Noakes et al., 2005; St Clair Gibson & Noakes, 2004). According to the theory, exercise intensity and the activity of different metabolic systems oscillate continuously as a result of multiple interactions between all the organs that contribute to this complex system.

In our study an increased index of fatigue (Figure 5) was recorded (increase of RPE over the 5 circuits). However, fatigue negatively influenced ball velocity only in the first part of the fatigue protocol and not in the same way in the second part.

Millet’s flush model (Millet, 2011), based on the principles of the governor model, explains the regulation of fatigue in endurance activities specifically adapted to ultra endurance running by citing the role of motivation and what he calls a security reserve. According to the flush model, there is always a reserve for muscle recruitment (the security reserve) that can be used for the so called “end spurt” at the highest level of peripheral fatigue. A capacity to increase acceleration close to the finish of ultra marathon running in face of decreasing energy was found to be an effect of mental motivation. Thus, although the RPE increases over longer distance and running velocity at first decreases, velocity is recuperated at the end due to increased motivation (as the runner approaches the finishing line) and/or a recruitment from the security reserve.

We observed the same principles in our study. A decline in ball velocity was followed by an increase in ball kicking velocity after the third circuit. We assume that this was possible due to muscle recruitment from the security reserve and/or an increase in motivation arising from the subjects' awareness that they were nearing the end. In the final circuit, ball speed reached similar values to those measured at the start, perhaps because subjects knew that this was really the last time and that they could therefore use (consciously or not) the security reserve. This was also shown by a slight increase in distance covered (Figure 6), heart rate (Figure 4) and a slight fall in lactate concentration (Figure 7). After the final circuit, the higher heart rate and the increased distance covered indicated higher energy use by subjects, reinforced by the fact that lactate levels also fell slightly. This fall in lactate concentrate was probably due to its use as a fuel; since it has been found that, during high intensity exercise, substrates other than glucose (such as lactate) may contribute significantly to cardiac energy production (Chatham, 2002).

The concepts as “security reserve” and “pacing strategy” seem to have relevance in our study and we can also find reasons in literature specifically related with soccer players. According to Edwards & Noakes (2009) soccer players are well known to self-regulate match-play efforts following numerous intrinsic and extrinsic factors. They suggested that players modulate effort according to a subconscious strategy. As such, subconscious physiological factors influence conscious behavioral decisions to regulate effort. Also, fatigue seems to affect pacing strategies of the players (Orendurff et al., 2010). Consequently as shown in our study, we suggest that players may have self-regulated their effort (pacing strategy) throughout the protocol. Since they knew the number of repetitions of the circuit, the players could pace themselves and perform better in the last repetition due to the fact that they knew that it was their last time. Future studies involving this knowledge about length of a fatigue protocol should be conducted to investigate this effect of knowledge upon a possible pacing strategy in soccer kicking.

## Practical Applications and Conclusions

Our study demonstrated and strengthened the hypothesis concerning the potential negative effects of fatigue on kicking in soccer and showed in addition that the effect of fatigue can be variable, i.e. neither linear nor progressive. The reported findings can be related to the effect of fatigue on kicking soccer theorized according to the central governor model as a holistic and complex approach. The “security reserve” and the associated mental/motivational concept as “pacing” may have significant explanatory potential. Therefore, practitioners should be aware that fatigue influences ball velocity in kicking as during soccer games. However, this performance can be variable and maybe dependent on self-regulation of the effort of the players according to some conscious and subconscious factors. However, future studies need to be conducted to confirm and understand the influence of fatigue from different "pacing strategies" in close actions as a kicking but also in broader contexts such as training and during competition.

# Study 2

## The effect of fatigue and duration knowledge of exercise on kicking performance in soccer players

## Abstract

The purpose of this study was to investigate the influence of fatigue upon kicking maximal ball velocity and the target-hitting accuracy of soccer players; and also to examine the effect of the knowledge of the exercise duration upon these two parameters. Twenty-four semi-professional soccer players participated in this study and performed maximal instep kicks before and after the implementation of an exercise protocol, either with or without knowledge of the duration of this protocol. A mixed model of analysis of variance showed that kicking maximal ball velocity was significantly affected ($F_{5,85}=11.6$; $p<.001$; $\eta^2=0.39$) but only after just one circuit of the fatigue protocol and then remained similar. Accuracy did not change during the protocol ($F_{5,75}=0.23$; $p=0.76$; $\eta^2=0.03$) and knowing the duration of exercitation did not affect accuracy and velocity development ($F_{1,23}\leq1.04$; $p\geq0.32$; $\eta^2\leq0.06$). These findings demonstrated the potential negative effects of fatigue on kicking ball velocity in soccer but not in the kicking accuracy and that the effect of fatigue may not be progressive over time. Knowing or not knowing the duration of exercitation did not affect the results.

Keywords: fatigue; pacing; kicking ball velocity; self-regulation of effort; perception of effort

# Introduction

Fatigue in soccer is a crucial factor that has raised scientific interest (Kellis et al., 2006; McMorris & Graydon, 1997; Mohr et al., 2002; Mohr et al., 2005). It can be considered to be a performance constraint that affects motor and perceptual processing (Kellis et al., 2006; McMorris & Graydon, 1997; Mohr et al., 2002). This negative effect is often expressed in the reduced ability of the player to perform game-specific actions due to physiological and metabolic causes conducive to decreasing muscular strength capacity and changes in coordination (Kellis et al., 2006; Krustrup et al., 2010; Mohr et al., 2005;). Moreover, fatigue can also limit a player's decision-making during a game and is an important factor in the cognitive response analysis of the player during the effort (Kellis et al., 2006; McMorris & Graydon, 1997; Mohr et al., 2002; Mohr et al., 2005; Thomson et al., 2009).

According to several authors (Currell et al., 2009; Ferraz et al., 2012; Kellis et al., 2006; Russel et al., 2011) fatigue has been found to have different effects upon kicking ball velocity. On this topic, Kellis et al. (2006) found a significant decrease in ball kicking ball velocity following a fatigue protocol, while Currell et al. (2009) reported that kicking ball performance did not change during simulated match play. Further, Russell et al. (2011) found no evidence that fatigue affects average kicking ball velocity, although they concluded that peak kicking ball velocity tends to reduce in the second half of a simulation protocol of a soccer match (including passing, dribbling and shooting skills).

Despite the effect of fatigue on biomechanical and muscular kicking performance in soccer (Mohr et al., 2005; Rampinini et al., 2009; Russell et al., 2011; Stone & Oliver, 2009), the practical effect upon skills performances, particularly kicking, remains unclear (Currell et al., 2009; Kellis et al., 2009; Russell et al., 2011). The protocols used in the studies above consisted of measuring fatigue and kicking ball velocity before, during and after the protocol. This approach may limit the validity of the results because during regular soccer matches, several short and intense periods occur, which can cause numerous moments of temporary fatigue and accumulate fatigue over a longer period (Waldron & Highton, 2014). More recently, Ferraz et al. (2012) investigated the effect of several bouts of fatigue by simulating commonly used movements in soccer in order to understand the variability of the fatigue effect. The results of this study only partially confirmed the hypothesis of the negative influence of fatigue. Indeed, at the end of the protocol and despite players feeling more tired, kicking ball velocity has not decreased and even approached the initial values. According to the authors, these results occurred because the players knew the number of repetitions of the protocol (i.e. the exercise duration) and thus unconsciously regulated self-effort in the final part (Billaut et al., 2011; Millet, 2011).

Recent scientific theories aimed to explain the intensity regulation and effort tolerance that occurs with fatigue by using endurance exercises to examine the practical effect of fatigue (Abbiss & Laursen, 2005; Edwards & Noakes, 2009; Mauger et al., 2009). All these approaches contribute to show that fatigue has to be assessed within a complex framework of multiple interactions that takes into account aspects such as the knowledge of exercise duration, unconscious self-effort regulation, or the importance of the role of perceived exertion in relation to exercise (Amann & Dempsey, 2008; Amann & Secher, 2010; Billaut et al., 2011; Crewe et al., 2008; Kayser, 2003; Marcora, 2008; Marcora & Staiano, 2010; Mauger et al., 2009; Millet, 2011; Morree et al., 2012; Noakes, 2012; Presland et al., 2005). In accordance with these approaches Billaut et al. (2011) examined the influence of prior knowledge of sprint number on repeated-sprint exercise performance. The authors concluded that pacing occurs during repeated-sprint exercise in anticipation of the number of efforts that are expected to be included in the bout. Similarly and as noted above, Ferraz et al. (2012) found that participants may use unconscious pacing strategies when they know the exercise duration. Therefore, participants spread their energy use over the fatigue protocol and never need to go over their limits (also called reserves in the flush model of Millet (Millet, 2011).

During a soccer game or training exercises, the type and duration of effort cannot be known exactly. Therefore, the regulation of this effort and pacing based on the knowledge of duration may not always be possible. Hence, it is important to investigate and compare the effect of fatigue when the duration of a particularly intense activity is unknown. However, despite the importance attributed to this topic, there is still a lack of related studies, particularly in soccer skills performance and to the best of our knowledge, no such study has been done. Thus, the aim of this study was twofold. The first goal was to investigate the influence of fatigue upon kicking maximal ball velocity and hitting accuracy of soccer players. The second aim was to examine the influence of knowing the exercise duration upon kicking ball velocity and accuracy. It was hypothesized that fatigue negatively influences kicking ball velocity and accuracy but the effect can be variable due to the influence of knowing the exercise duration, and when the duration of a fatigue protocol is unknown, players pacing strategy is different to when the duration is known.

## Methods

### Participants

Twenty-four semi-professional male soccer players (age 19.7 years ± 4.1; height 1.82 m ± 0.38; weight 72 kg ± 5.05; training experience 12.5 years ± 4.3), playing in the second division of the Norwegian National Competition participated in this study, during a competitive period. All players trained every day in the field and had physical training in the gym twice a week. All were informed about the experimental procedures and an informed consent was signed prior to all testing in accordance with the recommendations of the local ethics committee and current ethical standards in sports and exercise research.

## Design

A randomized repeated-measures study with cross over design with two groups of semi-professional soccer players was used to determine the influence of acutely induced fatigue and duration knowledge upon kicking ball velocity and accuracy. Fatigue was induced by requiring participants to complete five circuits involving different soccer movements (1.5 min each). The participants were divided into two groups in which one group started a circuit consisting of high intensity activities similar to soccer with the knowledge of the number of rounds to conduct, while the second group performed the same circuit without this knowledge. At the second visit, the groups swapped protocols.

## Procedures

An adaptation of the Ferraz et al. (2012) exhaustion protocol test was used. After a general warm-up of 15 min, which included jogging and kicking drills, kicking performance was tested from 11 m (“penalty kick”). A standard soccer ball (weight approximately 0.43 kg, circumference 70 cm) was used. The instruction was to kick a regular ball with maximum force and attempt to hit a target, aiming at a 1 × 1 m circled target at 1 m height located in the middle of a goal (7.32 × 2.44 m). Three attempts were made regardless if the ball hit the target or not. Immediately afterwards, participants embarked upon the circuit (Figure 1) involving high-intensity actions. The circuit consisted of a set of specific and explosive exercises including jumps, skipping, multiple quick changes of direction, driving the ball, passing, bursts of sprinting and some slow running (Figure 1). After conducting the circuit for 90 s, participants kicked the ball again three times, followed by 2 min of rest before the start of the next 90 s on the circuit. Participants performed the circuit five times. If a participant completed the circuit in less than 90 s, he continued a new round until the time was reached.

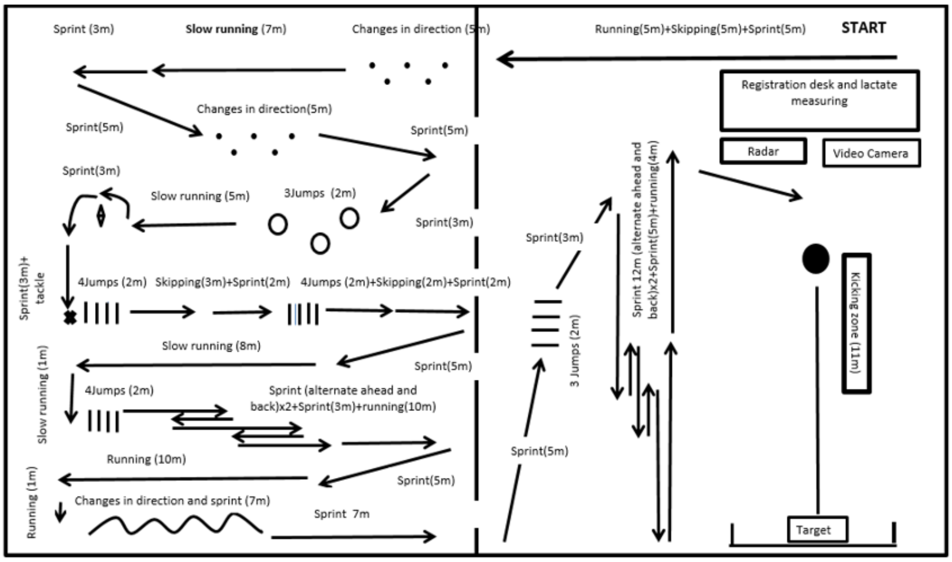

Figure 1. Circuit design

## Measurements

The kicking maximal ball velocity was determined by using a Doppler radar gun (Sports Radar 3300, Sports Electronics Inc.), with ± 0.028 $m \cdot s^{-1}$ accuracy within a field of 10 degrees from the gun. The radar gun was located 2 m behind the 11 m line at ball height during the kick. The highest kicking velocity of all three attempts after each 90 s circuit was used for further analysis together with average ball velocity and standard deviation to discover whether variability in kicking velocity had increased.

