

## MASTER OF SCIENCE BY RESEARCH

### The effect of fatigue on decision-making in amateur Rugby League players

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# **The Effect of Fatigue on Decision-making in Amateur Rugby League Players**

**By**

**Darry Minova**

**October 2015**



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***A thesis submitted in partial fulfilment of the University's requirements for  
the Degree of Master of Research***

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## **Presentation of the results**

Results of the present thesis have been presented at home and international conferences.

**Minova, D.**, Duncan, M., Lyons, M. and Hankey, J. 'The Effect of Match-related Physical Exertion on Reactive Agility in Amateur Rugby League' Oral presentation at the 4th Annual Faculty of Health and Life Sciences Conference, March 2015

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## **Abstract**

### **Introduction**

Previous research in Rugby League has reported reductions in agility following game-specific exercise. A fundamental component of agility is decision-making as players are required to execute a quick change of direction in response to unpredictable stimuli (Serpell *et al.* 2010). Considering that the high physiological demands of the sport force players to compete in a fatigued state, the aim of the study was to examine the impact of match-related fatigue on decision-making, accounting for participant's aerobic capacity.

### **Methods**

Twelve Rugby League players (mean  $\pm$  SD, age  $22.9 \pm 2.9$  years, height  $178.9 \pm 9.3$  m, body mass  $87.7 \pm 11.5$  kg) participated in this study following ethics approval and informed consent. In the first session participants undertook measurements of anthropometry, fitness testing and an assessment of aerobic capacity (20 m Multi-stage Fitness Test (Ramsbottom *et al.* 1988)). During the second session participants were asked to perform an 80-minute match simulation protocol (Sykes *et al.* 2013) with the repeated Reactive Agility Test (rRAT; Jordan *et al.* 2013) performed at six time points throughout the simulation protocol.

Decision time, sprint time and total time were assessed using a two-way analysis of variance (ANOVA) with repeated measures (time point [6] x trial [3]) to assess their variability over time and between trials.

Measures of heart rate, ratings of perceived exertion and blood lactate and glucose concentration were also taken continuously throughout the protocol and were assessed using one-way repeated measures ANOVA.

The Pearson product moment correlation coefficient was used to determine the relationship between RAT times and physiological variables (HR, RPE, BLa, blood glucose) and between RAT times and physical qualities (agility, sprint speed).

## Results

Decision time following the first half (RAT3) and following the second half (RAT5) did not significantly differ from baseline ( $F_{(2, 22)} = 5$ ,  $P = 0.388$ ,  $\eta^2_P = 0.102$ ). However, further analysis revealed that decision time immediately following cessation of exercise increased, as the time taken to complete the first trial of each rRAT was significantly higher than the time taken to complete the third trial ( $P = 0.027$ ) across the six time points. Analysis was then performed again using individual aerobic capacity as covariate. No significant interaction was reported. There were no significant main effects on sprint and total time.

Mean blood lactate concentrations during the simulated protocol was  $2.86 \pm 0.54$  mmol.l<sup>-1</sup>, with concentrations following 1<sup>st</sup> half and following 2<sup>nd</sup> half being significantly higher than rest ( $P = 0.006$  and  $P = 0.008$ , respectively). Mean heart rate reported was  $152 \pm 16.7$  beats.min<sup>-1</sup>, with values following RAT3 and RAT5 significantly different from RAT1 ( $P = 0.011$  and  $P = 0.008$ , respectively). Similarly, ratings of perceived exertion following RAT3 and RAT5 significantly differed from RAT1 ( $P < 0.001$  and  $P < 0.001$ , respectively). In addition values following RAT2 and RAT6 were also significantly

different from one another ( $P = 0.002$ ). Blood glucose concentration levels at rest were  $4.26 \pm 1.20 \text{ mmol.l}^{-1}$  and remained elevated during the 1<sup>st</sup> half of the game as well as half time ( $4.52 \pm 1.68 \text{ mmol.l}^{-1}$ ), and then decreased during the 2<sup>nd</sup> half ( $3.99 \pm 1.66 \text{ mmol.l}^{-1}$ ), values did not significantly change ( $P > 0.05$ ) however, during the simulated game.

## **Discussion**

The current findings that decision-making time increased following periods of rugby league-specific exercise, but not over time, may suggest that there is only an acute effect of match-related fatigue on decision-making and not a cumulative. As decision time is comprised of both perceptual processes and peripheral events, the findings cannot be explained by a single mechanism. Future research taking into account the neurochemical

# **1. Introduction**

## **1.1 The Phenomenon of Fatigue**

The phenomenon of fatigue during exercise has been the subject of increased attention in different scientific fields. The term exercise-induced fatigue stands for a transient decline in the ability to perform physical activity (Enoka and Duchateau 2008). However, the complexity of its nature has evoked a series of debates for more than a century about how to best describe it. In the fundamental work on the topic of fatigue, Mosso (1889) described fatigue as a form of “poisoning” caused by the generation of waste materials which reduces the sensitivity of the muscles (Di Giulio, Daniele and Tipton 2006). Almost hundred years later Edwards (1977) proposed a new, more focused definition of fatigue as an inability to maintain the required or expected power output. This definition is supported by Lorist *et al.* (2002) who defined fatigue as a decline in one’s ability to exert force. On the other hand, St Clair Gibson *et al.* (2003) argues that fatigue is a sensation rather than a neuromuscular deficiency and describes it as the conscious perception in response to changes in subconscious homeostatic control systems.

It appears that fatigue can be associated with a motor deficit, a sensation or a decrease in brain activity (St Clair Gibson *et al.* 2003). Also, in this situation, it encompasses phenomena that are the result of different physiological mechanisms. Such broad usage of the term ‘fatigue’ can therefore be problematic in terms of identifying the cause of fatigue. To avoid this limitation, most researchers subscribe to a more focused definition of fatigue which describes it as an exercise-induced decrement in the ability of the muscle

to voluntarily exert muscle force or power whether or not the task can be sustained (Søgaard *et al.* 2006; Enoka and Duchateau 2008). This more precise definition is of convenience in applied sports science particularly, where fatigue is seen as a major threat to performance. For the purpose of this study physical exertion and the associated changes will be referred to as fatigue.

### **1.1.1 Fatigue and Sporting Performance**

Exercise performance is dependent on the physiological characteristics of the athlete, their technical and decision-making skills amongst other factors. However, successful exercise performance is reliant on the athlete's ability to sustain high levels of these skills throughout a competition. Decline in any of these skills could manifest as a symptom of fatigue and ultimately result in performance decrements (Knicker *et al.*, 2011). In sporting competition, it has been posited by some authors that decline in an athlete's skill towards the final stages of a match or event is due to accumulated fatigue (Royal *et al.*, 2006). Initially, performance as a sum of different technical skills, is sustained through a compensatory behaviour of altered firing patterns in the working motor units and through progressive recruitment of new motor units (Knicker *et al.* 2011). In terms of skill execution, it is established that there is no single or general mechanism that results in an acute decline in the ability to perform a motor task (Weir *et al.* 2006). A number of different physiological processes can underlie the mechanisms responsible for fatigue development, from accumulation of muscle metabolites to abnormal motor command signal sent to the active muscles (Enoka and Duchateau 2008). However, the most important determinant of the fatigue mechanisms for a particular performance are the specific task conditions- type of muscle contraction, number of motor units recruited and

the duration of activity (Enoka 1995). Considering that fatigue mechanisms are task-dependent, manifestation of fatigue will differ between different modes of exercise and different sports. Changes in subjective perceptions, motor skills and cognitive performance have been described in the literature (McMorris and Graydon 1997; Royal *et al.* 2006; Fontana *et al.* 2009; Rampinini *et al.* 2008) and will be covered in the following sections.

### **1.1.2 Subjective Fatigue**

The sensation of fatigue is thought to be triggered by changes in the level of motor activity which subsequently evoke changes in brain neural function. This results in a conscious awareness of these changes and a sense of increasing effort in order to be able to sustain a given task (St Clair Gibson *et al.* 2003). In this sense, St Clair Gibson *et al.* (2003) suggest that fatigue can be dependent on an athlete's motivation, emotion, past experiences as well as the type of exercise. For instance, the sensation of fatigue experienced during a sustained isometric contraction would differ to that developed during a marathon run due to differences in the underlying physiological processes (Enoka and Duchateau 2008). The first sensation, developed from a sustained isometric contraction, is related to metabolite accumulation and may not produce lasting sensations of tiredness. In contrast, during a marathon, the first sensation are characterized by a marked muscle glycogen depletion and a sense of effort lasting for one to several days post competition (Weir *et al.* 2006).

Nielsen *et al.* (2002) suggested that the perception of effort, also known as perceived exertion (defined by Marcora (2010) as ‘the conscious sensation of how hard, heavy and

strenuous a physical task is’’), is created by a corticofugal feedback system, however the mechanism of subjective fatigue is not entirely clear. Exercise induced changes in the body’s regulatory mechanisms send feedback through afferent pathways to the central nervous system (CNS) in regard to the current status of the internal environment. The feedback is then integrated by nuclei of the brainstem and hypothalamus (where the homeostatic control systems are situated), which are thought to regulate the higher centres of the brain. This process modulates the gradual change from a subconscious to a conscious awareness of the sensation of fatigue as the highest centres of the brain are reached (Ament and Verkerke 2009).

Recently, Marcora (2009) has challenged the afferent feedback model by proposing that the perception of effort is centrally generated and results from forwarding neural signals, termed corollary discharges, from motor to sensory areas of the cerebral cortex. The corollary discharge and the resulting increase in perceived effort is associated with an increase in the central motor command to sustain exercising at the same workload and counteract muscle fatigue (Marcora 2009). In relation to fatigue and exercise regulation, there has been increased attention on the underlying physiological mechanisms and factors, but the role of the psychological factors as exercise modulator has been neglected (Smirmaul *et al.* 2013). A new framework – the Psychobiological model- has been proposed by Marcora (2008) in order to give greater attention to the perceptual and motivational factors and their influence on fatigue and performance. The Psychobiological model is an effort-based model explaining self-paced endurance performance and is based on the motivational intensity theory (Brehm and Self 1989). In light of this theory the inability to sustain a task is seen as task disengagement rather than task failure. According to the Psychobiological model, the ability or inability to sustain a



task is dependent on three main motivational factors: perception of effort, potential motivation or the maximum effort an individual is willing to invest in order to complete an exercise task, knowledge of distance/time to cover (Smirmaul *et al.* 2013). The Psychobiological model predicts that exercise tolerance will be increased if potential motivation is increased or if perception of effort is decreased and that they both could be affected by physiological and/or environmental factors. For example, metabolic changes in the muscles would result in increasing muscle fatigue. This would then elicit an increased central motor command to sustain the required force, leading to an increased perception of effort (Smirmaul *et al.* 2013). In regard to potential motivation, it will be higher during an event of higher importance (cup final versus league game) or during an event involving competition compared to an individual performance.