Kicking accuracy was measured with a video camera (Sony HDR-FX100, Tokyo, Japan) at a distance of 12 m from the goal. The camera was placed such that the subject did not obstruct the field of vision between the camera and the goal. The position of the centre of the ball was measured at the moment that the ball struck the goal (wall). Mean radial error as described by Hancock et al., (1995) and Van den Tillaar & Ettema (2007) was used as the measurement of accuracy. This was measured as the average of the absolute distance to the centre of the target.

The total distance covered during the 90 s of the circuit was also measured. This was represented by the sum of the metres previously marked along the circuit rounded up to the nearest metre. Participants wore a pulse belt (Polar, RS300x, Oulu, Finland) for the duration of the exercise. Heart rate was measured immediately following the completion of 90 s in the circuit and just before the start of the next, together with the rating of perceived exertion (RPE) on a 20-point Borg scale (Borg, 1973).

Blood lactate concentrations were measured after the warm-up and directly after the three kicks following each 90 s. Blood was taken from the fingertip and lactate measurement was performed by using a portable machine (Roche Accutrend Lactate Test Strips, Basel, Switzerland).

### Statistical analyses

To assess the effects of duration knowledge and fatigue upon kicking maximal ball velocity, kicking accuracy, heart rate, lactate, RPE and total metres covered after the completion of the circuits, a 2 (duration knowledge: with or without) × 5 (circuits) ANOVA repeated-measures design was used. Holm–Bonferroni post-hoc analyses were conducted to locate differences. All results are presented as mean ± SD. Where the sphericity assumption was violated, the Greenhouse–Geisser adjustments of the p-values were reported. The criterion level for significance was set at $p<0.05$. Effect size was evaluated with $\eta^2$ (Eta partial squared) where $0.01<\eta^2<0.06$ constitutes a small effect, $0.06<\eta^2<0.14$ a medium effect and $\eta^2>0.14$ a large effect (Cohen, 1988). To test the reliability of the protocol and variability of the day the kicking performance (three kicks) straight after the warm-up on both testing days were used to calculate ICC by Crombachs' Alpha together with the SEM and CV. Statistical analysis was performed in SPSS version 18.0 (SPSS, Inc., Chicago, IL).

## Results

The reliability of the kicking velocity and accuracy was high (ICC=0.89; SEM= 0.92 m/s; CV= 3.5%; ICC=0.83; SEM= 0.7 m; CV= 5.4%) with no influence of testing day (F=2.3; p=0.15; F=9.4; p=0.09). Maximal ball velocity was affected significantly after the completion of the circuit ($F_{5,85}=11.6$; $p<.001$; $\eta^2=0.39$). Post-hoc comparisons showed that the ball velocity decreased significantly ($p<0.05$) after just one circuit of the fatigue protocol compared with the ball velocity before the start of the circuit. However, after the first circuit, there were no longer any significant differences (Figure 2). Accuracy did not significantly change during the protocol ($F_{5,75}=0.23$; $p=0.76$; $\eta^2=0.03$; Figure 3), while duration knowledge did not have any effect on accuracy or velocity development ($F_{1,23}\leq1.04$; $p\geq0.32$; $\eta^2\leq0.06$).

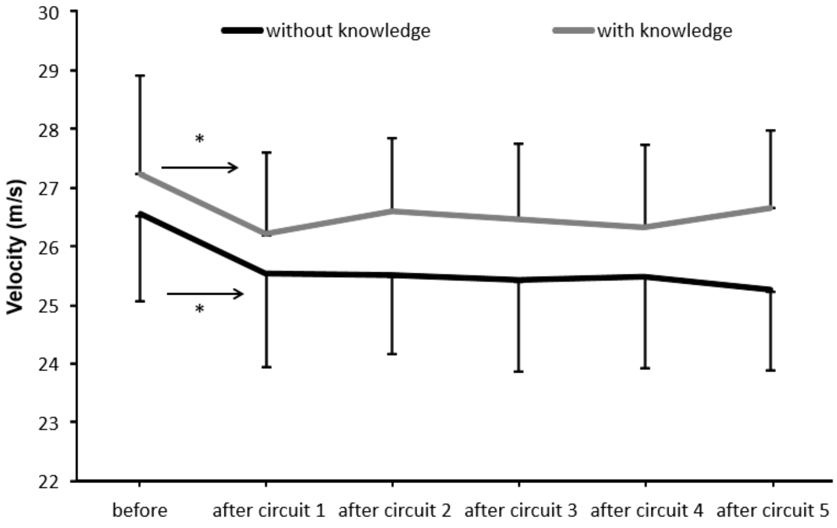

Figure 2. Maximal kicking ball velocity (±SD) before and after conducting each circuit (m/s) and according to the effect of duration knowledge (with or without knowledge). * indicates a significant difference between these two ball velocities at a .05 level.

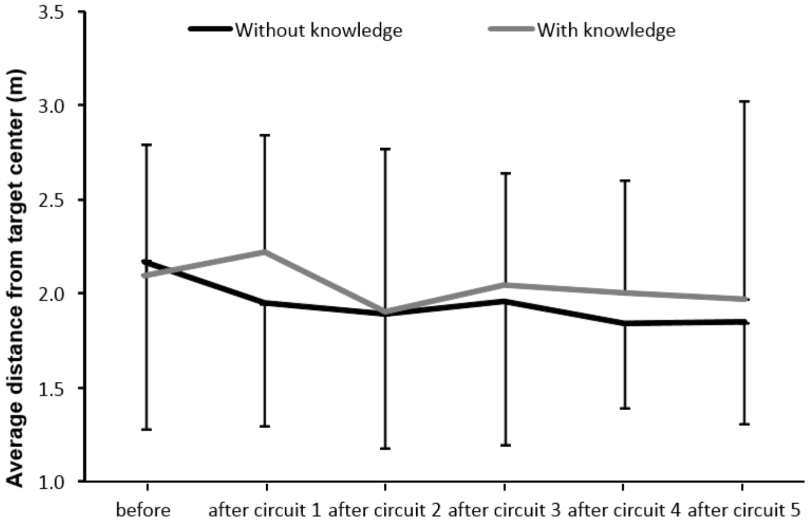

Figure 3. Average distance from the centre of the target before and after conducting each circuit and according to the effect of duration knowledge (with or without knowledge)

Heart rate and RPE as measured before the start of each fatigue circuit ($F_{1.87,30.89} \geq 74.7$; $p<0.001$; $\eta^2 \geq 0.81$) and after each circuit ($F_{(1.25,16.29)} \geq 14.3$; $p<0.001$; $\eta^2 \geq 0.51$) increased significantly over the exercise period (Figures 4 and 5). The post-hoc comparison showed that the heart rate before the start of each fatigue circuit significantly increased until the start of circuit 4, while that after each circuit significantly increased until circuit 3 and increased again after the last circuit compared with circuits 1–3 (Figure 4). RPE increased significantly before and after each circuit (Fig. 5). However, no significant effect of knowledge was found for RPE and heart rate before and after the circuits ($F_{1,23}$≤2.7; p≥0.125; $\eta^2$≤0.16; Figures 4 and 5).

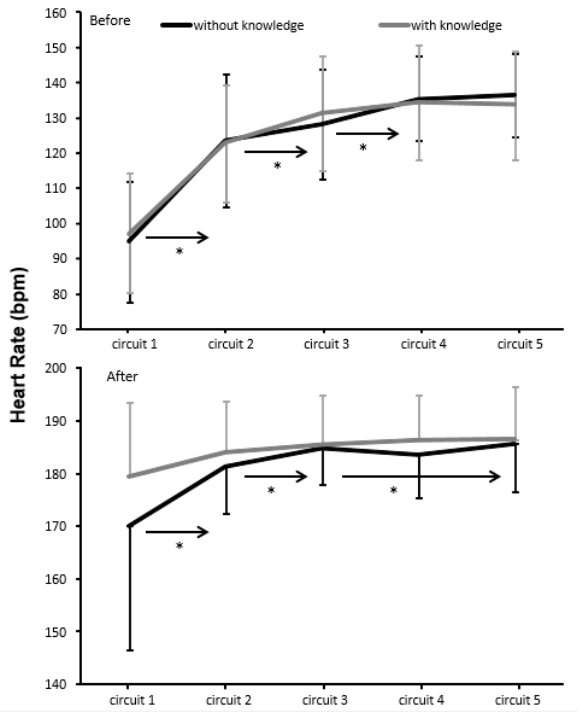

Figure 4. Mean (±SD) heart rates before and after each circuit and according to the effect of duration knowledge (with or without knowledge). * indicates a significant difference at a .05 level between these two conditions.

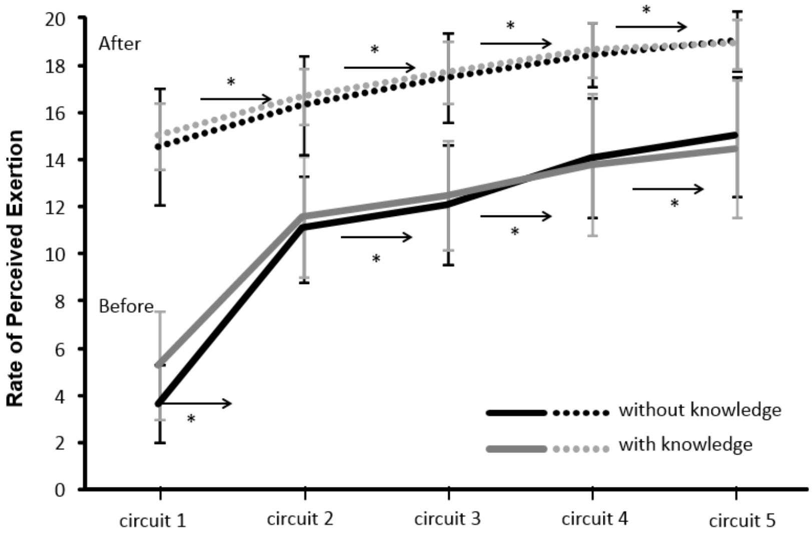

Figure 5. Mean (±SD) rate of perceived exhaustion before and after each circuit and according to the effect of duration knowledge (with or without knowledge).* indicates a significant difference at a .05 level between these two conditions.

Lactate concentration changed significantly during the protocol ($F_{5,70}$=17.0; p<0.001; $\eta^2$=0.53). The post-hoc comparison showed that lactate concentration increased significantly just after completion of the first fatigue circuit and increased again after the last circuit compared with circuits 1–3 (Figure 6).

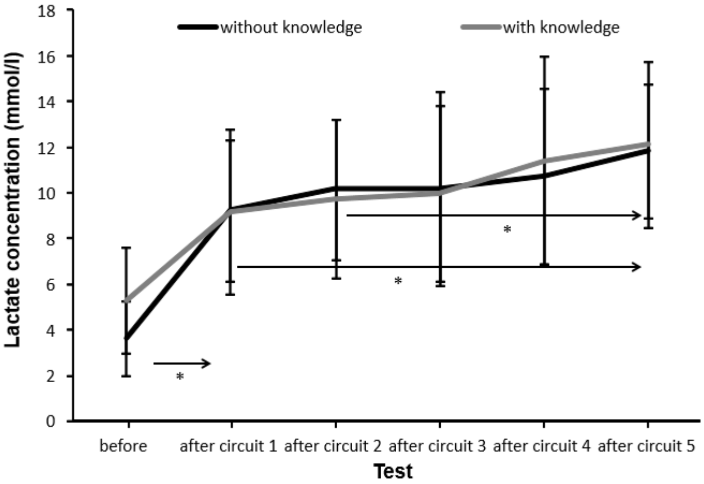

Figure 6. Mean (±SD) initial lactate concentration measured before and after each circuit and according to the effect of duration knowledge (with or without knowledge). * indicates a significant difference at a .05 level between these two conditions.

The distance covered during the 90 s of the circuit was almost the same after each one, with no significant differences ($F_{1.97,68}$=1.17; p=0.33; $\eta^2$=0.06; Figure 7). In addition, no significant effect of knowledge was found for these two parameters ($F_{1,23}$≤1.7; p≥0.204; $\eta^2$≤0.09).

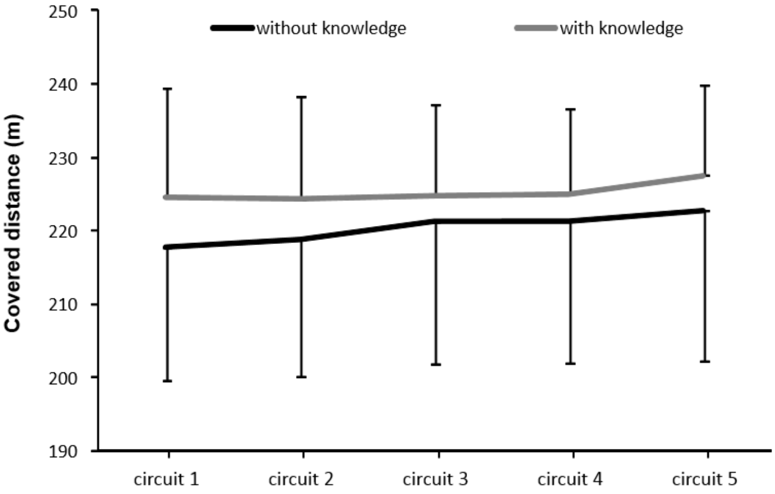

Figure 7. Mean (±SD) distance covered after ending each circuit and according to the effect of duration knowledge (with or without knowledge)

# Discussion

The current study is the first to identify the effect of fatigue associated with the duration knowledge of exercise on soccer skills, specifically kicking. The purpose was to investigate the influence of fatigue upon kicking maximal ball velocity and the target-hitting accuracy of soccer players and also to examine the effect of the knowledge of the exercise duration upon these two parameters. The main findings were that kicking maximal ball velocity was affected only after the first circuit, while accuracy and distance covered were not affected in the whole protocol despite the increase in fatigue as demonstrated by the heart rate, RPE and lactate measurements. Furthermore, no effect of duration knowledge was found on these parameters.

These results contradict the findings of some studies (Ismail et al., 2010; Kellis et al., 2006) that have reported a progressive and linear negative effect of fatigue. It was suggested that the negative influence of fatigue on kicking ball velocity and accuracy in soccer kicking could be explained by biomechanical and physiological causes (Ismail et al., 2010; Kellis et al., 2006; Seyed et al., 2010). As we observed in our study, lactate, RPE and heart rate increased after conducting each circuit, indicating progressively greater fatigue. However, the motor skill expressed in kicking ball velocity and accuracy changed little. The kicking ball velocity only decreased after the first circuit and the accuracy was always similar. Although classical studies have suggested that kicking performance should decrease progressively due to physiological reasons such as generated muscle incapacity with a decrease in strength, a reduction in movement stability, especially in the knee and hip range of motion, or a decrease in limb velocity (Forestier & Nougier, 1998; Gates & Dingwell, 2011; Rahnama et al., 2003; Rodacki et al., 2001; Seyed et al., 2010; Sparto et al., 1997) these effects were not verified in the current study. Conversely, our findings are in line with studies that reported other causes aside from physiological ones to be associated with the effect of fatigue (Edwards & Noakes, 2009; Ferraz et al., 2012; Mauger et al., 2009; Swart et al., 2009; Waldron & Highton, 2014). Indeed, Ferraz et al. (2012) suggested that knowing the duration of the protocol might affect the results, as players use unconscious pacing strategies. Billaut et al. (2011) concluded that pacing occurs during repeated-sprint exercise in anticipation of the number of efforts that are expected to be included in the bout. The Millet's flush model (2011) based on the principles of the governor model also explained the regulation of fatigue adapted to ultra-endurance running by mentioning the role of motivation and "security reserves". The capacity to increase acceleration due to the fact of knowing the finish line of an ultra marathon is close, and despite decreased energy, was found to be affected by mental motivation. Further, Mauger et al. (2009) in their cycling study showed that the prior knowledge of a certain distance seems to allow the establishment of an internal relative distance that is used to set a pacing strategy. Likewise, Swart et al. (2009) found that the increased familiarity of the exercise bout and certainty about its endpoint were associated with a more aggressive RPE strategy that produces a higher exercise performance. Thus, certainty about the endpoint and exercise duration affects both the RPE strategy and performance. Interestingly, our results found no effect for this variable in any of the assessed parameters, indicating that knowing the exercise duration did not influence performance, with no changes upon self-effort regulation.

These findings suggest that caution is needed when analyzing the practical effects of fatigue and particularly the influence of knowledge duration. Firstly, kicking ball velocity only changed after the first circuit. This result indicates that the effect of fatigue is variable (non-progressive) possibly not only for physiological reasons. Nevertheless, this variability cannot be explained by the knowledge duration of the protocol as initially supposed. Indeed, it is possible that during the entire of the protocol a possible learning effect (previous exercise experience) of the protocol may occur between the first repetition of the circuit and the second, and may have influenced the pacing strategies of the players and it may have directly affected the influence of the duration knowledge. This highlights the possible importance of the previous experience of the exercise which is also predicted by the contemporary research of fatigue (Noakes, 2012). In addition and according to recent fatigue studies (Abbiss & Laursen, 2005; Amann & Dempsey, 2008; Amann & Secher, 2010; Billaut et al., 2011; Edwards & Noakes, 2009; Ferraz et al., 2012; Mauger et al., 2009; Marcora & Staiano, 2010; Millet, 2011; Noakes, 2012; Swart et al., 2009), several factors may interact – not just the knowledge duration or the physiological ones – to influence soccer skills performance and minimize the effect of fatigue as a result of high-intensity efforts. In fact, the results should be analyzed under the knowledge of the complexity of interfering factors that depend on many contextual psychophysiological aspects, such as previous exercise experience, the emotional state of the player, their higher or lower experience level or their reaction to interpretation of the situation. Therefore, several psychophysiological aspects that work together may exist, explaining the present results about fatigue effect on kicking performance, and we must try to study the interaction between them. Although fatigue is a negative physiological consequence of exercise, this negative effect in high-intensity exercise seems to be variable and could be minimized. These interactions may lead to improvement in the kicking results, minimizing the progressive negative effects of fatigue and highlighting the possible positive impact of other factors such as the self-regulation of effort, perception of effort exertion, the physical and emotional state of the player and their individual and singular capacity to interpret effort. Hence, future studies should explore the kinds of mechanisms that may exist behind these apparent factors and their interactions, including the influence of the type of protocol/exercise.

With respect to the accuracy variable and contrary to the majority of the related research, no differences were found in the present study. It would be expected that accuracy was conditioned. It is known that fatigue results in changes in coordination due to inherent physiological causes (Ismail et al., 2010; Seyed et al., 2010), changes in the force (as shown by velocity) of the leg before ball contact, a decrease in the strength of the muscles or decreased muscle glycogen connected to impaired neuromuscular performance affecting coordination (Ismail et al., 2010; Kellis et al., 2006; Mohr et al., 2005; Seyed et al., 2010). Yet, in our study, despite the increase in fatigue, players retained the same accuracy at all times. Draganidis et al. (2013) showed that soccer skills are minimally affected by acute resistance exercise independent of intensity. The absence of any significant effects of resistance exercise on soccer skills performance in this study may be explained by the fact that knee extensor muscle strength remained unaffected during the protocol application. Here, Van den Tillaar and Ulvik (2014) considered the influence of the instruction. They showed that kicking accuracy was only affected when the main priority was hitting the target. In the current study, the instruction was to kick as hard as possible and try to hit the target. Therefore, the priority was equally or more upon kicking velocity. Under the same instructions, Van den Tillaar and Ulvik (2014) found that accuracy did not change. Therefore, it was expected that accuracy would not change during the fatigue protocol. In other words, if the instruction was to hit the target, fatigue could have an influence. This psychological aspect should be considered when performing future studies about how fatigue affects technical skills including the accuracy of movements. Nevertheless, accuracy does not seem to be totally dependent on the same factors as the kick factor.

## Conclusion

The present study demonstrated the potential negative effects of fatigue on kicking velocity in soccer. In addition, it was found that kicking accuracy is not affected and that the effect of fatigue may not be linear over time. There was no effect of knowing the exercise duration, leading us to believe that other mechanisms aside from physiological ones may contribute to the variability of the fatigue effect. A player, even highly tired, may develop mechanisms for the minimization of fatigue and maximization of performance related to psychophysiological factors, which opens up new perspectives. The reasons for the variable and non-progressive effect of fatigue on kicking performance, especially on kicking velocity, should be developed in further studies. Moreover, it would be interesting to study the effect of fatigue and the knowledge of exercise duration using an experimental protocol in a broader context and more closely related to the reality of the game such as soccer small-sided games. Furthermore, it would be interesting to continue to analyze the impact of psychophysiological factors on the perception and regulation of fatigue by players and the relationship between the effect/regulation of fatigue and the playing style of a team or the type of exercise used, according to recent psychophysiological fatigue studies.

# Study 3

## The influence of different exercise intensities on kicking accuracy and velocity in soccer players

## Abstract

The aim of this study is to investigate the influence of different exercise intensities induced by a soccer specific protocol on kicking performance in soccer players. Twelve semi-professional male soccer players participated in this study and performed maximal instep kicks before and after the implementation of an exercise protocol to determine the influence of different intensities upon kicking ball velocity and the target-hitting accuracy. Analysis of variance designs with repeated measures showed that maximal ball velocity was affected only after the most intense circuit (F(6,66)=2.3; p=0.041; η2=0.18), while accuracy was not affected in the protocol (F(6,66)=0.19; p=0.98; η2=0.02). Low and moderate intensities did not affect accuracy or kicking ball velocity. These findings suggest that kicking ball velocity is influenced by high-exercise intensities. Low and moderate exercise intensities do not affect the performance of the kick, and intensity do not influence accuracy. Otherwise, it is possible that other mechanisms (not only physiological) may influence players during the exercise.

**Keywords:** kicking soccer, fatigue, exercise intensity, pacing.

# Introduction

Exercise intensity in sports is an aspect that determines the characteristics of effort and, consequently, is also an important factor for control and regulation of training (Draganidis et al., 2013; Mohr et al., 2003). The type of intensity developed in each sport determines its specificity of effort. Particularly in soccer, the type of effort is intermittent due to permanent changes in intensity, including alternation between critical moments of high-intensity and moments of near rest (Bangsbo, 1994; Mohr et al., 2003; Rampinini et al., 2009). In fact, in soccer, there seems to be two patterns of effort: the pattern as a result of short-term high-intensity effort and the pattern as a result of long-term exercise (Lyons et al., 2006; Szgula et al., 2003).

In general, regarding high-intensity efforts, soccer players perform 150–200 brief, powerful actions during a game; for example, sprinting, changing pace and direction, tackling, accelerations, decelerations and jumping (Mohr et al., 2003). This high level of intensity is considered decisive in soccer and causes high levels of fatigue, which affect the player’s performance during a game (Lyons et al., 2006; Rampinini et al., 2008; Rampinini et al., 2009).

However, the importance of intensity in soccer activities is not limited to high-intensity moments. In fact, the game is also characterized by lower levels of intensity representative of the other type of actions that are also required during the game (Draganidis et al., 2013; Lyons et al., 2006; Rampinini et al., 2009). Because of this, it would be interesting to determine the influence of lower and different intensities on player performance. It is known that each level of intensity requires different levels of strength and endurance in relation to each action (Draganidis et al., 2013; Lyons et al., 2006). Therefore, each action can be conditioned by the state of temporary and accumulated fatigue in players; thus, these aspects have consequences on tactical and technical performance (Draganidis et al., 2013; Lyons et al., 2006; Rampinini et al., 2008; Rampinini et al., 2009). Because of this possible connection between exercise intensity, fatigue and player performance, it would be interesting to better understand the influence of different intensities on soccer performance, particularly on kicking, as it is considered an important parameter for success in soccer (Rampinini et al., 2009;Russell et al., 2011).

In terms of kicking performance as result of high exercise intensity, results of previous studies showed a possible negative effect on motor coordination and a reduction of movement stability, especially in knee and hip range of motion, which is mainly due to fatigue (Drust et al., 2000; Rahnama et al., 2003; Rampinini et al., 2009). Rampini et al. (2008) reinforced this idea when it was found that short passing ability decreased both during a game and after brief bouts of high-intensity activities.

However, a recent study (Ferraz et al., 2012) showed that this classical idea of the negative cause/effect relationship between high-intensity activities and performance skills cannot be linear, but should be variable and consider aspects such as self-unconscious effort regulation (pacing strategy), the importance of the role of perceived exertion in relation to the exercise, and the critical importance of psychological aspects: all of which were supported in recent fatigue studies (Amann & Dempsey, 2008; Amann & Secher, 2010; Marcora & Staiano, 2010; Mauger et al., 2009; Millet, 2011; Noakes, 2012; Noakes et al., 2005; Swart et al., 2009). In addition, other previous studies also concluded that soccer skills were not affected (and kicking during soccer was only minimally affected) after high-intensity exercises (Draganidis et al., 2013; McMorris et al., 1994). These studies advance a muscular reason, stating that knee extensor muscle strength remained unaffected in all exercise trials (Draganidis et al., 2013).

Thereby, and despite the differences between the protocols used that can explain differences in the results, it seems to be expected and desirable that the investigation about the impact of different intensities on kicking performance should continue; the studies are still inconclusive, but new conclusions continue to emerge. Furthermore, most research is very focused on the effect of high-intensity efforts. In our opinion, it also seems important to understand what happens during kicking after different intensities of exercise (not only after high-intensities). Additionally, we also consider it important to use a protocol with activities/exercises related to training and games.