Recent findings of Marcora and Staiano (2010) are in support of the Psychobiological model. They tested maximal voluntary cycling power (MVCP) before, during a time to exhaustion incremental test and immediately following the exhaustive exercise and reported that MVCP measured immediately after exhaustion was three times the power output required by the time to exhaustion test. These findings fail to support the traditional assumption that following exhaustive exercise, power output should not be significantly different from the one required by the time to exhaustion test and are likely to be a result of psychological factors. Marcora and Staiano (2010) speculated that the reason for the observed results was the participants' knowledge (or lack of knowledge) of the exact duration of exercise to be performed. The participants had no knowledge of how long the test would continue for which is likely to have demotivated them from investing maximal effort. In the final 5-second MVCP test they knew exactly how long they had to exercise for and were motivated to invest further effort following the time to exhaustion test as it

would only last 5 seconds. The results from this study suggest that the ability to sustain a task in highly motivated participants is limited by perception of effort as postulated by the Psychobiological model, challenging the traditional model that central or peripheral muscle fatigue result in inability to succeed in high intensity aerobic exercise task. However, further research is needed to examine the validity of the model and assess the effects of potential motivation and perceived exertion on exercise performance.

To quantify subjective fatigue, ratings of perceived exertion (RPE) have been taken, using the Borg scale (Borg 1970). The scale consists of psychological components or units that refer to the experienced sensations of exertion (15 rating points of exertion) and a physical component to represent the workload (heart rate). Heart rate and RPE values are often taken together and have been recorded in fatigue-related past research in tennis, as they provide a relatively reliable and valid measurement of physical effort and intensity during a game (Lyons *et al.* 2013; Mendez- Villanueva *et al.* 2007; Fernandez-Fernandez *et al.* 2006). RPE is likely to be guided by a central feed- forward increase in motor drive; however the highest RPE is the result of the combination of peripheral processes such as hypoglycaemia, muscle glycogen depletion, dehydration or hypoxia (Knicker *et al.* 2011). RPE is known to be influenced by psychological factors, mood states, environmental conditions, type of exercise, and age (Ritchie 2012) which makes subjective fatigue difficult to accurately quantify in order for its effects to be examined. In the section which follows, the effects of fatigue on motor skills will be examined.

### 1.1.3 Motor Skills

It has recently been suggested that the match demands of high-intensity intermittent sports may result not only in accumulated fatigue, but also in transient fatigue-related reduction in performance (Mohr *et al.* 2003; Mohr *et al.* 2005; Bradley *et al.* 2009; Kempton *et al.* 2013). In addition, the influence of fatigue on physiological components and game-specific skills has been described. A decrease in sprint performance and agility over a basketball competition was reported by Montgomery *et al.* (2008). In soccer, Bradley *et al.* (2009) examined high-speed running during a large number of elite-standard soccer matches for various playing positions. They reported that high-speed running distance declined in the final quarter of matches when compared to the first quarter. Another finding of the study was a decrease in exercise intensity following short bouts of high-speed running, suggesting that soccer players experienced transient fatigue. In addition, Rampinini *et al.* (2008) examined whether the fatigue accumulated during a match had any effect on short-passing ability in junior soccer players. Short-passing ability was measured during and after the first and the second halves and the results indicated a decline in technical proficiency. Appiantono *et al.* (2006) stated that there was a decline in the ability to generate force and consequently less coordinated kicking motion following loaded knee extension and flexion. Zemkova and Hamar (2009) reported an impairment of dynamic balance and agility performance after a soccer match. These findings support that the main tendency is reduction in motor performance due to fatigue-induced changes.

Changes in skill execution do not necessarily correspond to a reduced skill outcome as a consequence of fatigue (Knicker *et al.* 2011). Royal *et al.* (2006) reported that under conditions of high levels of fatigue technical skills in water polo players decreased, however the speed and accuracy of shots were unaffected. In addition, a study by Rampinini *et al.* (2008) showed that immediately after an elite soccer game, short-passing skill remained unchanged. A possible explanation can be found in the concept of dynamic systems theory. It is hypothesized that variability of movement patterns allows for easily adaptive motor system behaviour in order to sustain a constant task or to achieve a certain outcome (Davids *et al.* 2005). As there can be several muscles/joints that are used to create movement, task demands can be met through different patterns of movement coordination; hence technique would deviate rather than deteriorate (Knicker *et al.* 2011).

Changes in technique/ motor skill execution that have arisen with the progression of exercise/fatigue have also been reported for racquet sports. Davey *et al.* (2002) investigated the effect of fatigue from maximal tennis hitting on skilled performance. Participants performed test of groundstroke and service accuracy pre- and post the Loughborough Intermittent Tennis Test. A decrease of 69% in groundstroke hitting accuracy from start to volitional fatigue was observed as well as a 30% decline in service accuracy to the right court. The findings of the study suggest that fatigue had a detrimental effect on some but not all tennis skills. Recent research by Lyons *et al.* (2013) used the modified Loughborough Tennis Skills Test to induce fatigue at two different intensities (moderate and high) and explored the effect on groundstroke accuracy in expert and novice tennis players. Results showed that in both groups groundstroke accuracy declined following high-intensity fatigue compared to performance at rest and under moderate

fatigue. These findings are consistent with Davey *et al.* (2002) but are in contrast with Royal *et al.* (2006) and provide no support for the dynamic systems theory as groundstroke accuracy was significantly poorer under high-intensity fatigue conditions in both expert and non-expert tennis players.

In team sports, few studies have assessed the influence of fatigue on technical abilities during match-play and existing findings provide conflicting findings. This is due to the difficulty of developing fatigue protocols that accurately mimic match-play and assessing fatigue related decrements in skill performance using sport specific tests. In Rugby League, a time-motion analysis study by Sirotic *et al.* (2009) compared physical performance and game-specific skills in elite and semi-elite rugby league players during match-play. In terms of technical skills, results showed no reduction in frequency of a variety of technical skills (including carriers, touches of the ball, play-the-ball, tackles made) between the two halves. In soccer, Rampinini *et al.* (2009) investigated the changes in technical and physical performance between the first and second half during official elite soccer matches. It was reported that, together with a reduction in physical performance, there was also a decline in some technical skills (involvement with the ball, number of short passes and successful short passes). It was also reported that most penalties were awarded following fatigue at 90%. Lyons *et al.* (2006) investigated passing performance under three different conditions - rest, moderate fatigue (70%) and high-intensity fatigue (90%). Results showed a significant decrease in passing performance and accuracy following high-intensity fatigue. Most of the studies that have examined the effect of fatigue on skill performance (Sunderland and Nevill 2005; Lyons *et al.* 2006; Gabbett *et al.* 2008a), but not all (Royal *et al.* 2006; Sirotic *et al.* 2009) have reported

reductions in players ability to perform sport-specific skills when subjected to simulated match-related fatigue. Discrepancies in the literature are likely to have arisen due to an inability to replicate match-related fatigue in a controlled way. Another possible reason is different methods used to assess skill performance. Some of the researchers used computerised video match analysis systems (Sunderland and Nevill 2005; Rampinini *et al.* 2009; Sirotic *et al.* 2009) which is associated with a systematic error (Burgess *et al.* 2006). In contrast, Royal *et al.* (2006) and Lyons *et al.* (2006) used sport-specific protocols to assess skill performance in a controlled environment. Inconsistencies are also likely to be related to the choice of population sample as some researchers used a large population sample, consisting of players from different clubs (Bradley *et al.* 2009; Rampinini *et al.* 2009), others used participants within one club (Lyons *et al.* 2006; Royal *et al.* 2006). As training structures and coaching styles are very club- specific findings might not be indicative for the whole population. In addition, participants' expertise is also likely to have an effect on results. Royal *et al.* (2006) recruited elite athletes accustomed to performing under conditions of maximal exertion, whereas Lyons *et al.* (2006) employed moderately skilled college athletes. Conflicting findings might also be associated with failure to control for intervening variables in the research design, such as participant's aerobic capacity, a point acknowledged by authors such as Lyons *et al.* (2006).

Fatigue development and the subsequent changes during team sports can be attributed to several mechanisms. Low muscle glycogen has been suggested as the probable cause for sustained fatigue towards the end of a game (Mohr *et al.* 2005). In addition, low levels of glycogen pre-game have been shown to have a detrimental effect on sprinting and kicking

ability (Krustrup *et al.* 2006; Ali *et al.* 2007). Temporary fatigue is thought to develop as a result of changes in intramuscular phosphates, accumulation of extracellular potassium and increased RPE (Mohr *et al.* 2005; Krustrup *et al.* 2006). According to Baker *et al.* (2007) dehydration can result in increased RPE and decreased agility. However, this warrants further investigation as these factors change very rapidly.

## **1.2 Cognitive Performance**

According to the information-processing model (Proctor *et al.* 1990), behaviour is the final ‘product’ of the sequence of three independent phases, during which information from the environment is extracted and processed. During the first phase sensory events are transformed and given meaning (stimulus-identification phase). The second phase involves decision-making processes that determine what response/action will be made to the situation/event (response-selection phase). The third phase is characterized by processes that prepare the motor system to execute the response/movement (response-programming phase). The information-processing model has been successfully implemented as a framework to assess the effect of factors, such as fatigue, on cognitive performance (Arcelin *et al.* 1998). A substantial body of research has been conducted to investigate the effects of physical fatigue on cognition (Lambourne and Tomporowski 2010) however the findings of these studies are inconsistent. During acute to prolonged exercise (from 10 to 60 min) at moderate intensity, research findings (Davranche *et al.* 2005; Davranche *et al.* 2006; Audiffren, Tomporowski and Zagrodnik 2008; Hüttermann and Memmert 2014) point to a positive effect on motor time in choice–reaction time tasks completed. This positive effect on basic information processing tasks is generally thought

to be related to exercise-induced increases in physiological arousal or activation (Audiffren, Tomporowski and Zadrodni 2009). However, with activities lasting longer than an hour, fatigue is reported along with alternation in cognitive performance (Collardeau *et al.* 2001). A meta-regression analysis by Lambourne and Tomporowski (2010) reported that in studies with cognitive measures during exercise, where exercise was designed to induce fatigue, fatigue had a negative effect on processing speed tasks. On the other hand, in some studies where the cognitive task is performed following exercise, participants' cognitive performance improved. In other studies (Grego *et al.* 2004, Tomporowski *et al.* 2007) a decline in cognitive performance was demonstrated when participants had to exercise for two hours or more, under controlled hydration conditions. The controversies have been interpreted in terms of different methodologies, type of cognitive task, type of exercise performed and the time at which the cognitive task is measured and individual differences in the physical fitness of participants (Grego *et al.* 2004). Different cognitive tasks employed measure different processes ranging from basic, information-processing speed, simple- and choice-reaction time; to more complex decision-making and executive control processes. A study by Etnier *et al.* (1997) evaluated the type of cognitive task as a variable and reported larger effects for studies measuring basic processes than studies using tasks to measure more complex cognitive processes. In terms of the type of exercise, treadmill running and cycling on an ergometer are the most common modes of exercise selected. Running on a treadmill requires greater attention compared to sitting on an ergometer as it is considerably more demanding for the athletes who have to maintain their balance and a good upper and lower body coordination to prevent falling. This is suggesting that larger effect sizes would be observed for studies using running as a mode of exercise compared to ergometer protocols



as fewer attentional resources would be available to runners when performing cognitive tasks under dual-task conditions (Lambourne and Tomporowski, 2010). Finally, the time interval between exercise onset and the cognitive test greatly influences the effects found, the trend reported is a decline in cognitive performance in the initial 10 minutes following the cessation of exercise and the following 10 minute interval. However, there is a positive effect on performance when the cognitive task lasts for 20 minutes or more (Lambourne and Tomporowski, 2010).

Lyons *et al.* (2008) examined the effects of moderate and high intensity exercise on coincidence anticipation in expert and novice Gaelic games players. There were no differences in cognitive performance across exercise intensities in the expert group. However, there was a significant improvement in performance following the moderate-intensity exercise in the novice group. Findings suggest that expert players are able to maintain coincidence anticipation performance across different exercise intensities, thus expertise might be another moderator variable in the fatigue - cognition relationship (Lyons *et al.* 2008). In addition, as most of the research has been conducted in a laboratory setting, the protocols used to induce fatigue may not be replicating accurately physiological demands representative of naturalistic sport (Lambourne and Tomporowski 2010).

The reported effects of fatigue on complex executive functions are less unequivocal. Brisswalter, Collardeau and Rene (2002) collated the findings of research on the influence of acute physical exercise on cognitive performance and reported a facilitating effect. It

was hypothesised that the observed positive effect could be explained as a result of an increase in arousal level related to physical activity and resource allocation during exercise. There was no association reported between improvements in cognitive performance and personal characteristics such as aerobic capacity (Brisswalter, Collardeau and Rene 2002). In addition, Pesce *et al.* (2007) investigated visual attention and reaction time after acute bouts of exercise in expert soccer players and also reported a positive effect on cognitive performance. Arcelin *et al.* (1998) examined the effect of moderate-intensity exercise on information processing mechanisms, measuring choice reaction time at rest and during exercise, while manipulating three task variables. Results reported improvement in reaction time when time uncertainty increased. No interactions between exercise and the other two variables were reported. In elite athletes from a range of sports (handball, basketball, tennis, soccer), Davranche and Audiffren (2004) examined the effect of different cycling intensities on reaction time and reported a facilitating effect of exercise on response performance. In handball, Tenenbaum *et al.* (1993) reported improvements in decision-making following moderate fatigue induced by running. On the other hand, Dietrich and Sparling (2004) examined the effect of exercise on higher-cognitive skills while participants were exercising at a sustained, moderate pace and reported decrements in executive function. Discrepancies are likely to be a result of the selection of the cognitive task. Some of the studies have focused on lesser-cognitive functions and have used relatively basic executive tasks (choice reaction time and visual recognition task), which are simple tasks positively affected by arousal. Dietrich and Sparling (2004) used a complex executive task, where arousal was not likely to be associated with improved performance. Therefore, a comparison between studies is not appropriate due to these differences in task complexity and exercise mode.

Consequently, reviewed literature in the present study focused on decision-making, which falls in the category of executive functions (Lezak *et al.* 2004) and is crucial in sports, where players must simultaneously manage physiological and cognitive loads (Davranche and Audiffren 2004).

### **1.2.1 Arousal**

Certain physiological responses induced by exercise, such as increases in heart rate, blood pressure and level of catecholamines, coincide with changes that occur as the level of arousal increases (Cooper 1973 cited in Lyons *et al.* 2006). However, the fact that exercise and arousal share some common processes does not explain the relationship between the two. Many researchers have attempted to define the relationship between exercise, arousal and performance, formulating different theories. The primary model that had been used by researchers is the Inverted-U Theory based on the work of Yerkes and Dodson (1908). This hypothesis suggested that optimal performance coincides with moderate levels of arousal and that any increase or decrease in arousal would result in decline in performance (Arent and Landers 2003). The physiological basis of the theory is that acute exercise is associated with the release of cortisol which is known to control arousal levels by restricting the synthesis of corticotrophin releasing hormone (CRH) and adrenocorticotrophin hormone (ACTH). Cortisol production is unable to restrict the increasing levels of CRH and ACTH associated with increasing exercise duration or intensity and performance is jeopardized due to the increase in arousal (Lambourne and Tomporowski 2010). The Inverted-U Theory has been subject to various modifications. One of them involved its application in sport and suggested that the relationship between

performance and arousal is also dynamic as any shifts to the left or right can be influenced by individual characteristics and the type of task (Landers and Arent 2001).

In terms of cognitive performance, Tomporowski and Ellis (1986) suggested that the Inverted-U effect of exercise can be explained based upon the Cue Utilisation Theory developed by Easterbrook (1959). According to Easterbrook (1959), at low levels of arousal, the individual's attention is concentrated on cues, both relevant and irrelevant, so performance remains low. As arousal increases and reaches moderate levels (top of the inverted U), attention narrows and only cues relevant to the task are identified, allowing optimal performance. However, further increase in arousal can be detrimental to performance and decrease it to baseline levels as attention continues to narrow and even relevant cues are missed (McMorris and Graydon 1997).

A conceptual limitation of the aforementioned theories is the definition of arousal. Some researchers (Anderson 1990; Jones 1990) have criticised the fact that arousal is perceived as unidimensional (physiological), therefore Arent and Landers (2003) proposed a broader definition to include a behavioural dimension as well. The first theory to account for the multidimensional nature of arousal was proposed by Kahneman (1973). According to this theory, performance is affected by arousal, referred to as the resources available to the central nervous system, and cognitive effort, responsible for the allocation of these resources. If arousal is low and enough resources can be allocated to the task, performance will be optimal. However, as exercise intensity and arousal increase, cognitive effort cannot focus attention only to the task-relevant signals which results in increases in

distractibility (Kahneman 1973). The principle behind ‘distractibility’ is that the individual attends to many different sources of information as arousal rises, some of which are irrelevant to the task, leading to task-relevant cues to be missed and ultimately a decline in performance. An example of this in the sporting setting would be individual focusing attention on perception of pain or fatigue which can mean task-relevant signals are missed (Easterbrooks 1959).

Most recently, McMorris *et al.* (2015) collated the research in the area of arousal and exercise with the aim to examine whether acute exercise affects the performance of whole-body, psychomotor skills in an inverted-U fashion. Psychomotor tasks were grouped according to whether they were performed following moderate (40-79% of maximum power output ( $\dot{W}_{MAX}$ ) or heavy ( $\geq 80\% \dot{W}_{MAX}$ ) intensity exercise. Furthermore, McMorris *et al.* (2015) compared the effects of acute exercise on static versus dynamic, ballistic tasks. The data examined suggested that psychomotor skills were negatively affected during heavy intensity exercise, due to large increases in brain concentrations of catecholamines, which negatively affects the activity of the prefrontal cortex. This activity includes integration and regulation of sensory and perceptual information as well as inhibition of inappropriate motor responses hence the negative effect on psychomotor skills (Goldman-Rakic 1987). It was also reported that the effect of moderate intensity exercise was positive but not significantly so. Improved cognitive performance has been demonstrated at or immediately following the catecholamine thresholds (McMorris *et al.* 1999), however exercising at moderate intensity might not stimulate an increase in brain catecholamine levels and therefore not show an improvement in performance (McMorris *et al.* 2015). Conversely, exercising above the catecholamine thresholds might induce a

large increase in catecholamine concentrations, hence negatively affecting the cognitive aspect of the psychomotor task. Another possible explanation for the non-significant effect on performance can be the disruption in CNS and PNS integrity due to increases in blood and muscle lactate levels, and the large difference between ventilatory carbon dioxide and ventilatory oxygen levels, affecting the motor aspect of psychomotor performance (McMorris *et al.* 2005). McMorris *et al.* (2015) concluded that when cognition and motor performance are combined, the interaction between the Central Nervous System (CNS) and the Peripheral Nervous System (PNF) may become very complex and so inducing different effects compared to when cognition is isolated from motor performance.

### **1.2.2 Decision-making**

The end goal of sporting performance is winning through optimal levels of performance. The sporting environment, in comparison to a laboratory setting, has some quite prominent distinctions; teammates, opponents, audience, as well as management and stress due to importance of the event/result. Hence, decision-making and psychological features have strong influences on sporting performance (Knicker *et al.* 2011). As team sport is a complex dynamical system, consisting of a number of decision agents (coaches, players), tasks (play-calling, ball allocation) and contexts (during attack/ defence, during play/break) and a quickly changing environment, often within the time frame of a required decision. The way these factors combine and the unique interactions they create affect the decision-making process (Johnsons 2006), therefore this must be considered when choosing a method to study such decision-makings.

Decision-making in sports has been described as the ability to recognize advanced cues, deduce meaning from them and execute fast and accurate responses to those cues (Gabbett *et al.* 2008b). This ability to ‘read and react’ to a stimulus is thought to be a determinant of player’s expertise (Berry *et al.* 2008). Using game-specific decision making protocols, most of them consisting of video tasks, researchers have measured the effects of expertise on decision making and motor skill execution and have successfully discriminated between experienced and novice athletes (soccer- Williams 2000; Araujo *et al.* 2005; racquet sports- Del Villar *et al.* 2007; Wright *et al.* 2011; Australian football- Lorains *et al.* 2013). Del Villar *et al.* (2007) reported significant differences in decision making and skill execution between expert and novice tennis players, where expert players demonstrated greater decision making accuracy and skill execution with greater efficacy. In addition, a study by Lorains *et al.* (2013) on Australian football players investigated expertise differences in decision-making using a video task and reported significantly better decision making accuracy in the elite group in comparison to the sub-elite and novice groups, and better accuracy for the sub-elite players compared to the novice players. Araujo *et al.* (2005) investigated the effects of expertise on decision-making during an interactive computerised regatta in three groups of sailors (divided depending on skill ranking) and a non-sailor group. Results reported differences in the use of information during the regatta between non-sailors and sailors and expert sailors demonstrated better performance than less-skilled sailors. However, research on decision-making that has been conducted in the laboratory setting is likely to involve limitations that may affect the results/findings. As decisions in sport have been referred to as naturalistic- the agents or the players are familiar with the task and the task is performed

in the environment within which they naturally face the decision (Orasanu and Connolly 1993). Decisions performed outside of this environment might not be representative of those within the sporting environment. To evaluate the differences in players' decision-making ability, other researchers (Sheppard *et al.* 2006; Gabbett and Benton 2007; Serpell *et al.* 2010; Jordan *et al.* 2013) have used field tests that include a reaction to a stimulus that replicates the patterns of the sport instead of video-based tasks.

The influence of fatigue on decision making has been reported in other sports, with the majority of this research conducted in soccer. McMorris and Graydon (1997) examined the effect of moderate and maximal exercise on the cognitive performance of experienced soccer players. The players were presented with a visual task and their speed and accuracy of decision was measured during rest and while cycling at 70% and 100% of  $\dot{V}O_{2max}$ . The findings of this study indicated that speed of decision-making was significantly faster during 70% and 100% of  $\dot{V}O_{2max}$  and that accuracy of decision-making was significantly different between rest and 100% of  $\dot{V}O_{2max}$ , the latter inducing higher performance. The decision making instrument consisted of forms/photographic slides with identical situations, only difference was where on the field the situation occurred. It is likely that the participants noticed the similarity and repeated the same answers throughout the different conditions. In addition, the mode of exercise chosen for the test was cycling. However, the movement pattern of the sport involves rapid acceleration, deceleration and - while in possession of the ball- rapid changes in direction to avoid being tackled. Optimal performance during a game of soccer relies upon the successful execution of motor tasks (running, sprinting, kicking) simultaneously with cognitive and perceptual tasks in a rapidly changing environment that requires constant adaptation by the players.