Therefore, the aim of this study was to investigate the effect of different intensities induced by a soccer specific protocol upon kicking ball velocity and the target-hitting accuracy of soccer players. Although kicking performance is considered crucial for successful soccer performance, there is limited information regarding this interaction with different exercise intensities. It was hypothesised that different intensities may result in different levels of fatigue, which may affect kicking performance. Still, progressive exercise intensity may cause progressive levels of fatigue, which can result in progressive kicking performance deterioration. However, and according to recent studies, it is possible that the effect is minimal, and not linear or progressive (Draganidis et al., 2013; Lyons et al., 2006; Ferraz et al., 2012) because of this, it is also possible that, with a moderate and chosen intensity, performance can be expected to increase more so than in higher or lower intensities.

# Methods

## Participants

Twelve semi-professional male football players (age 19.7 ± 4.9; height 1.79 m ± 0.56; weight 703.14 N ± 77.47; training experience 13 years ± 5.6) playing in the second division of the Norwegian National Competition in competitive period participated in this study. The subjects were fully informed about the protocol before participating in this experiment. Informed consent, in accordance with the recommendations of the local ethics committee and current ethical standards in sports and exercise research, was obtained prior to all testing from all subjects.

## Design

A repeated-measures design with one group of active amateur soccer players was used to determine the influence of different intensities (fatigue) on kicking ball velocity and accuracy of soccer player subjects.

## Procedures

An adaptation of the Ferraz et al. (2012) protocol was used. The subjects had a familiarisation session one week before in which they, as a part of the warm-up, completed the circuit. This was done to avoid the learning effect. After a general warm-up of 15 minutes, which included jogging and kicking drills, kicking performance was tested from 11 m (penalty kick). A standard soccer ball (mass approximately 430 g with a circumference of 70 cm) was used. The instruction was to kick a regular ball with maximum force and attempt to hit a target from 11 m away; the target was a 1 x 1 m circle that was 1 m off the ground and located in the middle of a goal (7.32 x 2.44 m). Three attempts per condition were made. After three kicks, the participants started the circuit at intensity three (their own preferred tempo) to obtain an idea of what their preferred tempo was. Then, all intensities were randomised (including intensity three) to avoid a learning and/or fatigue effect. The random order was based on a random number generator. The circuit consisted of a set of specific and explosive exercises including jumping, skipping, multiple quick changes of direction, driving the ball, passing, bursts of sprinting and slow running (Figure 1). The five different prescribed intensities were:

Slowest - Perform the circuit slowly and comfortably.

A bit slower - Perform the circuit at a tempo that is a bit slower than your own preferred tempo (a bit slower).

Preferred tempo - Perform the circuit at your preferred tempo.

A bit faster - Perform the circuit at a tempo that is a bit faster than your preferred tempo but not as fast as possible.

Fastest - Perform the circuit as fast as possible.

After each circuit, the participants had to kick the ball three times. After the three kicks, the participants had five minutes to rest and recover so that the previous intensity did not have an influence on the next intensity.

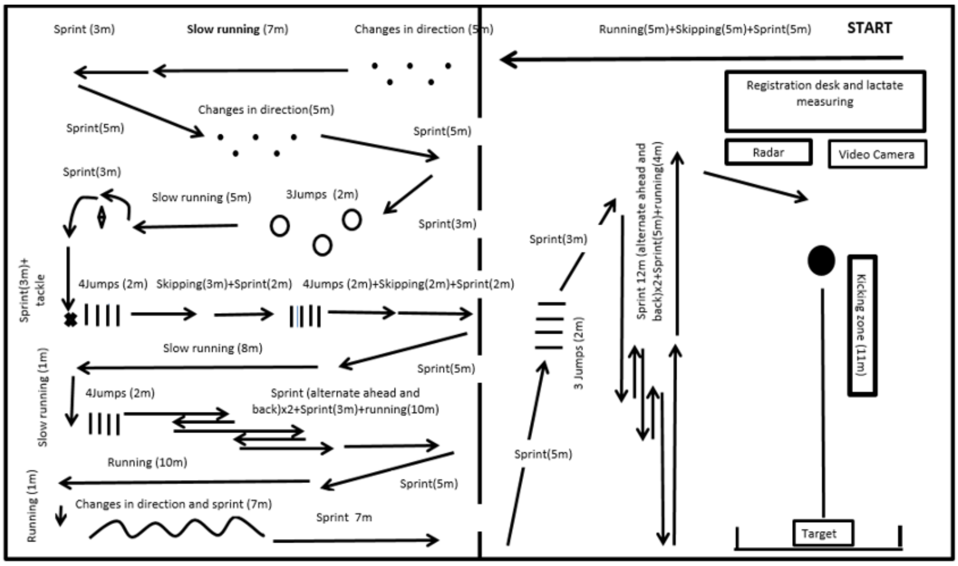

Figure 1. Circuit design.

## Measurements

The kicking ball velocity of the ball was determined using a Doppler radar gun (Sports Radar 3300, Sports Electronics Inc.) with ± 0.028 m•s-1 accuracy within a field of 10 degrees from the gun. The radar gun was located 2 m behind the 11 m line at ball height during the kick. The average kicking ball velocity after each circuit was used for further analysis.

Kicking accuracy was measured with a video camera (Sony HDR-FX100, Tokyo, Japan) placed at a distance of 12 m from the goal. The camera was positioned so that the subject did not obstruct the field of vision between the camera and the goal. The position of the centre of the ball was measured at the moment it struck the goal. Mean radial error (MRE), as described by van den Tillaar & Ettema (2007), was used as a measurement of accuracy. MRE was measured as the average of absolute distance to the centre of the target.

The time of each circuit was also measured. Participants wore a pulse belt (Polar, RS300x, Oulu, Finland) for the duration of the experiment. Heart rate (HR) was measured immediately following the completion of a circuit and just before the start of the next one, as was the rating of perceived exertion (RPE), which was on a 20 point Borg scale 22. Lactate was measured after the warm-up and directly after the three kicks following each circuit. Blood was taken from the fingertip, and a lactate measurement was performed using a portable machine (Roche Accutrend Lactate Test Strips, Basel, Switzerland).

### Statistical analyses

To assess differences in maximal ball velocity, a repeated ANOVA was used for kicking accuracy, HR, lactate, RPE and time of each circuit. Post hoc comparisons with Holm-Bonferroni corrections were conducted to locate differences. All results are presented as mean ± SD. Where sphericity assumptions, measured by the Mauchti's tests of sphericity, were violated, Greenhouse-Geisser adjustments of the p-values were reported. The level of significance was set at $p<0.05$. Effect size was evaluated with $\eta2$ (Eta partial squared) where $0.01<\eta2<0.06$ constitutes a small effect, $0.06<\eta2<0.14$ constitutes a medium effect and $\eta2>0.14$ constitutes a large effect 23. Statistical analysis was performed with SPSS, version 18.0 (SPSS, Inc., Chicago, IL).

## Results

The time to cover the circuit, average kicking ball velocity and accuracy were not significantly different when performing the circuit directly after the warm-up compared to the later circuits ($p\geq0.14$, Figures 2,3), contrary to the lactate concentration which was significantly different ($p<0,05$, figure 4) except in comparison with the slowest one. HR and RPE were significantly ($p\leq0.02$) higher when performing the circuit at the preferred tempo for the second time (Figure 5). The time used for completing the circuit was significantly shorter after each circuit when the intensity was increased ($F(5,50)=74.9$; $p<0.001$; $\eta2=0.88$; Figure 2).

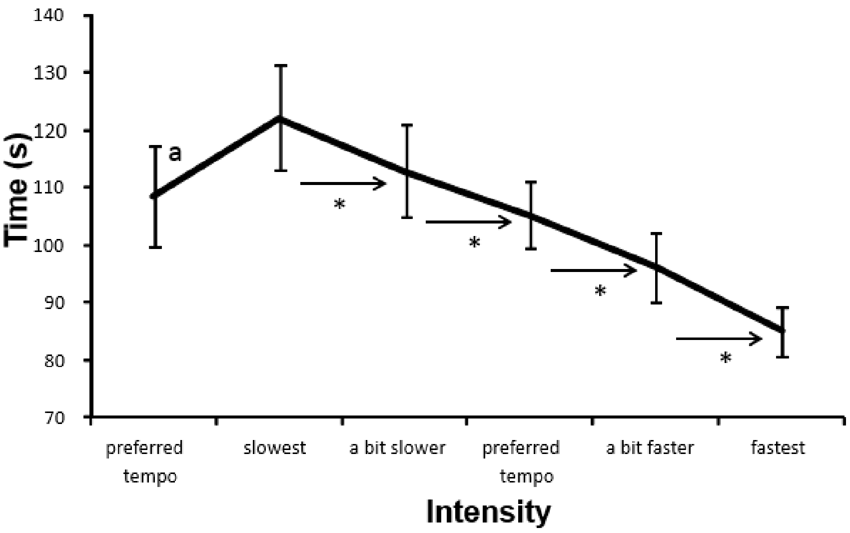

Figure 2. Time used to cover the circuits at different intensities. *p<0.05, compared with all next intensities; $^{a}$p<0.05, compared with all intensities except with preferred tempo and a bit slower.

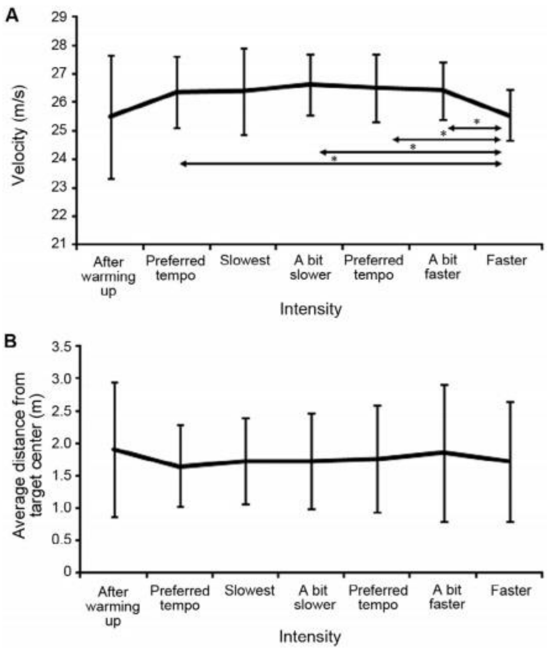

Figure 3. Average ball velocity (A) and accuracy (B) at the different intensities averaged over all participants (mean±SD).
*Indicates a significant difference between two intensities (p<0.05).

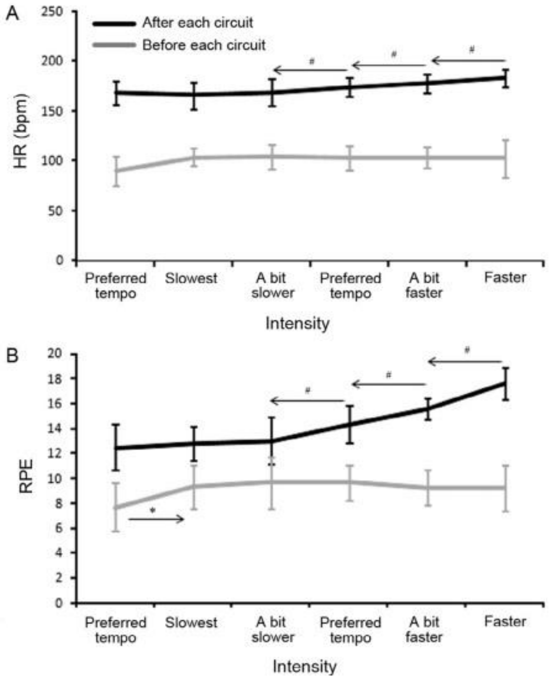

Figure 5. Hear rate (HR) and rating of perceived exertion (RPE) before and after each circuit at the different intensities averaged over all participants (mean±SD). *p<0.05, compared with all next intensities right of the sign; #p<0.05, compared with all next intensities left of the sign.

Average (F(6,66)=2.3; p=0.041; η2=0.18) ball velocity was significantly affected after completion of the circuit. A post hoc comparison showed that the ball velocity only decreased significantly at the highest intensity compared with all others, except with the one after the warm-up and the slowest performed circuit. Accuracy (F(6,66)=0.19; p=0.98; η2=0.02; Figure 3) did not significantly change during the protocol.

Lactate concentration changed significantly during the protocol (F(6,66)=4.81; p<0.001; η2=0.3). A post hoc comparison showed that lactate concentration was significantly lower directly after the warm-up compared with most intensities (except the lowest one). Furthermore, the lactate concentration was only significantly higher after the faster and fastest conducted circuits compared to the slowest circuit (Figure 4).