Although successful in inducing fatigue, the protocol used by McMorris and Graydon (1997) was not soccer- specific as it does not replicate movement patterns of the sport and might have created an environment different from the one during game-play. Therefore, it might not be accurate for the results of the study to be applied to this sport/population.

In an attempt to address the limitations of the study by McMorris and Graydon (1997), Fontana *et al.* (2009) conducted a study investigating the effect of exercise intensity on decision making in experienced and inexperienced soccer players. Decision-making video tasks were projected on a wall in front of a treadmill during rest and exercise intensities (corresponding to 40%, 60%, and 80%  $\dot{V}O_{2max}$ ), which were randomly selected to better simulate soccer conditions. The results reported that both the level of experience and exercise intensity had a significant effect on the decision making of the players. In particular, the results showed that when compared to rest, speed of decision making improved for the conditions performed at 60% and 80%  $\dot{V}O_{2max}$  but the accuracy of decision making remained similar to rest for both groups across conditions. An acknowledged limitation of the study is that the decision making video protocol is not ecologically valid. In watching the videos, the players were faced with a greater number of cues to analyse and extract meaning from compared to an actual game situation.

The finding of Fontana *et al.* (2009) that decision making accuracy remained unchanged is in conflict with recent research conducted in water polo players (Royal *et al.* 2006). Royal *et al.* (2006) reported that decision making accuracy improved under conditions of

high levels of fatigue. This discrepancy is likely related to methodological differences as one of the key differences is participant characteristics. Royal *et al.* (2006) used highly-trained elite athletes who were accustomed to performing under fatigue, whereas Fontana *et al.* (2009) used a group of moderately trained players and a group of novice players. Another acknowledged difference lies in the fact that Royal *et al.* (2006) used a very specific water polo task to control fatigue; in contrast, Fontana used a treadmill protocol which did not replicate accurately the patterns of the sport.

### **1.2.3 Decision- making as a Component of Reactive Agility**

Agility has traditionally been described as the ability to accelerate, decelerate and change direction rapidly (Sheppard *et al.*, 2006). Agility has been classified as a closed motor skill and researchers have been using tests such as the L-run, 505, Illinois Agility Test, to assess agility. These tests rely on pre-planned movements, executed in a stable environment, which define closed motor skill. However, according to Sheppard and Young (2006), agility in team sport is not simply a change of direction. Instead, it consists of both a cognitive component (decision time or reaction time) as well as a physical component (sprint time);(Jordan *et al.* 2013). Hence, they defined agility as an open motor skill that requires a constant adaptation and decision-making ability by the player in a continuously changing environment or in response to a sport-specific stimulus (such as the action of an opposing player or ball motion). Recently, researchers have started to acknowledge and focus on the decision-making element when assessing agility in team sport athletes and some support for this novel definition of agility was provided. Farrow, Young and Bruce (2005), Sheppard *et al.* (2006) and Serpell *et al.* (2010) have described the development and application of a test for reactive agility. Reactive agility tests (RATs)

require athletes to execute a quick change of direction in response to unpredictable stimuli (Serpell *et al.* 2010). In Rugby League decision-making has been investigated as one of the key elements of agility performance, as the players are required to execute rapid changes in direction or speed in response to movement of the ball or movement of an opponent (Gabbett 2008b; Serpell *et al.*, 2010). Sheppard *et al.* (2006) developed a test of agility for Australian football that involves both decision-making and movement response (change of direction and sprint) components. The RAT requires the athletes to react to the movement of testers and change direction to the left or right, respectively to the tester's direction of movement. Using this reactive agility test, Gabbett and Benton (2007) successfully differentiated between high and low skilled Rugby League players. Henry *et al.* (2011) used a reactive agility test to compare decision-making accuracy and time between higher - and lower-standard Australian football players. Feint and nonfeint scenarios were incorporated into the RATs. Henry *et al.* (2011) reported that decision-making errors resulted in a decrease in reactive agility performance; however a successful anticipation of a feint scenario resulted in increased agility performance. In addition, highly skilled players had a superior anticipation of feint scenarios when compared to the less skilled group. While successfully discriminating between expert and novice players, the findings from Sheppard *et al.* (2006); Gabbett and Benton (2007); Serpell *et al.* (2010); Henry *et al.* (2011) highlight the importance of decision-making skill to successful agility performance in athletes.

Although testers in the aforementioned studies were all expected to strictly follow instructions during the RATs, variability associated with different people executing the stimulus is likely to have a significant effect on the results. The RAT developed for netball

by Farrow, Young and Bruce (2005) was more reproducible as it consisted of life-size videos of offensive play that the participants had to respond to. Serpell *et al.* (2010) developed a RAT for Rugby League which was deemed valid and reliable and differences in performance on the RAT were attributed to changes in decision-making skills and reaction time. Although there were some methodological differences, a strength that these studies shared was the use of 1-on-1 scenarios. In this way there were no peripheral cues introduced from other opponents (i.e. 1-on-3 scenarios) and players were able to focus better and identify key kinematic cues from their direct opponent.

### **1.3 Reactive Agility in Rugby League**

Rugby League is a collision sport recognized worldwide. A Rugby League match is played over two halves (40 minutes each) with a 10 minute rest in between. It can be described as a high-intensity sport, consisting of predominantly aerobic running with intermittent bouts of intense anaerobic exercise (sprinting, tackling). Total match load in Rugby League can be assessed using a combination of internal and external measurements. Wallace, Slattery and Coutts (2009) define internal load as the relative physiological and psychological stress imposed on players (e.g. heart rate and lactate response, perception of effort), where external load is related to the work completed, measured independent of their individual characteristics (e.g. speed, distance covered). Both internal and external load during Rugby League performance have been widely measured as researchers suggest that it may be the relationship between both that will help in monitoring fatigue (Hals0n 2014). Research on the physiological demands of the sport reported mean heart rate of 152 beats.min<sup>-1</sup> (Gabbett 2003) and a mean  $\dot{V}O_{2max}$  of

39 ml.kg<sup>-1</sup>.min<sup>-1</sup> for amateur Rugby League players, which is 20-42% lower compared to the  $\dot{V}O_{2\max}$  values reported in professional Rugby League players (Gabbett 2000). The lower  $\dot{V}O_{2\max}$  reported for amateur players in the study by Gabbett (2000) was associated with low intensity and frequency of the games and training sessions. However, it should be noted that the demands placed on the amateur players may increase during a match, as all players, regardless of position, are involved in both attack and defence. The mean total distance covered by players in a match is  $8.503 \pm 631$  m, with the backs covering the most distance of  $8.800 \pm 581$  m. Players spend on average between 5.3% and 8.1% of the time in high intensity running, sprinting or contact (Sykes *et al.* 2009). In addition to the high intensity running, the internal load during a Rugby League match is also increased due to the number and intensity of tackles that the players are involved in (Gabbett *et al.* 2012). Hence, Rugby League players are required to develop and sustain excellent repeated-sprint ability and aerobic capacity, as well as to be able to demonstrate first-class technical and decision-making skills under fatigue to ensure high-level performance (Gabbett *et al.* 2008).

Kempton *et al.* (2013) investigated the influence of fatigue on physical and technical skill performance in two different (elite and junior elite) levels of Rugby League. It was concluded that players at both levels demonstrated reductions in physical performance (decline in distance covered, decline in number of collisions and involvements) and technical performance (decline in the quality of skill involvements) towards the end of the match and following brief periods of high-intensity exercise during the match. This data is consistent with research findings on fatigue patterns in other sport codes that have also reported reductions in performance towards end of a match, as well as temporary

reductions following intense periods of activity during the match (Mohr *et al.*, 2003; Mohr *et al.*, 2005; Montgomery *et al.*, 2008; Sykes *et al.* 2011; Waldron *et al.* 2013).

Gabbett (2008a) investigated the influence of fatigue on tackling technique in Rugby League players and reported progressive decrements in tackling technique as fatigue levels increased. It was suggested that the perceptual component would have an effect on the skill execution and was indicated that future research should focus not only on the technical but also on the decision-making skill of the players (Gabbett 2008a). In addition, Gabbett (2008a) found a significant association between estimated  $\dot{V}O_{2\max}$  and fatigue-induced decrements in tackling technique, which suggests that participant's aerobic capacity may have a key role in attenuating the effect of fatigue on this skill. Similarly, Gabbett and Domrow (2005) found an association between estimated  $\dot{V}O_{2\max}$  and tackling injuries. Players with the lowest  $\dot{V}O_{2\max}$  reported high incidence of tackle-related injuries. The findings from both studies could be due to the fact that placing a high absolute workload on players with low  $\dot{V}O_{2\max}$  during match would result in higher physiological strain on them (Gabbett 2002). Consequently, recovery between high intensity bouts would be reduced, accelerating the onset of fatigue and making these players more injury-prone (Gabbett and Domrow 2005). As players become fatigued (accelerated for those with a low  $\dot{V}O_{2\max}$ ), tackling technique would be reduced (as reported by Gabbett 2008a), leading to an increased risk of injury in those players. Therefore, improving  $\dot{V}O_{2\max}$  could result in reduced fatigue and increased exercise tolerance during a match, attenuate any fatigue-related decrements in performance and lower risk of tackle-related injuries.

Further to the findings of Gabbett (2008a), unpublished data from Hankey *et al.* (2013) reported that increasing levels of fatigue resulted in progressive increases in L-run time, which corresponds to decrements in agility. As with Gabbett (2008a), Hankey *et al.* (2013) used a game specific, repeated-effort protocol of progressively increasing intensities to induce fatigue. This protocol lasted between 30-45 seconds and used 3 sets of 6 repetitions of a repeated-effort tackle test in order to simulate the most demanding parts of the game (Gabbett 2008a). Although, the findings from both studies are likely to be reflective of the reductions in agility as fatigue accumulates over an actual match; a more ecologically valid study is needed where the demands of an actual match (sprint distance covered, time spent jogging, time spent in contact) are accurately replicated.

#### **1.4 Rationale for the study**

While a substantial amount of research exists in relation to decision-making ability as a mean of discriminating between players of different performance levels, no study to date has investigated match-related patterns of decision-making. Considering that the high physiological demands of the sport mean players compete in a fatigued state, a study to examine the impact of match-related fatigue on decision-making, considering participant's aerobic capacity is needed.

## **2. Aims and Hypotheses**

### **2.1 Aims**

The primary aim of this study was to investigate the effect of game-related fatigue on the decision-making performance of amateur Rugby League players. A secondary aim was to assess whether there were any relationships between response time during the RAT and participant's aerobic capacity.

### **2.2 Research Hypotheses**

It was hypothesised that game-induced fatigue will result in increases in response time in the Reactive Agility Tests performed immediately after the 1<sup>st</sup> and the 2<sup>nd</sup> half of the simulation protocol. In addition, it was suggested that the increase in response time will be less in participants with higher aerobic capacity.