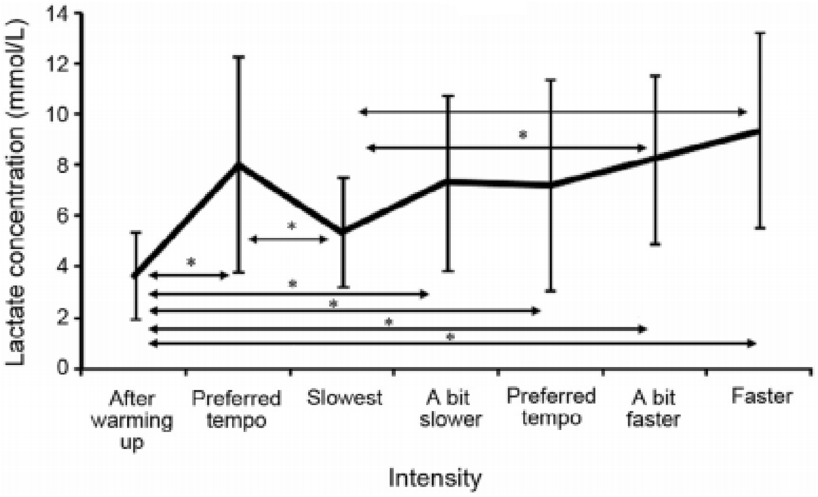

Figure 4. Lactate concentration after each circuit at the different intensities averaged over all participants (mean±SD). *Indicates a significant difference between two intensities (p<0.05).

HR and RPE before the start of each circuit changed significantly (F(5,40)≥4.07; p<0.04; η2 ≥ 0.27). A post hoc comparison revealed that HR and RPE only increased significantly from the preferred tempo intensity directly after the warm-up with all other intensities (Figure 5). When HR and RPE were measured after each circuit, they increased significantly over the exercise period (F(5,45)≥12.7; p<0.001; η2≥0.59). A post hoc comparison revealed that both HR and RPE significantly increased after every intensity, from the slower to the fastest circuit (Figure 5).

## Discussion

The main findings of the current study showed that maximal ball velocity was affected only after the most intense circuit, while accuracy was not affected in the protocol. The increased intensity corresponded to the expected decrease in duration in each circuit and the increase of fatigue, as demonstrated by HR, RPE and lactate. Our results suggest that kicking performance (ball velocity) is only affected after high-intensity exercises. Lower exercise intensities do not affect accuracy or kicking ball velocity.

Parts of these results are in accordance with previous studies about the effect of high-intensity exercises on kicking soccer balls. The studies reported the possible negative effect explained by biomechanical and physiological causes such as generated muscle incapacity with a decrease in strength, reduction of movement stability (especially in knee and hip range of motion), or a decrease of limb velocity (Forestier & Nougier, 1998; Gates & Dingwell, 2011; Gribble et al., 2004; Kellis et al., 2006; Rahnama et al., 2003; Rodacki et al., 2001; Sparto et al., 1997).

A previous study 5 that researched the variations between different exercise intensities also reported a detrimental effect on passing skill performance after high levels of localized fatigue. These findings are consistent with soccer-specific research (Chmura & Jusiak, 1994) which observed a detriment in the psychomotor performance of players following exhausting levels of exercise.

However, contradictory results were found by McMorris et al. (1994) considering passing skills. They found that performance in rest and high-intensity exercise did not differ. Also, Ferraz et al. (2012) according to the most recent fatigue theories and using a repetitive high-intensity protocol (exhaustion protocol), concluded that maximal ball velocity on kicking was also affected, but this effect was not linear or progressive and might be dependent upon factors other than those relating to physiology (Amann & Dempsey, 2008; Amann & Secher, 2010; Marcora & Staiano, 2010; Mauger et al., 2009; Millet, 2011; Noakes, 2012; Noakes et al., 2005; Swart el al., 2009). Another similar study 1 concluded that kicking accuracy and short passing ability were only minimally affected by high-intensity activities immediately post-exercise, but recovered thereafter in the case of kick.

The differences in the exercise protocols used in these studies may condition a comparative analysis of the results and can explain part of the contradictory outcomes. The majority of the studies pointed that high-intensity exercise was a potential negative factor on kicking performance due to fatigue. However, this potential was not found to be negative and could have been variable (Ferraz et al., 2012). It is also known that, in successive repetitions at a

high-intensity, the influence of fatigue may not always be the same; there may even be no practical effects on the performance of the kick, even if the player is exhausted (Ferraz et al., 2012).
Another point of discussion is the comparison between the intensity of the first and second selected tempo. No differences in kicking performance (Figure 3), time (Figure 2) and lactate (Figure 4) were found indicating the participants were pretty good in the perception of the prescribed intensity. Only the heart rate and RPE after the circuit was higher (Figure 5), but that can be explained by the fact that after the first selected tempo, the participants were not so fatigued, while after the second tempo the participants have already performed several circuits with different intensities. Due to the random order of these intensities, some participants could have been more fatigued and were therefore not fully recovered from the previous one, which increased the heart rate and RPE more in the second time (Green et al., 2005).

However, it is also possible that at the second selected tempo, the pacing strategy used was more tiring (more intense), although it was not reflected in most of the remaining values; it was, however, reflected in HR and RPE, probably due to stronger overall coupling among the two (Green et al., 2005). Thus, it seems that, during the protocol, the perception of selected tempo changed and, according to recent studies, perhaps the player modulated their effort, and the auto-regulation became slightly more aggressive, even without significant results in kicking performance (Ferraz et al., 2012; Mauger et al., 2009; Millet, 2011; Swart et al., 2009). This finding show a possible evidence that there may be mechanisms (not only physiological) that can influence players during exercise.

Regarding kicking accuracy, no effect was found. Conversely, some studies reported a negative effect on kicking accuracy in high-intensity efforts due to changes in coordination by inherent physiological causes (Gribble et al., 2004; Ismail et al., 2010), approach speed, skill level (Draganidis et al., 2013; Lees & Nolan, 1998) blood lactate level and decreased muscle glycogen in connection with impaired neuromuscular performance affecting coordination and, consequently, soccer skills (Ekblom, 1986). Otherwise, similar effects on kicking accuracy were found in a recent and related study 1, which showed that soccer skill performance was only minimally affected by acute resistance exercise independent of intensity because knee extensor muscle strength remained unaffected during protocol application. In addition, Ferraz et al. (2012) did not find any effect on kicking accuracy, which was similar to a study by Van den Tillaar and Ulvik (2014) that showed that kicking accuracy could only be affected when the main priority in instruction was upon hitting the target.

Future studies should focus upon kinematic analyses of coordination and strength patterns to investigate the changes that occurred after high intensity activities. It would give a better understanding about the possible impact of the mechanisms (not only physiological) that can influence the player during exercise, especially the possible role of the psychological/motivational aspects that should continue to be explored, in relation to the high intensity exercises, especially in team sports as a soccer.

## Conclusion

Kicking soccer velocity was conditioned by high intensity exercises. Additionally, we concluded that low and moderate exercise intensities did not affect the performance of the kick, and the intensity of exercise did not influence accuracy. A possible negative effect of fatigue due to high intensity exercises and possible changes related to patterns of coordination and strength were considered. Otherwise, it is possible that other mechanisms (not only physiological) could influence players during exercises, but more studies are needed to confirm and develop this hypothesis.

# Study 4

## Effects of knowing the task duration on players’ pacing strategies during soccer small-sided games.

## Abstract

The aim of this study was to identify the influence of prior knowledge of exercise duration on players’ pacing strategies during soccer small-sided games. Twenty semi-professional male soccer players (age 21.9 years ± 2.1) participated in this study. In the first game scenario, players were not told how long they would be required to play the small-sided game, the activity was terminated after 20-min (Unknown Condition). In the second game scenario, players were told that they would play the small-sided game for 10-min, but immediately after completing the 10-minute game, they were asked to complete another 10-min (Partially Condition). In the third game scenario, players were informed that they would play the small-sided game for 20 minutes and then they completed the 20-min game (Known Condition). Players’ tracking displacements were recorded using 5 Hz GPS units and results were analysed using uncertainty in the true differences of the scenarios and non-clinical magnitude-based inferences. The results presented a tendency of higher values in the first 10-min compared with the second 10-min. As the players’ previous knowledge about the tasks duration increased, the performance between two moments tended to be similar. Considering the entire 20-min game duration, the Partially Condition of the exercise was the most demanding condition. As a conclusion, the knowledge of shorter durations of the exercise seems to lead to an increase of exercise duration demand, and longer exercise durations possibly tend to decrease differences between full knowledge and not knowing the exercise duration.

**Key words**: Fatigue; Anticipation; Psychophysiology; Intermittent exercise; Perception of effort

## Introduction

Fatigue effects in high intensity, intermittent team sports and particularly in soccer is of substantial interest and discussion (Waldron & Higton, 2014). Mohr et al. (2005) have previously reviewed the topic of fatigue with reference to soccer performance, describing the temporal running patterns of players during matches and proposing a variety of responsible physiological mechanisms. Until recently, fatigue in matches was attributed to several individual physiological and psychological factors such as blood lactate and H+ accumulation, glycogen depletion, PCr depletion, dehydration, failure of neural transmission, motivational and mental mechanisms, or contextual and tactical factors (Edwards & Polman, 2014; Mohr et al., 2005; Waldron & Highton, 2014). The theory of terminal fatigue (i.e. depletion system capacity) has been proposed within various individual physiological systems (Mohr et al., 2005; Mohr et al., 2003; Reilly et al., 2008;), however, the topic of fatigue in team sports seems to have been updated recently, due to the possible effects of pacing, already demonstrated in continuous sports (Ferraz et al., 2012; Millet, 2011; Waldron & Highton, 2014.

Although the topic is still understudied, recent studies have confirmed the possibility that other mechanisms aside from physiological ones may contribute to the understanding of the fatigue effects, giving importance to pacing and psychophysiological theoretical approaches (Billaut et al., 2011; Edwards & Polman, 2014; Ferraz et al., 2012; Gabbett et al., 2015; Millet, 2011; Waldron & Highton, 2014). The concept of pacing is defined by Gabbett et al. (2015) as the management and strain distribution during an exercise in which the player, consciously and unconsciously, tries to complete the activity in a reasonable physiological state, controlling the onset of fatigue. Afferent sensations are sent from the musculoskeletal and cardiovascular systems to the central nervous system, where the pacing strategy is altered based on the brain's interpretation of the perceived exertion (Edwards & Noakes, 2009; Gabbett et al., 2015). This concept of pacing takes into account previous topics of temporary fatigue during team sports matches, but suggests and adds alternative mechanisms for the observed fluctuations in match-running performance based on the psychophysiological system (Edwards & Polman, 2014; Waldron & Highton, 2014). This view does not diminish the importance of physiological behavior, but it specifies and enhances the crucial role of the brain in the regulation of physical effort. The knowledge of the activity in addition to various forms of feedback sensations determines the psychophysiological process controlled by the brain (Edwards & Polman, 2014).

For example, various pacing profiles seems to characterize match running performance among soccer players (Waldron & Highton, 2014). Whole-match players supposedly adopt a "slow positive" pacing profile, characterized by a gradual decline in total and high-intensity running. In contrast, part-match players are thought to select either “all-out” or “reserve” strategies, depending on their role in the match, although this all-out end spurt may not be a common event. Additionally, it seems that the brain initiates a strategy at the start of a match, based on both the knowledge of the duration of the game and prior experience. Recently, Waldron et al. (2014) demonstrated that team-sport athletes that are required to compete for relatively short periods (e.g., substitutes) set a higher initial pacing strategy and exhibited a significantly greater end spurt than athletes required to play the entire match. This suggests that shorter anticipated exercise periods are associated with greater playing intensities. In a more closed approach, Billaut et al. (2011) examined the influence of prior knowledge of sprint number on repeated-sprint exercise performance. The authors concluded that pacing occurs during repeated-sprint exercises in anticipation of the number of efforts that are expected to be included in the bout.

In fact, the knowledge of the duration initially employed in continuous sports is known as a significant factor in the pacing strategy and it has been demonstrated to be a major factor in the allocation of physiological and psychological resources during continuous exercise, but also recently applicable and investigated in intermittent exercise (St Clair Gibson & Noakes, 2004).

Despite advances on this topic, few studies examined the influence of pacing as an explanation of the reduced work outputs in team sports. This is probably because of the difficulties in identifying an appropriate model that represents the complexity of the energetic demands and movement (Edwards & Polman, 2014). Additionally, in team sports it is difficult to isolate effects from the factors associated with the pacing concept.

Due to the general lack of experimental research at this purpose, more studies are needed. Objectively and about prior knowledge of exercise duration, only one study in rugby attempted to investigate its influence on the pacing strategies employed during game-based activities and the authors conclude that rugby players alter their pacing strategies based on the anticipated endpoint of the exercise bout (Gabbett et al., 2015). Nevertheless, it is difficult to generalize the conclusion of this study (Gabbett et al., 2015) to all team sports, because each one has its specificity and consequently is desirable to perform an analysis of the influence of duration knowledge of game exercise in soccer. Moreover, to understand the effect of knowledge, it is also important to control other possible variables directly or indirectly involved. In this study, (Gabbett et al., 2015) verbal encouragement was used, which may have influenced some results. Furthermore, the time duration of exercise is a crucial point of analysis and it seems to be relevant to understand and compare what happens not only in shorter durations of exercise such as was considered, but also in a perspective of longer durations.

Therefore, the purpose of this study was to investigate the influence of prior knowledge of exercise duration on the pacing strategies employed during game-based activities in soccer. The small-sided games were the method selected, due to their characteristics and their application in soccer training. Moreover, we tried to understand what happens in a longer time of exercise duration. We hypothesized that players alter their pacing strategy based on the knowledge of the exercise duration. Moreover, and based on findings of the other studies, we also hypothesized that players perform at higher intensities during an exercise of an anticipated shorter duration, and when the exercise is longer, the pacing strategy is to lower exercise intensity. However, it is also possible that at the end of the longer and known exercise, there will be an increase of intensity (Millet, 2011).

## Materials and Methods

### Subjects

Twenty semi-professional male soccer players (age 21.9 years ± 2.1) with 9.1 years ± 3.8 years of experience, playing in the second division of the Portuguese National Competition, participated in this study. All players performed 5 training sessions (90 min) per week and played an official game during the weekend. All of them were informed about the experimental procedures and an informed consent was signed prior to all testing in accordance with the recommendations of the local ethics committee and current ethical standards in sports and exercise research.

### Design

A cross-sectional field study and an adaptation of the Gabbett et al. (2015) protocol were used. Testing was conducted over 4 training sessions. The first session involved familiarization of players with the game-based activity, equipment and procedures. Within one week of the familiarization session, the players performed three randomized small-sided games separated by 7 days. In first game scenario, players were not told how long they would be required to play the small-sided game, but the activity was terminated after 20 minutes (Unknown Condition). In the second game scenario, players were told that they would play the small-sided game for 10 minutes, but immediately after completing the 10-minute game, they were asked to complete another 10 minutes, so that the total exercise duration was 20 minutes (Partially Condition). In the third game scenario, players were informed that they would play the small-sided game for 20 minutes and then completed the 20-minute game (Known Condition).

## Methodology

A small-sided game was played in each session. Players were separated into 4 balanced teams of 5 players taking into account playing positions, tactical/technical levels and physical capacities. Teams' constitutions and respective opponents were maintained for each played condition. The small-sided game was played in a standardized (20 m wide × 40 m long) playing pitch. Multiple balls were positioned around the field so that in the case of a ball leaving the field another was quickly introduced to ensure the game continued.

At the completion of each condition, players provided an overall rating of perceived exertion using the Borg 6-20 scale (RPE) (Borg, 1973). All players were familiar with the RPE scale and had previous experience rating the perceived exertion of training drills and small-sided games.

Players' tracking displacements were recorded by 20 GPS units working at a sampling frequency of 5 Hz (SPI-Pro X II, GPSports, Canberra, ACT, Australia) (Johnston et al., 2012). The processed variables were the total distance covered (m), game pace (obtained by the players' average speed displacements) and total impacts. In addition, three ratios were calculated to relate and compare the distance covered at high to very high (above 16 km/h), moderate (10.0–15.9 km/h) and low intensity (7.0–9.9 km/h), normalized for each 100 m for comparison purposes. These work-rest ratios are frequently used in the literature to describe activity profiles (Abade et al., 2014).

## Statistical Analysis

A descriptive analysis was performed using mean and standard deviations. The comparison among game conditions were assessed via standardized mean differences, computed with pooled variance and respective 90% confidence intervals (Cumming, 2012). Thresholds for ES statistics were 0.2, trivial; 0.6, small; 1.2, moderate; 2.0, large; and 2.0, very large (Hopkins et al., 2009). Differences in means, i.e., 1st vs. 2nd 10' bouts for each condition, and comparison among the entire 20' condition, were expressed in percept units with 90% confidence limits (CL). Smallest worthwhile differences were estimated from the standardized units multiplied by 0.2. Uncertainty in the true differences of the scenarios was assessed using non-clinical magnitude-based inferences (Batterham & Hopkins, 2006; Hopkins et al., 2009).

## Results

Table 1 and Figure 1 (a, b and c) present the results when comparing the 1st 10’ vs. 2nd 10’ game performance for the three condition games. Overall is presented a tendency of higher values, the 1st 10’ compared with the 2nd 10’, and the results also show that as the previous players’ knowledge about the tasks duration increases, the performance between two moments tend to be similar.

Considering the Unknown Condition, the players showed being from a likely 20.7; ±19.6% (mean difference %; 90% CL) decrease in H/VH ratio (small effect) to a most likely 27.3; ±8.4% decrease in Low ratio (moderate effect) when comparing the 1st 10’ vs. 2nd 10’.

In the Partially Condition, the difference between moments of performance decreased compared with the previous trend. However there was still a solid tendency with an exception to the Low ratio that presented an unclear result (-6.6; ±12.2% variation, with unclear effect).

When the player knew the duration of tasks, the performance tended to be similar between game bouts, and also the inter-players’ performance variabilities increased (as can be seen by the confidence intervals from effect sizes).

Table 1. Descriptive statistics when comparing 1st 10’ vs 2nd 10’ for the different condition game variables.

| Variables | Unknown | | Change in mean (%; 90% CL) | Partially known | | Change in mean (%; 90% CL) | Known | | Change in mean (%; 90% CL) |
|---|---|---|---|---|---|---|---|---|---|
| | 1st 10' | 2nd 10' | | 1st 10' | 2nd 10' | | 1st 10' | 2nd 10' | |
| Total distance meters/min | 107.9±14.3 | 96.2±15.9 | -11.2; ±2.9 Most likely ↓ | 108.8±12.8 | 102.3±15.5 | -6.5; ±2.5 Likely ↓ | 103.1±14.3 | 99.1±10.7 | -3.6; ±5.1 Possible ↓ |
| Ratio (H/VH) meters | 19.2±12.5 | 14.5±8.4 | -20.7; ±19.6 Likely ↓ | 25.9±13.4 | 21.2±11.4 | -22.9; ±10.8 Likely ↓ | 21.0±11.6 | 16.8±9.2 | -23.9; ±34.1 - |
| Ratio (Moderate) meters | 78.3±29.8 | 56.6±25.0 | -29.6; ±6.9 Most likely ↓ | 78.0±24.3 | 67.0±24.6 | -16.6; ±5.5 Very likely ↓ | 66.1±26.6 | 56.6±17.7 | -12.2; ±15.0 Possible ↓ |
| Ratio (Low) meters | 58.2±16.7 | 42.7±13.0 | -27.3; ±8.4 Most likely ↓ | 53.3±14.6 | 50.2±14.4 | -6.6; ±12.2 - | 47.1±16.2 | 44.5±12.4 | -4.9; ±14.6 - |
| Game pace km/h | 6.5±0.9 | 5.8±1.0 | -11.1; ±3.1 Most likely ↓ | 6.5±0.8 | 6.1±0.9 | -6.8; ±2.5 Very likely ↓ | 6.3±0.9 | 5.9±0.7 | -6.3; ±2.3 Likely ↓ |
| Total impacts a.u. | 137.1±37.2 | 113.4±34.8 | -17.7; ±7.6 Very likely ↓ | 158.9±33.7 | 133.5±43.3 | -18.5; ±6.7 Most likely ↓ | 146.4±46.6 | 135.3±39.4 | -6.0; ±8.1 Possible ↓ |

**Note:** Abbreviations and symbols: H/VH=high/very high; CL=confidence limits; ↓ =decrease; ↑ =increase.

Table 2 and Figure 1 (d, e and f) present the results when comparing the 3 conditions performance (for the entire 20' game duration). The Partially Condition was the most demanding condition. When compared to Unknown, the Partially information increased 49.1; ±47.7% (likely, small effect) of the H/VH values and 17.1; ±15.0% (likely, small effect) of the total impacts. However, the players' RPE were likely lower (-8.7; ±8.3%, moderate). When comparing Partially vs. Known, the higher difference was found in H/VH with likely 31.9; ±27.6% (small effect) higher values to the Partially Condition. Finally, when comparing the Unknown vs. Known Condition, the differences were declared unclear with respect to total impacts (likely 10.9; ±9.9% higher in Known) and RPE (likely 6.9; ±5.7% higher in Unknown).

Table 2. Descriptive statistics when comparing the 20' game different condition variables.

| Variables | Unknown (20' game) | Partially known (20' game) | Known (20' game) | Change in mean (%; 90% CL) |
|---|---|---|---|---|
| Total distance meters/min | 102.1±14.5 | 105.5±13.9 | 101.0±13.0 | a) 3.5; ±7.9<br>b) -0.9; ±5.0<br>c) -4.3; ±6.6* |
| Ratio (H/VH) meters | 16.7±9.1 | 23.5±11.7 | 17.7±9.0 | a) 49.1; ±47.7**<br>b) 1.5; ±45.2<br>c) -31.9; ±27.6** |
| Ratio (Moderate) meters | 66.9±26.2 | 72.4±23.8 | 64.1±20.8 | a) 10.8; ±24.9<br>b) -1.6; ±14.8<br>c) -11.2; ±16.4* |
| Ratio (Low) meters | 50.0±13.5 | 51.6±12.9 | 50.2±14.6 | a) 4.2; ±15.3<br>b) 0.0; ±13.3<br>c) -4.0; ±13.6 |
| Game pace km/h | 6.1±0.9 | 6.3±0.8 | 6.1±0.8 | a) 3.3; ±7.9<br>b) -1.0; ±5.0<br>c) -4.2; ±6.6* |
| Total impacts a.u. | 250.5±65.9 | 292.4±72.2 | 281.7±82.4 | a) 17.1; ±15.0**<br>b) 10.9; ±9.9**<br>c) -5.3; ±11.0 |
| RPE a.u. | 14.8±2.7 | 13.3±1.5 | 13.6±1.7 | a) -8.7; ±8.3**<br>b) -6.9; ±5.7**<br>c) 2.1; ±7.0 |

**Note:** Abbreviations and symbols: CL=confidence limits; ↓ =decrease; ↑ =increase. Differences in means ((%); ±90% CL) are identified as: a) Unknown vs. Partially; b) Unknown vs. Known; and c) Partially vs. Known. (*) Indicate the uncertainty in the true differences as follows: *=possible and **=likely.

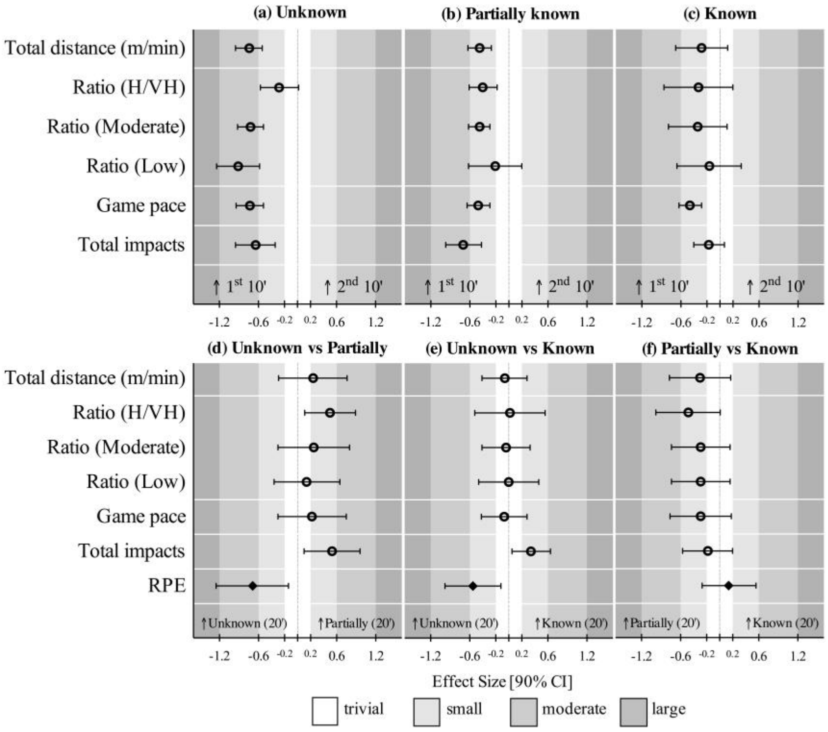

Figure 1. Comparative results of the 1st 10’ vs 2nd 10’ for the different condition game variables; and comparison between the different condition game variables during the 20’ game performance.

## Discussion

This study is the first to identify the influence of prior knowledge of exercise duration on the pacing strategies employed during small-sided games in soccer. In addition it is the first to compare what happens in a longer duration of exercise. The main findings were that with an increase of the previous players’ knowledge about the task duration, the general performance between the initial stage of exercise duration and the second one tended to be similar. Moreover, considering the entire 20’ game duration and the comparison between the three conditions performances, the partial knowledge condition (Partially Condition) of the exercise was the most demanding condition.

Primarily, our findings are in line with studies that reported that player pacing strategies are influenced by the duration knowledge of the exercise (Billaut et al., 2011; Gabbett et al., 2015; Lambert et al., 2005; Lander et al., 2009). According to these studies, it seems that the brain initiates a self-regulation strategy of effort based on prior knowledge of the task and this fact can explain the sport specific fitness of both greater total and higher intensity work. Also in our study it seems to have been a conscious or unconscious mechanism of regulation that led to changes in performance on the basis of previous different pieces of information provided.