### **3. Methods**

#### **3.1 Participants**

12 male Rugby League players (Mean  $\pm$  SD, age  $23 \pm 3$  years, height  $179 \pm 9$  cm, body mass  $88 \pm 12$  kg, estimated  $\dot{V}O_{2\max}$   $48 \pm 4$  ml.kg<sup>-1</sup>.min<sup>-1</sup>) were recruited on a voluntary basis. Players were given a detailed explanation about the benefits and risks involved in the study and written informed consent was obtained. To be eligible to take part in the study, participants had to be involved in Rugby League specific training at least twice a week and be able to reach Level 9 on the Multistage Fitness Test (Sykes *et al.* 2013). Any players taking medication or supplementation that could affect heart rate or players with cardiovascular conditions or injuries, highlighted by the Coventry University Health Questionnaire were excluded from the study. All experimental procedures were approved by Coventry University Ethics Committee.

#### **3.2 Experimental Design**

The present study used a repeated-measures experimental design to investigate match-related changes in decision-making ability in amateur Rugby League players. Testing consisted of 2 occasions, separated by a minimum of 72 hours to allow muscle function to be restored to normal (Bosak *et al.* 2009). In the first session, participants undertook measurement of anthropometry and physical qualities, including 5, 10, 30 m sprint, agility and estimated  $\dot{V}O_{2\max}$  (20m Multi-stage Fitness Test Ramsbottom *et al.* 1988). During the second session participants were asked to perform an 80-minute match simulation protocol, as well as repeated tests of reactive agility.

### **3.3 Experimental Procedures**

#### **3.3.1 Anthropometric Measurements**

Session 1 was performed outdoors during a normal training session. At the beginning of the session anthropometric measurements (height, mass and body composition) were taken from each participant, using a height measure (Seca 213, Hamburg, Germany) and body composition scales (Tanita BC305, Tokyo, Japan).

#### **3.3.2 Fitness Battery**

Following anthropometry, players were then asked to perform a 10 minute standardized warm-up routine consisting of jogging, dynamic stretching and high speed running. After the warm-up, participants underwent measurements of agility, sprint speed and estimated  $\dot{V}O_{2max}$ .

##### **Sprint speed**

Sprint speed of the players was assessed with a 5-, 10- and 30-m sprint. Four pairs of timing gates (Smartspeed, Fusion Sport, Queensland, Australia) were positioned over a course of 30 m at 5, 10 and 30 m from a fixed starting point. Players were instructed to place their front foot behind the first pair of gates (at 0-m point) and to run as fast as possible along the 30-m distance from a standing start.

## **Agility**

Agility was evaluated using the L-run agility test. Three cones were positioned in the shape of the letter 'L', 5 m apart from one another (See Appendix A), with a pair of timing gates (Smartspeed, Fusion Sport, Queensland, Australia) placed at the start/end point. Players were then instructed to run as quickly as possible through the pair of gates, around the cones and finish through the pair of gates again. Players were asked to perform three trials of the L-run.

## **$\dot{V}O_2\text{max}$**

Following the agility and speed tests, participant's  $\dot{V}O_2\text{max}$  was estimated using the Multi-stage Fitness Test. The Multi-stage Fitness Test is deemed a valid way to predict maximal aerobic capacity ( $\dot{V}O_2\text{max}$ ; Ramsbottom *et al.* 1988) and is recommended by the British Association of Sport and Exercise Sciences as an appropriate tool for predicting aerobic capacity in Rugby League players (Winter *et al.* 2007). The participants were instructed to run back and forth along a 20-m course (marked with cones at each end) and keep in time with a series of signals (beeps) dictated by a CD. The frequency of the beeps was progressively increasing with each stage, until participants reached exhaustion. If the participant failed to reach the end of the shuttle before the beep they were allowed 2 further shuttles to attempt to regain the required pace before being withdrawn. To encourage a maximal effort, participants received verbal encouragement throughout the test.  $\dot{V}O_2\text{max}$  was then estimated using equations described by Ramsbottom *et al.* (1988).

### 3.3.3 Familiarisation

On completion of the physiological tests participants were given clear instructions and a familiarisation session was carried out on how to perform the 6 repeated reactive agility tests (rRAT). From pilot testing, it was determined that three trials were needed in order for the players to be familiarised with the rRAT. Also, another rRAT (rRAT1) was included in order to ensure that completing a RAT prior to another RAT would not affect the results from the latter one. rRAT6 was included to monitor recovery. In addition, two familiarisation cycles of Part A and Part B (Table I) of the Rugby League Match Simulation Protocol (RLMSP) (See Appendix B) were performed as suggested by Sykes *et al.* (2013).

**Table I. The two components of each cycle of the Rugby League Match Simulation Protocol.**

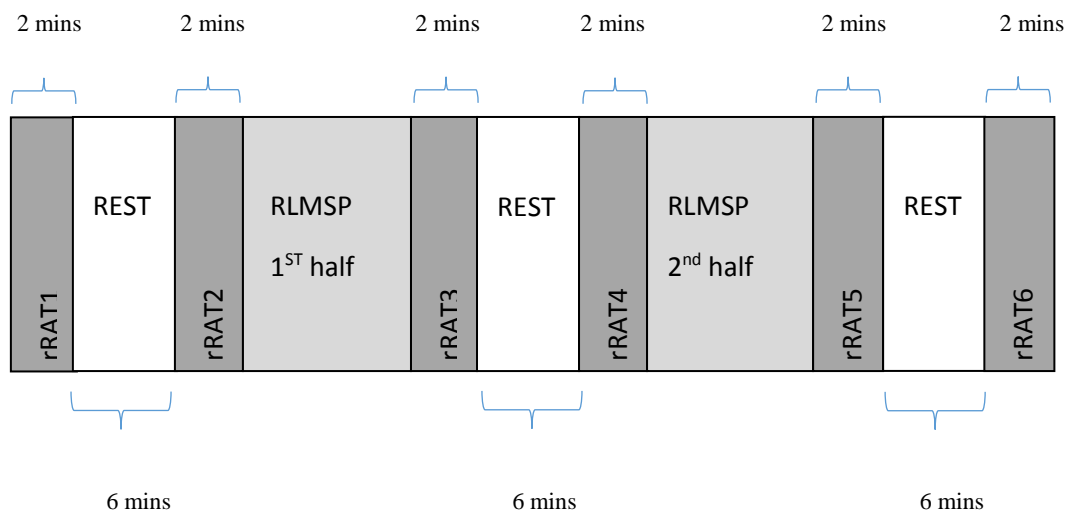
<b>Part A</b>	<b>Part B</b>
<ul style="list-style-type: none"> <li>. 10.5 m jog (<math>2.9 \text{ ms}^{-1}</math>) from yellow to red cones followed by 180° turn;</li> <li>. 10.5 m walk (<math>1.1 \text{ ms}^{-1}</math>) from red to yellow cones followed by 180° turn;</li> <li>. 20.5 m maximal effort sprint from yellow to blue cones;</li> <li>. 8 m deceleration to white cone followed by 1.70 s simulated contact (down and up off the ground);</li> <li>. 13 m jog (<math>2.9 \text{ ms}^{-1}</math>) from white to green cones;</li> <li>. 15.5 m walk (<math>1.1 \text{ ms}^{-1}</math>) from green to yellow cones</li> </ul>	<ul style="list-style-type: none"> <li>. 10.5 m walk (<math>1.1 \text{ ms}^{-1}</math>) from yellow to red cones followed by 180° turn;</li> <li>. 10.5 m walk (<math>1.1 \text{ ms}^{-1}</math>) from red to yellow cones followed by 180° turn;</li> <li>. 6.00 s passive rest at yellow cone;</li> <li>. 15.5 m jog (<math>2.9 \text{ ms}^{-1}</math>) from yellow to green cone followed by 180° turn;</li> <li>. 15.5 m walk (<math>1.1 \text{ ms}^{-1}</math>) from green to yellow cones;</li> <li>. 4.75 s passive rest at yellow cone.</li> </ul>

### 3.3.4 rRAT

At the beginning of the second testing session, heart rate monitors (Polar FT2, Polar Electro, Kempele, Finland) were attached and participants were asked to sit upright quietly for 5 minutes in order for resting heart rate to be taken. The Borg Scale (Borg 1970) was used to assess the perceived rating of exertion (RPE) following memory anchoring to the Borg 15-category scale as per Gearhart (2008). Memory anchoring involves giving a verbal explanation of the feelings corresponding with the high and low perceptual anchors with no presence of physical work (Gearhart 2008).

Participants were then asked to perform the rRAT (six trials in total throughout the protocol – see Fig. 1). Each rRAT consisted of 3 trials with 30 seconds rest. HR and RPE were measured during the 30 seconds recovery period between each trial of the rRAT as indicators of exercise intensity. Five pairs of timing gates were positioned (See Fig. 2), with the tester initiating the movement and thereby beginning the timing. A combination of the following conditions were performed: step forward with right foot and change direction to the left or right or step forward with the left foot and change direction to the left or right. The participant was required to react to the investigator's movements and to finish through a timing gate in the appropriate direction. The timing stopped when the participant triggered the timing gate on either side. A high-speed video camera (Sony camera) was positioned 5m behind the participants in order to record the change of movement direction relative to the investigator. Decision-making time was measured as the time between the investigator initiating the movement and the player running through the first pair of gates, and was used as a measurement of cognitive performance. Sprint time was defined as the time taken to sprint from gate 1 to the finishing gate and was used as a measurement of the physical component (Jordan *et al.* 2013). As suggested by

Gabbett *et al.* (2008b) the RAT is a valid way of assessing decision-making times and accuracy in Rugby League. Sheppard *et al.* (2008) investigated the reliability of the test and intra-class correlation analysis revealed a high level of reliability ( $r = 0.904$ ).



**Figure 1. The testing procedure including repeated reactive agility test and the Rugby League match simulation protocol**

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**Figure 2. Reactive Agility Test (Jordan *et al.* 2013)**

### 3.3.5 RLMSP

On completion of the second RAT, participants were asked to perform the RLMSP, after a 10-minute standardised warm-up, consisting of low and high speed running and dynamic stretching. As the RLMSP replicates movement patterns and physiological demands of actual game conditions, it has been suggested as a reliable way of measuring match-related physical performance in non-elite players (Sykes *et al.* 2013) due to its high external validity. The total distance covered during the RLMSP ( $8.444 \pm 212\text{m}$ ) is similar to that reported for elite Rugby League matches ( $8.503 \pm 631\text{m}$  (Sykes *et al.* 2009)). In addition, the percentage of time for standing, walking, jogging and running, sprinting and contact in the protocol was also similar to time spent in each of the activities during match-play (Sykes *et al.* 2009).

The RLMSP consisted of two halves of 43.4 minutes (86.8 minutes in total) split by a 10 minute interval to simulate half-time. Participants were required to walk, jog, sprint, stand and simulate contact between a series of cones positioned on a 28.5 m linear course and the movements were dictated by an audio CD, with changes being signalled by a “beep” and an instructive voice command. To simulate collision, participants were required to lie prone on the floor with their waist level with the white cones and chest on the floor and then regain their feet as rapidly as possible after the deceleration from each sprint. There were 40x 2 min 10 s cycles which were identical in the RLMSP. Each cycle consisted of two different elements- Part A, which replicates movement patterns when the ball is in play and was performed twice, and Part B, which was designed to replicate movement patterns when the ball is out of play. The reactive agility test was set up in close proximity to the end of the RLMSP to minimize recovery effects which have adversely affected previous studies of this nature.