Comparing the initial [10 minute] exercise period and the second for the three conditions, the initial [10 minute] exercise period have higher values. Primarily and according to the literature and from a physiological point of view, this can be explained by the effect of accumulated fatigue during the exercise time, probably due to the accumulation of H+ that contributes to decreased muscle pH, which impairs the cellular process that produces energy and muscle contraction. However, we can also conclude that seems the players adopted a “slow positive” pacing profile (Waldron & Highton, 2014) characterized by a gradual decline in total and high-intensity running between the initial [10 minute] exercise period and the second. Moreover, the differences between the 1st 10’ and 2nd 10’ tend to decrease when knowledge of exercise duration increases. This means that most of the variables have a tendency to be higher in the initial [10 minute] exercise period of exercise but there is a better balance in the regulation of effort when the knowledge is greater.

Gabbett et al. (2015) found similar results with a significant effect of condition and time on the relative intensity of the small-sided games with higher initial intensities, although there is no correspondence comparing the results of different groups / conditions in relation to our study. Protocol differences and the specificity of each sport perhaps can influence the results of each condition. Likewise, the results may confirm the possibility of the changes in the pacing strategies of the players due to the effect of knowledge leading to the possibility of the non-linearity of the fatigue effect already pointed out in some studies (Ferraz et al., 2012; Millet, 2011). Similarly, and according to the study of Millet et al. (2011) applied in ultra marathon running, it is possible that the players control their effort in order to increase their performance in the last part of the exercise duration, as a result of a more aggressive regulation strategy in this part of the exercise, possibly due to having the knowledge of the exercise duration (previous knowledge about exercise duration and knowledge about time remaining), despite the physiological accumulation of fatigue.

When we compared the three different performance conditions for the entire 20 min game duration we found that the Partially Condition always presents a tendency to higher values of all variables when compared with the other conditions, except RPE. Seems the players adopted the “all-out” or “reserve” pacing pattern (more aggressive pacing pattern) (Waldron & Highton, 2014) when they knew the partial duration time (Partially Condition). These results are not fully consistent with the findings of Gabbett et al. (2015). In this study there is no condition that always shows better or the same results compared to the other conditions, perhaps due to reasons already mentioned. However, and in line with Billaut et al. (2011) study, when the players were deceived so as to believe that they had to perform only 10 minutes (i.e., the Partially Condition), they probably produced higher power and work than in the two other conditions, and it’s possible that there was a greater subconscious neural drive, probably because of the reduced time duration of exercise, which led to greater muscle recruitment and thus greater performance output. These results reinforce the possibility that the control of the initial exercise performance was, at least in part, regulated in anticipation of the exercise. This anticipation according to Billaut el al. (2011) would have been based on the knowledge of the duration of the exercise performance, which may be considered in the present study as the end point of the exercise (Noakes et al., 2005; St Clair Gibson et al., 2006; St Clair Gibson & Noakes, 2004). Moreover, it was expected that RPE values were higher in the Partially Condition due to the possibility that a greater conscious perception of effort occurs when the ratio of high-speed-running intensity is higher (Edwards & Noakes, 2009) due to the knowledge of a shorter exercise duration (Gabbett et al., 2015). Therefore, we can also consider that in the Unknown Condition RPE values would be lower (Billaut et al., 2011). Corroborating these hypotheses, a recent study has also suggested that RPE is a key mediator in the regulation of work rate during continuous exercise based on the anticipatory feedback model (Tucker, 2009).

The anticipatory feedback model of performance suggests that the CNS (which plays a role in most types of fatigue) may continuously compare the consciously perceived exertion generated from the sum of all afferent cues with a RPE “template” based on prior knowledge (Tucker, 2009) preceding physiological fatigue. Baden et al. (2005) have suggested that changes in RPE are the result of affective processes responding to an unexpected sudden increase in exercise duration or the sudden imposition of a mismatch between the previously anticipated and the newly required exercise duration (similar to our Partially Condition). However, and contrary to expectations, RPE values were significantly higher in the Unknown Condition compared with the other conditions, in which they presented similar values, not showing corresponding values to the demands of exercise and not following the anticipatory feedback model theory.

To this purpose, some studies have also shown that perceived exertion may be a psychological construct that is altered by changes in affect and cognitive focus of the athlete (Baden et al., 2005; St Clair Gibson et al., 2006). In our study, the Unknown Condition probably leads to a perception of greater effort which is also reflected in practice and in RPE values. The other conditions tend to be similar, perhaps because the knowledge of exercise duration changed the cognitive focus of the player, leading him to a more conscientious perception of effort. Thus, we can suppose that a direct association between exercise intensity and RPE values does not always occur.

Furthermore and still considering the entire 20 min game duration, results show that having or not having full knowledge cannot significantly influence the final performance of the exercise, and having only partial knowledge (knowledge of 10 min) may lead to increase performance. In fact, we also consider plausible that with the increase of exercise duration, the regulation of effort appears to become less accurate, more uncertain and because of this, it becomes economic. This also shows that the duration time of exercise can be an important factor regarding pacing strategies. Longer exercise duration, even with full knowledge of this duration, probably leads to a greater uncertainty in the effort regulation and an increase of exercise economy, compared to short-term exercise duration. The pacing pattern between unknown condition and known condition therefore tends to be similar probably because the degree of uncertainty in both conditions may be very similar

In this sense, it seems that the physical performance of intermittent exercise in soccer is probably higher in short-term exercises with partial knowledge of the information. But more studies are needed to confirm all of these assumptions.

## Conclusions

This study provides some evidence that during small-sided games in soccer, athletes alter their pacing strategies based on the knowledge of the exercise duration. Furthermore, the knowledge of a shorter duration seems to lead to an increase of exercise duration demand, and longer exercise durations possibly tend to decrease differences between full knowledge and not knowing the exercise duration. In fact, the knowledge of duration of exercise seems to be an important variable in pacing strategies on soccer, and coaches should consider the potential and the possibilities of the manipulation of this variable in terms of the physical impact regulation in their training exercises.

## Practical Applications

This study highlights the importance of the knowledge of exercise duration on pacing strategies in soccer and objectively in the physical performance of players. The coaches can manipulate this variable in order to manage the fatigue effect in exercise and this can be an important point to add in terms of the methodology of soccer training, specifically in preparation and control of the training tasks. For example, if the coach wants to keep a high physical performance of the exercise, he should choose short durations and inform the players previously about these task durations. But if he wants a more balanced effort management during the entire time of the exercise, he should enhance the duration of the exercise and also inform players about this task duration. Similarly, and according to the technical and/or tactical objectives of the exercise, the coach can develop these objectives in different situations of fatigue, manipulating the duration of the exercise and the information about this duration. For example, if the coach wants to create an exercise with fewer physical requirements and allows a greater physical availability to learning the other aspects during the duration, he should choose a longer exercise (e.g. 20 min), giving prior information to the players about the duration of it. But if he wants to develop tactical/technical content, with a greater physical performance scenario, he must perform the exercise in shorter blocks of duration, giving prior information about the time duration of each block (e.g. 10 min +10 min). Future studies should use the potential of this issue and provide information to coaches adding other training variables (e.g. technical and tactical aspects).

# Chapter 4. General Discussion

The purpose of this investigation was to analyze the effects of fatigue and task knowledge duration on soccer kicking performance and pacing strategies of soccer players. The lack of research about the effects of fatigue on kicking skill in soccer was the starting point of our experimental research. Our findings confirmed partially the hypothesis of the negative influence of fatigue upon kicked ball velocity in soccer (Studies 1–3). In addition, our data confirmed that kicked ball velocity is influenced only by high-exercise intensities and accuracy does not seem to be conditioned by fatigue (Studies 2–3). The results also support the hypothesis that psychophysiological factors are involved in fatigue in soccer activities (Studies 1-4) and knowledge of the task duration influences pacing strategies employed during soccer activities although this influence depends on the type of activity used (Study 2,4).

These findings were partially consistent with previous reports of a negative influence on soccer kicking due to muscular incapacity (Kellis et al., 2006), changes in skill-level patterns (Lees and Nolan, 1998), changes in coordination due to inherent physiological causes (Ismail et al., 2010; Seyed et al., 2010), changes in the moment of force (as shown in velocity) of the leg before ball contact and consequent decrease in strength of the muscles involved in kicking. However, our data revealed that performance was not consistent with the fatigue indicators during the intensive exercise/protocol. The progression of fatigue throughout the high-intensity exercises was not expressed proportionally on kicking performance and distance covered. In Study 1, the players started and finished each circuit showing considerably more fatigue, but they were able to attain a similar distance covered. Curiously, after two circuits, kicked ball velocity started to increase again after initially decreasing. In Study 2, maximal kicked ball velocity was affected only after the first circuit, while distance covered was not affected in the whole protocol. Study 3 showed that only high-intensity exercises influenced kicked ball velocity, corroborating with the results of the Study 1 and Study 2. Thus, it was possible to confirm the expected negative effect of fatigue but also the variability of this effect considering high-intensity exercises. This leads us to speculate on the possibility of the influence of other mechanisms rather than only physiological ones.

Our results showed that kicking accuracy was not altered, independent of the state of fatigue of the player and the intensity of the exercise (Study 2, 3). It would be expected that accuracy was conditioned by the changes in coordination due to inherent physiological causes (Sterzing, 2010; Stone & Oliver, 2009), the changes in the force of the leg before ball contact, or a decrease in the muscle strength or decreased muscle glycogen and impaired neuromuscular performance (Bangsbo, 1994; Currell et al., 2009; Sterzing, 2010; Stone & Oliver, 2009). However, players retained the same accuracy at all times; perhaps the technical level of the players was not high enough or the fact that knee extensor muscle strength remained unaffected during the protocol application as seen in Dragannidis et al. (2013). According to Van den Tillaar & Ulvik (2014), another possibility may be related to the focus of the player. When the main focus is upon velocity and secondary aim is accuracy, no difference in accuracy is found. Only when the aim focus is accuracy does the velocity decrease and the accuracy increase. In our research studies, the main aim chosen was velocity and the secondary aim was accuracy and this could explain the results. Despite the fact that they are linked in the same action, accuracy does not seem to be dependent on the factors that affect velocity.

The results showing the variability of fatigue effect on kicked ball velocity is one of the central points of the conclusions (Study 1 and Study 2) and needs to be examined with some caution as it is hard to explain based on previous research studies. According to the most recent literature related to fatigue, we could consider that these results express the complexity of the fatigue phenomenon and the relevance of the theory of the central regulation of exercise performance (Edwards & Polman, 2014; Noakes & Tucker 2008; Swart et al., 2012; Tucker, 2009; Waldron & Highton, 2014). Our findings showed the possibility that other mechanisms—not only physiological—contribute decisively to the central regulation of fatigue during exercise with consequences in the kicking action in soccer, especially after an intensive workout. Moreover, they showed that players displayed an anticipatory aspect of exercise regulation, possibly related to psychophysiological factors. Previous information about exercise duration and previous experience of the exercise (Study 1 and Study 2); the possible physiological status and afferent physiological feedback as described in the literature, may contribute to the variability of these results (Noakes, 2012; Swart et al., 2012; Tucker, 2009).

The initial decline in ball velocity followed by an increase after the third circuit in Study 1, together with the slight increase in distance covered and heart rate, showed the possible occurrence of the end-spurt phenomenon (Eston et al., 2012; Millet, 2011). The knowledge of the end-point of exercise (both expected duration from the onset of the exercise period and the duration of exercise remaining at any point during the exercise period) expresses the possible control made by the brain in determining the appropriate exercise intensity linked with a motivation factor (Eston et al., 2012; Millet, 2011). During the exercise, there was often a degree of uncertainty about the precise end, and the type of effort that was needed on the part of the players. If the exercise duration is unknown, the brain cannot accurately regulate the physiological status of the body with the remaining exercise duration. This could influence the pacing strategies of the players and this uncertainty may result in the maintenance of a motor unit and metabolic reserve throughout exercise. This neuromuscular metabolic reserve possibly was used in final part of the exercise and this is a possible support for the anticipatory feedback model applied in this study (Eston et al., 2012; Millet, 2011;

Noakes, 2012; Swart et al., 2012; Tucker, 2009). Thus, we can suppose that the knowledge of exercise duration has an important role on self-paced exercise (pacing strategies) in order to allow the brain to predict the most appropriate exercise intensity that will enable optimal performance without causing severe disruption to homeostasis (Tucker, 2009).