Players were asked to abstain from strenuous exercise 24 hours before testing. Water intake during the RLMSP was controlled, based on the recommended guidelines (7ml per kg of body weight; Dunford and Doyle 2011). The water bottles were weighed on portable scales to the nearest 1 g prior to the start of the RLMPS and were available for consumption during the rest periods. The ambient conditions (barometric pressure: 52 mmHg, humidity: 70% and temperature: 20°C) were recorded at regular intervals during the RLMSP.

### **3.4 Blood analysis**

A capillary blood sample (5µl) was obtained in duplicate from the index finger at rest, immediately after RAT1, RAT3, RAT5 and RAT6 and prior to RAT2 and RAT4 to monitor fatigue development and recovery. Samples were then analysed for blood lactate concentration (mmol/L) and blood glucose (mmol/L) using the Biosen C-Line Analyzer (EKF Diagnostic, Cardiff, United Kingdom).

### **3.5 Statistical Analysis**

Timings from the rRATs were split into decision time, sprint time and total time and were entered into SPSS software Version 20.0 (SPSS Inc., Chicago, IL) together with raw data for HR, RPE,  $\dot{V}O_{2max}$ , BLa and glucose. The Shapiro- Wilk test was applied in order to assess for a normal distribution of data. The test reported that some of the dependent variables were not normally distributed (i.e. RAT3 DTa, RAT1 STa, RAT1\_TTa, RAT1



STc, RAT1 TTc, RAT3 STa, RAT3 TTa, RAT3 STc, RAT4 STa, RAT4 TTa, RAT5 STa, RAT6 DTc, RAT6 TTc, RAT6 HR, RAT1 RPE). Research by Khan and Rayner (2003) reported that even for non-normal data, parametric tests are a better option for small samples when compared to a non-parametric alternative. Furthermore, studies by Glass *et al.* (1972) and Harwell *et al.* (1992) showed that not satisfying the assumption of normality had only a slight effect on false positive rates. Therefore, analysis of variance (ANOVA) was chosen for the analysis of data, also taking into account that most of the variables were normally distributed.

Values for HR, RPE, blood lactate and glucose were compared throughout the six time points for each participant using One-way repeated measures analysis of variance (ANOVA). Post hoc analysis was then performed using the Least Significant Difference (LSD) test.

Decision time, sprint time and total time were also compared throughout the six time points using a two-way ANOVA with repeated measures (time point [6] x trial [3]) to assess their variability over time and between trials. The Greenhouse-Geisser adjustment was employed if the assumptions of sphericity were violated. Analyses were repeated using participant's individual aerobic capacity as a covariate. Effect size was used to quantify the meaningfulness of any differences found between conditions and calculated using partial  $\eta^2$  and was defined as: trivial ( $<0.1$ ), small (0.1-0.3), moderate (0.3-0.5) or large ( $>0.5$ ) (Hopkins *et al.* 2009). An alpha level of  $P<0.05$  was considered statistically significant. The Pearson product moment correlation coefficient was used to determine the relationship between RAT times and physiological variables (HR, RPE, BLa, blood glucose) and between RAT times and physical qualities and anthropometric measurements (sprint speed, agility, height, body mass, body fat, age).

## 4. Results

Data are reported as mean  $\pm$  standard deviation (SD). Anthropometric and physiological characteristics of participants are reported in Table II. Mean $\pm$ SD of decision-making time (seconds), sprint time (seconds) and total time (seconds) throughout the six repeated reactive agility tests is shown in Table III. Correlations between RAT and physiological measures is presented in Table IV. Correlations between decision time and physical qualities and between sprint time and physical qualities are reported in Table V and Table VI, respectively.

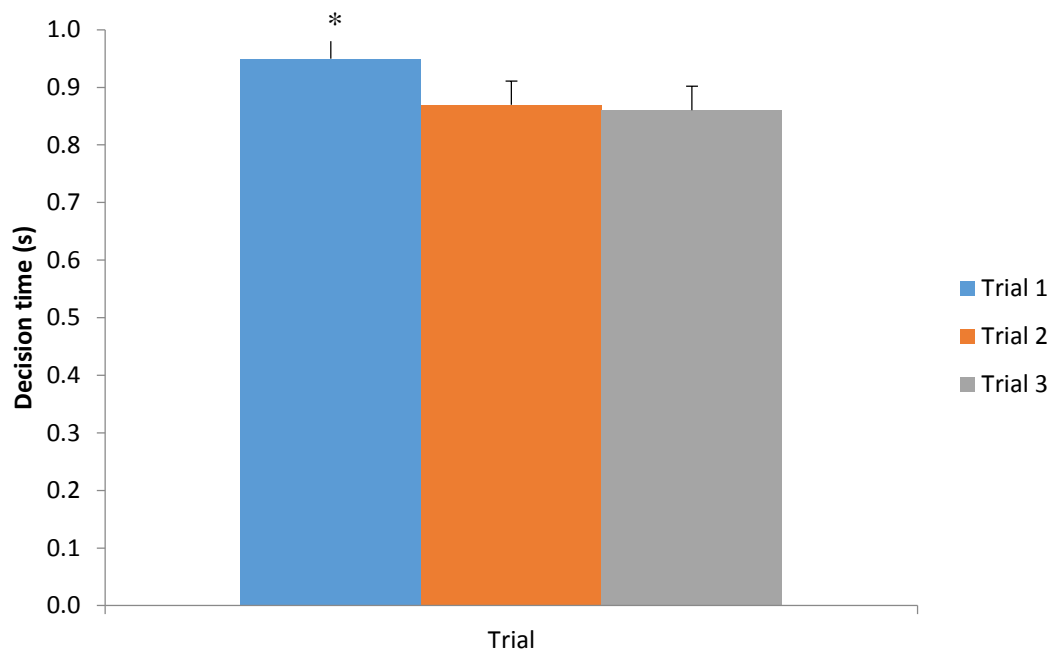
**Table II. Mean  $\pm$ SD of anthropometric and physiological characteristics of participants**

Variable	
Age (y)	23 $\pm$ 3
Height (cm)	179 $\pm$ 9
Body mass (kg)	88 $\pm$ 12
Body fat (%)	20 $\pm$ 3
Agility (s)	6 $\pm$ 0.3
5-m sprint (s)	1 $\pm$ 0.1
10-m sprint (s)	2 $\pm$ 0.1
30-m sprint (s)	4 $\pm$ 0.1
$\dot{V}O_2\text{max}$ (ml.kg <sup>-1</sup> .min <sup>-1</sup> )	48 $\pm$ 4

### 4.1 Decision Time (DT)

There was a significant main trial effect on decision-making time,  $F_{(1, 12)} = 1$ ,  $P = 0.033$ ,  $\eta_p^2 = 0.372$ . Post hoc tests using the Least Significant Difference correction revealed that the time taken to complete the first trial of each rRAT was significantly higher than the

time taken to complete the third trial ( $P = 0.027$  95% CI =  $0.012 \pm 0.158$ ) across the six time points at which the rRATs were performed (Fig.3). There was no significant effect of time point at which rRAT was performed on decision-making time,  $F_{(2, 22)} = 5$ ,  $P = 0.388$ ,  $\eta_p^2 = 0.102$ . Analysis of covariance was then run using individual aerobic capacity as a covariate. No interactions between time point and individual aerobic capacity and trial and individual aerobic capacity were reported ( $F_{(5, 40)} = 0.2$ ,  $P = 0.951$ ,  $\eta_p^2 = 0.027$  and ( $F_{(2, 16)} = 0.2$ ,  $P = 0.794$ ,  $\eta_p^2 = 0.028$ , respectively).



**Figure 3. Mean  $\pm$ SD of the decision times of trials 1, 2 and 3.**

\* Significantly different from trial 3

## 4.2 Sprint Time (ST)

A non-significant main effect of time point ( $F_{(2, 21)} = 2, P = 0.136, \eta_p^2 = 0.192$ ) and trial ( $F_{(2, 18)} = 2, P = 0.140, \eta_p^2 = 0.196$ ) on sprint time was observed. There was no interaction between time point and trial interaction for sprint time ( $F_{(2, 20)} = 0.555, P = 0.604, \eta_p^2 = 0.058$ ). Analysis was then re-run using individual aerobic capacity as a covariate. The results of statistical analysis reported above remained unchanged.

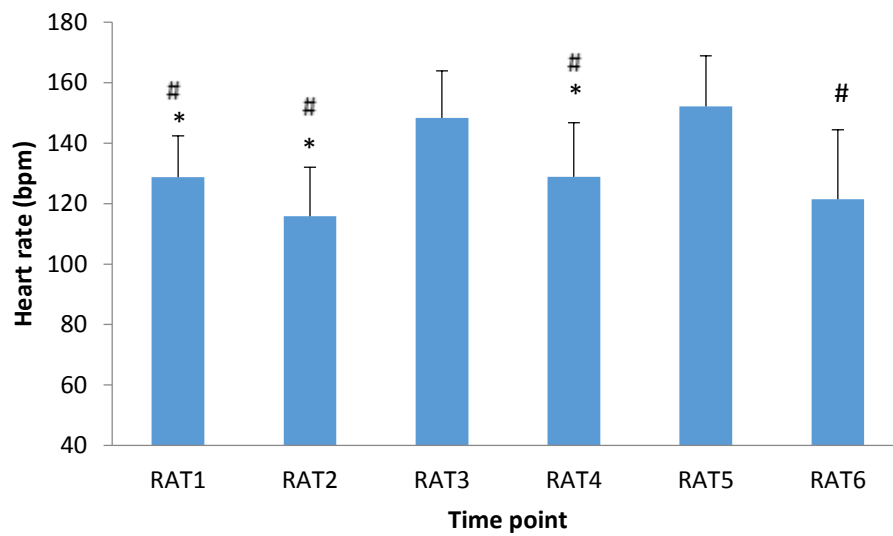
## 4.3 Total Time (TT)

A non-significant effect on total time was reported for both time point ( $F_{(2, 21)} = 2, P = 0.207, \eta_p^2 = 0.157$ ) and trial ( $F_{(1, 12)} = 4, P = 0.071, \eta_p^2 = 0.291$ ). In addition, no interaction between time point and trial interaction for total time was observed ( $F_{(2, 17)} = 1, P = 0.396, \eta_p^2 = 0.097$ ). The data was then analysed using individual aerobic capacity as a covariate. There was no interaction between time point and individual aerobic capacity ( $F_{(2, 19)} = 1, P = 0.651, \eta_p^2 = 0.057$ ), as well as no interaction between trial and individual aerobic capacity ( $F_{(2, 16)} = 0.4, P = 0.682, \eta_p^2 = 0.047$ ).