Although the complexity of the phenomenon urges some caution in the direct interpretation of the findings, because in Study 2 no effect of duration of exercise knowledge was found, contrary to the initial hypothesis. The absence of the direct influence of knowledge duration in this study reinforces the need for a broader understanding of the phenomenon as a cause of multiple factors. A possible learning effect (previous exercise experience) of the protocol may occur between the first repetition of the circuit and the second, and may have influenced the pacing strategies of the players and it may have directly affected the influence of the duration knowledge. This highlights the possible importance of the previous experience of the exercise, which is also predicted by the anticipatory feedback model. Therefore, we can assume that the variability of the fatigue effect should be looked at based on the hypothesis that players self-regulate their effort, with variable consequences on the kicking performance. Different pacing patterns were used throughout the protocol, perhaps due to previous exercise experience (task familiarization), aspect of the anticipatory feedback model of fatigue (Lambert et al., 2005; Noakes, 2012; Noakes et al., 2005; Tucker, 2009;). Nevertheless, these results corroborated authors who have stated this model is excessively complex and provides significant challenges to researchers who attempt to experimentally investigate it.

We can also consider the presence of central regulation of exercise in Study 3 where it was confirmed that players had a great capacity to control, self-regulate and adjust their pace (self pace/chosen intensity) of the exercise according to the prescribed intensity. This study also expressed a valid perception of the required intensity by players, supporting the possibility that during fixed exercise intensities RPE is probably set by the brain at the onset of exercise (Tucker, 2009). Moreover, we can observe that exercise in accordance with tempo does not necessarily mean choosing a low or most easy intensity of effort.

The analysis of the results between the first and second selected tempos, highlighted the importance of the mechanisms emphasized in the anticipatory feedback model. The results show no differences in kicking performance, time to completion of task, and even lactate concentration between each tempo. Only the heart rate and RPE after the circuit was higher after the second selected tempo. This can be explained by the classical fatigue theory, based on physiological reasons. After the second tempo the participants have already performed several circuits with different intensities and due to the random order of these intensities, some participants could have been more fatigued and were therefore not fully recovered

from the previous one, which increased the heart rate and RPE more after the second selected tempo (Green et al., 2005).
Nevertheless, and according to the psychophysiological approach it is possible that at the second selected tempo, the pacing strategy used was more tiring (more intense), reflected by HR and RPE, probably due to stronger overall coupling among the two (Green et al., 2005). Thus, it seems that, during the protocol, the perception of selected tempo changed and perhaps the players modulated their effort, and auto-regulation became slightly more aggressive, even though without significant changes in kicking performance. These findings may reflect a subconscious improvement in the second select tempo and this again highlights that knowledge of the end point of exercise probably plays a role in the perceptual and physiological responses in that exercise period (Morton, 2009). Completing the sustained first select tempo circuit, the player improves task familiarity, responds to the exercise challenge confidently and shows the capacity to determine a self-selected preference for work intensity.

These findings reinforces the possibility that the results should be analyzed knowing the complexity of interfering factors that depend on many contextual psychophysiological aspects. Not just the knowledge duration or the physiological factors may interact to regulate exercise performance as pointed out by Study 2 and confirmed by the literature (Tucker, 2009; Noakes, 2012; Waldron & Highton, 2014).

Researchers should be aware that it is not easy to identify in each situation or context the potential psychophysiological factors associated with the variability of the fatigue effect, evidenced by the lack of experimental research. More research is needed on this important issue, and it seems pertinent to begin the investigation in broader context such as small-side games, a usual exercitation during soccer training.

In order to begin to answer this question, we investigated the influence of knowledge of exercise duration on the pacing strategies using soccer small-side games (Study 4). The main findings were that with an increase of player knowledge about the task duration, the general performance between the initial [10 minute] exercise period and the second tended to be similar. Moreover, considering the entire 20 min game duration and the comparison between the three performance conditions, the Partial Knowledge Condition of the exercise was the most demanding condition. Our findings suggest that player pacing strategies are influenced by the knowledge of duration of the exercise (Billaut et al., 2011; Gabbett et al., 2015) and are in line with some studies and the possibilities advanced in our previous studies (Studies 1–3). It seems to have been a conscious or unconscious mechanism of regulation that led to changes in performance based on knowledge of duration provided, which reinforced the possibility that the control of the initial exercise performance was, at least in part, regulated in anticipation of the exercise as discussed previously (Studies 1–3) and in accord with the anticipatory feedback model. However, two curious conclusions were revealed in this study and require some caution in generalizing the findings, as also occurred in Study 2. First, the results showed that having or not having full knowledge of duration did not significantly influence the final performance of the exercise, and having only partial knowledge may lead to increased performance; and second, RPE values were significantly higher in the Unknown Duration Condition, compared with the other conditions, which presented similar values each to other, and whose RPE values did not correspond to the exercise demands and in this point did not follow the anticipatory feedback model theory. Moreover, these findings does not seem to follow, in a certain perspective, the hypothesis that RPE values are robust when the exercise duration is known, even when no information is provided to the participant about how much distance has been covered or the remaining duration (Faulkner et al., 2011).

With regard to the first conclusion, we consider plausible that with the increase of exercise duration, the regulation of effort appears to become less accurate, more uncertain and because of this, it becomes economic. This also shows that the duration time of exercise can be an important factor regarding pacing strategies. Longer exercise duration, even with full knowledge of this duration, probably leads to a greater uncertainty in the effort regulation and an increase of exercise economy, compared to short-term exercise duration. The pacing pattern between unknown condition and known condition therefore tends to be similar probably because the degree of uncertainty in both conditions may be very similar.

In terms of the second conclusion, it was expected that RPE values would be higher in the Partial Knowledge Condition due to the possibility that a greater conscious perception of effort occurs when the ratio of high-speed running intensity is higher due to the knowledge of a shorter exercise duration (Gabbett et al., 2015; see also the data from Studies 1–3). When the exercise duration is unknown, it was expected that the lowest values of RPE may reflect a possible subconscious improvement in exercise economy in order to conserve energy due to the unknown exercise duration (Billaut et al., 2011). Similar conclusions can be drawn from Study 1 and in part of Study 2, in which RPE increased over a progressive fatigue protocol, which may be considered a physical sign of fatigue and perhaps also mental fatigue. Smith et al. (2014) also support this conclusion, reporting that mental fatigue is associated with the increase of the perception of effort and causing a reduction in overall and low-intensity running during intermittent running. Also, in Study 3 the RPE increased with the increase in exercise intensity; moreover, we found that during the second selected tempo (same intensity previously performed), self-regulation was more aggressive and was also accompanied by an increase of RPE.

Contrary to all expectations, RPE values were significantly higher in the Unknown Knowledge Condition compared with the other conditions, in which they presented similar values to each other, and whose RPE values did not correspond to the exercise demands and did not follow, in this point, the anticipatory feedback model theory. Moreover, these findings still contradict the possibility that for the same exercise intensity an increase of RPE may occur when the Partial Knowledge Condition is observed (Baden et al., 2005; Billaut et al., 2011; Gabbett et al., 2015). Thus, it seems to be also possible that when players are required to exercise for an unknown duration of time, their RPE may be compared to exercise at the same intensity for a known duration. Also, in Study 2, RPE increased similarly over the protocol, whether or not the player had knowledge of the protocol duration.

The anticipatory feedback model states a “template” RPE is developed that enables RPE to reach its maximum at the predicted termination of exercise. If the conscious RPE and “template” RPE deviate too much, exercise intensity is altered as appropriate to correct this imbalance. However we confirm that RPE does not always correspond to the intensity of exercise, which can corroborates some criticisms of the model. For example Marcora (2008) stated that the anticipatory feedback model theory could exist without inclusion of effort perception. Although considering the concept crucial in deterring dangerous levels of exercise, he states that exercise termination occurs when the effort required to continue the exercise is equal to the maximum effort that the player is willing to provide, or when the player believes that they have provided a true maximal effort, minimizing the role of RPE in the theory  of central regulation of exercise (Marcora, 2008).

Other possibilities are also plausible. The unknown knowledge condition (“unknown condition”) probably leads to a perception of uncertain effort, which is reflected in variety of RPE values. The other conditions tend to be similar, perhaps because the knowledge of exercise duration changed the cognitive focus of the player, leading him to more certainty in his perception of effort. This also may confirm the suggestion that RPE may not be a direct reproduction of an exercising players´ physiological state, but may instead be an anticipatory sensory regulator of exercise performance and therefore a more volatile analytic measurement. As Baden et al. (2005) state, fatigue may be an emotional construct as opposed to a physical process and this emotion may be driven by expectations about the nature of the exercise that is to be completed.

Nevertheless, it seems that the “teleoancipatory strategy” governing exercise periods is adaptable and dynamic (Studies 1-4) and rather than a fixed “RPE template” (fixed regulatory criteria). Is possible that the brain generates an appropriate and acceptable perceived exertion strategy based not only on the expected duration of exercise remaining or the certainty of this duration (Paul et al., 2015), but according other contextual factors.

The anticipatory feedback model seems to have some support based on some evidence from our studies. However, it is far from being the perfect answer to the complexity of the phenomenon of fatigue. The combined integration of numerous physiological, metabolic, neurological, psychological and environmental factors (as well as the self-regulation of most of these factors in isolation) means that a comprehensive explanation for all within a centrally governed network has not yet been achieved, but it seems that this direction remains promising and more investigation and more experimental studies must be made to identify an appropriate model that represents the complexity of energetic and mental demands and movement, in particular, in soccer.

Some main limitations of this thesis can be addressed:

(i) The type of protocol used in Studies 1–4 is applicable in training contexts but it's not representative of the effort during a full soccer game.
(ii) There was no consideration of player diet in the days prior to the application of protocols.
(iii) In Study 4, there was no RPE information gathered in the middle of the task, which could improve the analysis of the results.

# Chapter 5. Overall Conclusions

Our study demonstrated and strengthened factors causing potential negative fatigue effects induced by high intensity exercises on kicked-ball velocity in soccer and showed that the effect of fatigue can be variable. It was also found that kicking accuracy is not affected by fatigue. About the effect of knowledge of the exercise duration, no effects were found on kicking performance but in respect of pacing strategies during soccer small-sided games, the findings showed the relevance of knowledge about exercise duration. The main conclusions of the present thesis were:

I. There is a lack of experimental research about the practical effect of fatigue on kicking performance and about the influence of knowledge duration on pacing strategies in soccer;
II. Fatigue induced by high intensity exercises has a negative influence on kicked ball velocity.
III. Fatigue does not influence kicking accuracy considering accuracy as a secondary aim in relation to kicking velocity;
IV. The practical effect of fatigue was variable, which could be due to the influence of psychophysiological factors such as the previous exercise experience or knowledge of the duration of exercise affecting pacing strategies, which is in accord with models showing to the central regulation of exercise as a holistic and complex approach;
V. Players showed a great capacity to control and self-regulate their effort during exercise due to a conscious or unconscious mechanism of exercise regulation;
VI. Players alter their pacing strategies based on the knowledge of the exercise duration;
VII. Knowledge of a shorter duration led to an increase of exercise duration demand during soccer small-side games;
VIII. Longer exercise durations tended to decrease differences between full knowledge and not knowledge of the exercise duration during soccer small-side games;
IX. It seems that the “teleoancipatory” strategy governing exercise periods is adaptable and dynamic, rather than a fixed “RPE template”;
X. Coaches should consider the potential and the possibilities of the manipulation of the knowledge of exercise duration variable, in terms of physical impact regulation in their training exercises;
XI. The results support the hypothesis about the involvement of psychophysiological factors and express the complexity of the fatigue phenomenon and the relevance of the theory of the central regulation of exercise performance and possible importance of the mechanisms based on anticipatory regulation;
XII. Soccer activity depends not only on energy systems but also on mental processes. The results of our studies may be attributed to a player’s physical capacity in connection with “mental fatigue” processes.

# Chapter 6. Suggestions for future research

This study provides some conclusions about soccer performance in which fatigue was the central point of discussion. Thus, future research into fatigue in sport and exercise should make use some of the developments found. However, there is certainly scope for further investigation into potential mechanisms of fatigue identified in this work. The following are some suggestions that we consider relevant from this study:

I. The perceived sensation of effort during exercise and the sensing of peripheral metabolic changes and how these signals may be integrated and contribute to development of fatigue all continue to require better understanding and a clearer application to the fatigue process;
II. To continue the experimental investigation in broader context as soccer small-side games;
III. To develop strategies of the regulation and control of fatigue that can be applicable to training program development;
IV. To continue to develop our understanding of the effect of knowledge of exercise duration and pacing strategies in soccer training exercises help control physical impact regulation;
V. To understand and compare the impact of playing style of a team or the type of exercise used on the perception and regulation of fatigue by players;
VI. To understand, integrate and find out the possible mechanisms of central regulation of exercise during the soccer game;
VII. To compare possible differences in the perception of effort by the players and its consequences between exercises of the game model and exercises not related to the game model.
VIII. To clarify the role of RPE as a regulator/quantifier of effort on soccer player's performance
IX. To understand if the regulation of effort is related to the team game model and with the degree of the identification of this model (or task) by player
X. To investigate the role, the interaction, the importance and the possible regulation of cognitive fatigue in the preparation of the games, during the game and throughout the season
XI. To compare the perception of effort between exercises with equal physiological demands but with different configurations
XII. To investigate whether the identification with the task allows a different perception of effort/performance.

# Chapter 7. References

## Chapter 1 - General Introduction

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## Chapter 2. Review of Literature

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# **Chapter 3.** Experimental Studies

## Study 1

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# Chapter 4. General Discussion

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