## 4.4 Heart Rate

A large significant effect of time on heart rate was reported ( $F_{(2, 23)} = 11, P < 0.000, \eta_p^2 = 0.527$ ). Post hoc analysis, using the LSD test revealed that heart rate differed significantly between RAT1 and RAT3 ( $P = 0.011, 95\% \text{ CI} = -45.962 \pm 7.566$ ), RAT1

and RAT5 ( $P = 0.008$ , 95% CI =  $-50.876 \pm -9.818$ ), RAT2 and RAT3 ( $P = 0.002$ , 95% CI =  $-61.146 \pm -18.243$ ), RAT2 and RAT5 ( $P < 0.000$ , 95% CI =  $-64.059 \pm -22.497$ ), RAT3 and RAT4 ( $P < 0.001$ , 95% CI =  $10.282 \pm 25.412$ ), RAT4 and RAT5 ( $P < 0.000$ , 95% CI =  $-29.550 \pm -13.312$ ) and RAT5 and RAT6 ( $P < 0.001$ , 95% CI =  $14.004 \pm 41.674$ ) (Fig. 4).

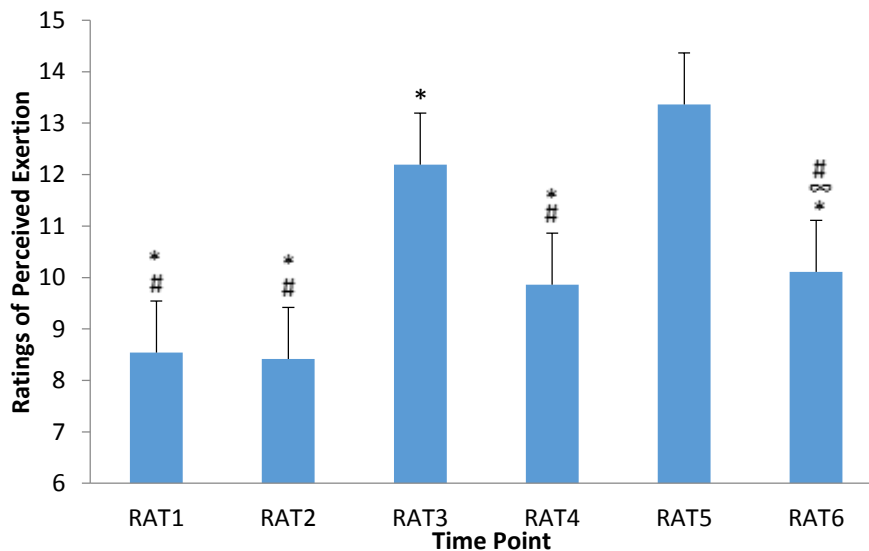


**Figure 4. Comparison of heart rate values between the six different time points.** Data is reported as mean  $\pm$ SD. \*Significantly different from RAT3. # Significantly different from RAT5.

#### 4.5 Rating of Perceived Exertion

Ratings of perceived exertion significantly changed across the six different time points, with the results reporting a large main effect ( $F_{(5, 55)} = 16$ ,  $P < 0.000$ ,  $\eta_p^2 = 0.598$ ). Post hoc analysis, using the LSD correction, revealed significant differences between RAT3

and RAT1 ( $P < 0.001$ , 95% CI =  $1.753 \pm 5.553$ ), RAT2 ( $P < 0.000$  95% CI =  $2.258 \pm 5.298$ ) and RAT6 ( $P = 0.002$ , 95% CI =  $0.923 \pm 3.244$ ). In addition, ratings of perceived exertion differed significantly between RAT5 and RAT1, RAT2, RAT3, RAT4 and RAT6,  $P < 0.000$  , 95% CI =  $2.905 \pm 6.734$ ;  $P < 0.000$ , 95% CI =  $3.543 \pm 6.346$ ;  $P = 0.043$ , 95% CI =  $0.044 \pm 2.289$ ;  $P < 0.001$ , 95% CI =  $1.709 \pm 5.291$  and  $P < 0.001$ , 95% CI =  $1.752 \pm 4.748$ , respectively (Fig.5).



**Figure 5. A comparison of rating of perceived exertion across the six different time points.** Data is reported as mean  $\pm$ SD.  $\infty$  Significantly different from RAT2.

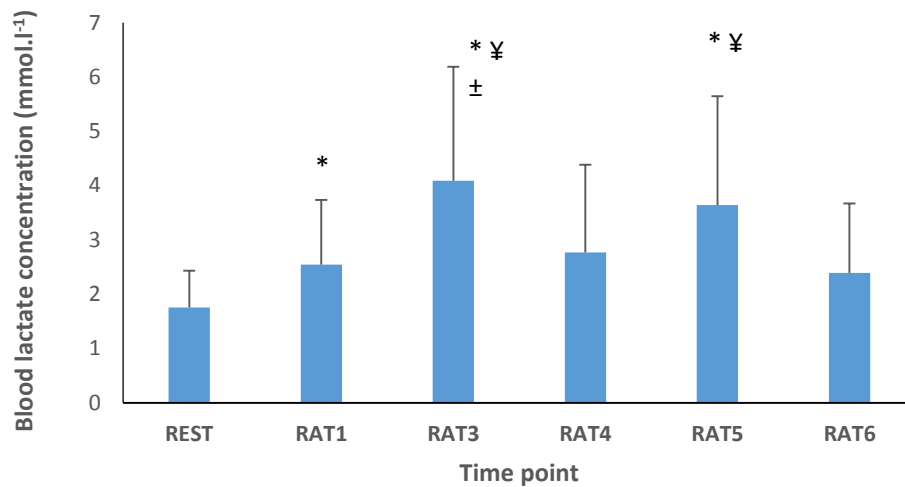
# Significantly different from RAT3. \*Significantly different from RAT5.

#### 4.6 Blood lactate

A LSD Post-hoc comparison was applied to determine any significant differences in blood lactate values over time. A significant effect of game-induced fatigue on blood

lactate concentration was reported ( $F_{(2, 27)} = 3.79$ ,  $P = 0.011$ ,  $\eta_p^2 = 0.303$ ). Post hoc comparisons using the LSD Test showed that lactate concentration values post RAT1, post RAT3 and post RAT5 were significantly higher compared to rest ( $P = 0.019$ ,  $P = 0.006$  and  $P = 0.008$ , respectively). In addition, values taken post RAT3 were significantly different to post RAT4 ( $P = 0.013$ ) and post RAT6 ( $P = 0.008$ ). There was a significant difference between lactate concentration post RAT5 and post RAT6 ( $P = 0.005$ ).

From the Mean  $\pm$  SD values for blood lactate across the six time points fatigue patterns were demonstrated on Fig. 6. Mean blood lactate throughout the protocol was  $2.86 \pm 0.54$  mmol.l<sup>-1</sup> and peak lactate reached during the RLMSP was  $4.09 \pm 2.09$  mmol.l<sup>-1</sup> after the 1<sup>st</sup> half.



**Figure 6. A comparison of blood lactate values across the six time points.** Data is reported as mean  $\pm$ SD. \*Significantly different to rest.  $\pm$ Significantly different to RAT4. ¥ Significantly different to RAT6.

#### 4.7 Blood glucose

Blood glucose concentration (GLC) was  $4.26 \pm 1.20 \text{ mmol.l}^{-1}$  at rest and did not significantly change ( $P > 0.05$ ) during the simulated game. Results of the one-way repeated measures ANOVA reported that blood glucose concentration levels did not significantly change over time ( $F_{(5, 55)} = 2.3, P = 0.061$ ).

	RAT1	RAT2	RAT3	RAT4	RAT5	RAT6
Decision Time (s)	0.94±0.09	0.83±0.05	0.91±0.19	0.83±0.03	0.87±0.02	0.88±0.02
Sprint Time (s)	1.04±0.11	0.98±0.03	1.10±0.29	1.02±0.11	1.00±0.04	1.03±0.04
Total Time (s)	1.98±0.22	1.79±0.02	2.01±0.58	1.85±0.08	1.87±0.01	1.92±0.02

**Table III. Mean±SD of decision time, sprint time and total time throughout the six repeated reactive agility tests.**

**Table IV. Pearson's correlation coefficients for RAT time and physiological measures.**

	$\dot{V}O_{2\max}$	HR	RPE	BLA	GLC
<b>DT</b>	$r = 0.224, P = 0.059$	$r = -0.383^*, P < 0.001$	$r = -0.093, P = 0.437$	$r = 0.138, P = 0.295$	$r = -0.073, P = 0.578$
<b>ST</b>	$r = -0.019, P = 0.872$	$r = -0.152, P = 0.203$	$r = -0.192, P = 0.106$	$r = -0.149, P = 0.257$	$r = 0.267, P = 0.039$
<b>TT</b>	$r = -0.016, P = 0.895$	$r = -0.166, P = 0.163$	$r = -0.194, P = 0.102$	$r = 0.017, P = 0.896$	$r = 0.106, P = 0.421$

\* Significant correlation,  $p < 0.05$



Changes in decision time were not significantly related to  $\dot{V}O_{2\max}$ , RPE, BLa or blood glucose, but were correlated to changes in HR (Table IV). However, only 15% of the change in HR could be explained by decision time. None of the variables measured correlated with sprint time or total time. According to the value of correlation coefficient (r), following categories were used for the interpretation of correlation: 0.0 – 0.19 = very weak to negligible correlation, 0.2 – 0.39 = weak, low correlation, 0.4 – 0.69 = moderate correlation, 0.7 – 0.89 = strong, high correlation and 0.9 – 1.0 = very strong correlation (Evans 1996).

**Table V. Pearson's correlation coefficients between RAT1, RAT2, RAT3, RAT4, RAT5 and RAT6 decision times and agility and sprint speed.**

	<b>L-run</b>	<b>5m</b>	<b>10m</b>	<b>30m</b>
<b>DT1</b>	0.088	-0.231	-0.221	-0.327
<b>DT2</b>	0.643*	-0.443	-0.352	-0.529
<b>DT3</b>	0.13	0.022	0.151	0.084
<b>DT4</b>	0.303	-0.446	-0.465	-0.625*
<b>DT5</b>	0.441	-0.57	-0.654*	-0.770**
<b>DT6</b>	0.335	-0.339	-0.454	-0.608*
<b>L-run</b>	1	-0.604*	-0.355	-0.216

\*Denotes significance at  $P < 0.05$

\*\*Denotes significance at  $P < 0.01$

Decision times during the six RATs were not significantly related to L-run times (Table with the exception of DT during RAT 2 which was moderately related to L-run time ( $r = 0.643$ ,  $P < 0.05$ ). In addition, there was no relationship between DT and 5m sprint speed. A significant moderate correlation was displayed between 10m sprint speed and RAT5 DT ( $r = 0.654$ ,  $P < 0.05$ ). There were moderate to strong negative correlations between DT for RAT4, RAT5 and 30 m sprint speed ( $r = -0.625$ ,  $P < 0.05$ ;  $r = -0.770$ ,  $P < 0.01$  and  $r = -0.608$ ,  $P < 0.05$ ).

**Table VI. Pearson's correlation coefficients between RAT1, RAT2, RAT3, RAT4, RAT5 and RAT6 sprint times and agility and sprint speed.**

	<b>L-run</b>	<b>5m</b>	<b>10m</b>	<b>30m</b>
<b>ST1</b>	-.362	-.044	-.033	.292
<b>ST2</b>	-.178	.205	.068	-.161
<b>ST3</b>	-.318	.520	.584*	.701*
<b>ST4</b>	-.593*	.349	.105	.151
<b>ST5</b>	-.305	.126	.143	.483
<b>ST6</b>	.008	-.074	.029	.434

\*Denotes significance at  $P < 0.05$

\*\*Denotes significance at  $P < 0.01$

Changes in sprint time during the six RATs were not significantly correlated to L-run times (Table VI), however there was a moderate negative correlation between sprint time

during RAT4 ( $r = -0.593$ ,  $P < 0.05$ ). Changes in sprint time during the six RATs were not significantly correlated to sprint speed, with the exception of ST during RAT3. There was a moderate linear relationship between RAT3 ST and 10 m sprint speed ( $r = 0.584$ ,  $P < 0.05$ ) and a strong linear correlation between RAT ST and 30 m sprint speed ( $r = 0.701$ ,  $P < 0.05$ ).

## **5. Discussion**

The present study sought to examine whether game-specific fatigue, induced by a Rugby League match simulation protocol, would affect decision-making ability in amateur Rugby League players. A secondary aim was to determine whether any differences in response time would be associated with differences in participants' aerobic capacity. The primary hypothesis that game-induced fatigue would result in increases in decision time in the rRATs performed immediately after the 1<sup>st</sup> (RAT3) and the 2<sup>nd</sup> half (RAT5) was not supported as there were no significant changes in decision time post RAT3 and RAT5 compared to rest. In addition participant's aerobic capacity did not affect decision time and therefore, the second hypothesis was also rejected. However, the present results indicated that throughout the protocol, the slowest decision-making performance was seen in the 1<sup>st</sup> trial of the rRATs, immediately following exercise cessation, suggesting an acute effect of moderate fatigue. To date, most of the research examining the effect of fatigue on cognition, in particular on decision-making, has been conducted in the laboratory setting, which is very different to the sporting environment. This study is novel because for the first time the decision-making component of agility was examined under Rugby League specific conditions in the appropriate field setting.

### **5.1 Internal measures of fatigue**

#### **5.1.1 HR**

Mean  $\pm$  SD for HR following the second half of the protocol was  $152 \pm 16.7$  beats.min<sup>-1</sup> which is the same as the value reported by Gabbett (2005) for average HR during an amateur game of Rugby League. As the current study used a simulation protocol it would

be expected for the HR to be lower from that in a competitive match as the emotional stress and the addition of physical contact would elevate HR (Sykes *et al.* 2011). However, this was not the case. Sykes *et al.* (2011) and Mullen, Highton and Twist (2015) reported that during a Rugby League simulation protocol, players perform more high intensity running than they would do in an actual match due to the lack of contact, which could explain the HR response.

### **5.1.2 RPE**

Mean  $\pm$  SD for RPE immediately following the second half of the simulated match was  $13 \pm 2.4$ . Norris *et al.* (2016) reported RPE of  $15.5 \pm 1.9$  following simulated contact with a weighted tackle sled and  $14.8 \pm 1.8$  following contact with a soft tackle bag. Similarly, Johnston and Gabbett (2011) reported RPE of  $16.2 \pm 1.1$  following simulated contact trials. The lower values reported in the present study are likely to be associated with the absence of contact. Johnston and Gabbett (2011) demonstrated that the addition of contact to repeated-sprint exercise increased the internal load on the player, resulting in higher RPE values. Mullen, Highton and Twist (2015) also reported that RPE values were higher when compared between a simulation protocol with and without contact, which explains the discrepancy between current findings and literature.

### **5.1.3 BLa**

Mean BLa concentrations ( $2.86 \pm 0.54 \text{ mmol.l}^{-1}$ ) reported in the present study are not in agreement with values reported in previous studies in Rugby League. Gabbett *et al.* (2003) reported mean values of lactate concentration of  $5.2 \text{ mmol.l}^{-1}$  for amateur players which tend to increase at higher levels of competition -  $7.2 \text{ mmol.l}^{-1}$  and  $9.1 \text{ mmol.l}^{-1}$  for

semi-professional (Coutts *et al.* 2003) and professional players (O'Connor *et al.* 1996), respectively. The disagreement is likely to be due to different timings of measurement as the activity in the 5 minutes prior to taking the sample has an effect on the measurement. Gabbett *et al.* (2003) and Coutts *et al.* (2003) measured lactate concentration during exercise, whereas the present study measured blood lactate immediately after the cessation of the RAT, on average 1 minute and 30 seconds following the end of each half of the protocol. The two halves of the protocol were identical as well as the patterns of the RAT, therefore lactate samples in the present study were taken following identical conditions. In addition, as suggested by Cairns *et al.* (2005) speed of recovery can affect results if measurements are not made immediately on exercise cessation. It has also been suggested that active recovery at low to moderate intensity, such as during the RAT, stimulates removal of lactate from the blood (Reilly 1997).

Similar to this study, Mullen, Highton and Twist (2015) reported lower blood lactate concentrations during a simulation of Rugby League match-play ( $\sim 4.5 \text{ mmol.l}^{-1}$ ). The lower values observed in the current study could be explained with the lack of contact with an opponent, as the different phases of contact (deceleration and consequent ‘wrestling’), which were not included in the RLMSP, would increase the metabolic strain on the neuromuscular system as suggested by Mullen, Highton and Twist (2015).

Blood lactate concentrations were higher following the first half of the simulated game protocol ( $4.1 \text{ mmol.l}^{-1}$ ) compared to the second half ( $3.6 \text{ mmol.l}^{-1}$ ). Coutts *et al.* (2003) also reported increased lactate concentrations during the first half of a game (8.4 vs. 5.9  $\text{mmol.l}^{-1}$ ). Measurements of blood lactate at the start and the end of halftime, as well as

after a game were taken to serve as an indicator of the net rate of lactate clearance, as suggested by Bangsbo *et al.* (2007). As shown on Fig. 6 mean lactate decreased from 4.1 mmol.l<sup>-1</sup> at the beginning of halftime to 2.8 mmol.l<sup>-1</sup> at end of halftime, within a 6-minute active recovery period, corresponding to a net blood lactate decrease rate of 0.2 mmol.l<sup>-1</sup> at halftime. The data is in consistency with results of 0.1 mmol.l<sup>-1</sup> mean rate of blood lactate turnover at halftime reported by Krstrup *et al.* (2006) for soccer players. In the present study the active recovery period at the end of the simulated game was similar (0.2 mmol.l<sup>-1</sup>) to the one at half-time. However, the rate of clearance in this study, as aforementioned, is affected by the accelerating of the removal of lactate during low to moderate intensity exercise. Results suggest that there is indeed some recovery during half-time, however it is speculated that in an actual match lactate removal at half-time would take longer, as players would mainly stand and listen to the coach talking or be in a seated position and would not be involved in low to moderate activities as in the present study.

Although some of the variables (HR) were the same as those reported during matches, overall the protocol did not accurately reflect the physiological responses of competitive Rugby League, likely due to the failure of replicating contact kinetics and kinematics. However, as values for HR, RPE and BLa, following the first and second half of the protocol were significantly different to rest (Figs.4, 5 and 6), it could be suggested that the patterns of cumulative fatigue were reflected correctly. From the HR, RPE and BLa levels, it was determined that the fatigue level throughout the protocol was moderate.

## 5.2 Decision-making

The main finding of the current study was that immediately following moderate levels of fatigue, decision-making time was significantly higher for the first trial of each rRAT ( $P = 0.027$ ) compared to the third (Fig. 3). Due to the novel nature of this study and the fact that there is a lack of research on fatigue and decision-making in Rugby League, comparisons of current findings to previous research are difficult. This is furthermore limited by the large variation in methodologies from study to study. Current findings do coincide however, with those of Royal *et al.* (2006) where decision-making performance deteriorated following moderate levels of exertion in water polo. In addition, a study by Bullock *et al.* (2012) reported a decline in reactive agility performance following soccer-specific exercise. However, the reactive agility test that was used by Bullock *et al.* (2012) did not measure decision and movement time components, like the present study. Therefore, increases in RAT time could be attributed to a decline in physical (sprinting) ability, which makes comparisons tenuous.

Despite this, the other finding of this research that decision times following the first and second half of the match protocol were not significantly different to rest is in contrast to those of McMorris and Graydon (1997), Tenenbaum *et al.* (1993) and Fontana *et al.* (2009) where decision-making was positively affected by moderate exercise. This is likely to be due to differences in the decision-making task employed. McMorris and Graydon (1997) and Tenenbaum *et al.* (1993) used a visual task, consisting of forms with identical situations, and Fontana *et al.* (2009) used videos and neither are ecologically valid. As suggested by Mann *et al.* (2007), the use of videos and slide presentations is



likely to alter the perceptual and sensory experience, as two-dimensional stimulus may inadequately replicate the dynamic nature of sport. Hence, this might be the reason for the discrepancy. In the present study, participants were faced by an opponent in a 1-on-1 scenario, which reflected more realistically game-play when players are required to respond accurately to opponents' movement in order to make a tackle. Although the nature of the decision made in the rRATs was more reflective of naturalistic sport than tests previously used, it still differs from the decisions made in a real world defensive or offensive tackling situation. It is likely that the current task required only a simple reaction ability, with the participants relying upon a pre-planned change of direction, realising the static conditions of the task (of opponent and environment). In contrast, making a tackle in a real game would require a complex reaction with a choice of responses to permanently changing stimuli from opponents, teammates, tactics and environment. Since it is likely that the participants had made a pre-planned decision as to which direction to choose this could possibly explain why the decision time following RAT3 and RAT5 remained similar to the rest of the time points. As it is likely that the decision-making process in the present study has been underestimated, a RAT reflecting more accurately the dynamic nature of the sport is needed in order for researchers to be able to investigate complex decisions under different conditions.

The present results showed an increased reaction time for the trial of the rRAT immediately following cessation of exercise. Reaction time is comprised of pre motor and motor time. Pre motor time (governed by the CNS) begins with the reception of the stimulus, includes processes such as transmission of the sensory information to the brain and decision-making and ends with the transmission of the efferent information to the muscles. Motor time (regulated by the PNS) is the time it takes the muscles to be activated

and to initiate a response (McMorris 2014). Therefore, the initial increase in decision time post exercise cessation could both be attributed to central or peripheral changes due to fatigue. As the present study did not measure premotor and motor time separately, changes in processes associated with any of the two could have affected the results. In regard to fatigue, it is manifested in two different patterns - one resulting from short-term effort of high intensity (temporary) and the second one - from long-term exercise (cumulative) (Szgula, Gawronski and Kalinski 2003). As the effect on decision-making was acute rather than cumulative, it might be associated with the accumulation of extracellular potassium and the consequent electrical disturbances in muscle cells, characteristic for temporary fatigue (Mohr *et al.* 2005). However, the complex nature of fatigue, involving both central (e.g. decline in neural drive) and peripheral (e.g. impaired activation/excitation of motor units) phenomena, makes it challenging to identify the mechanisms responsible for its effect on cognitive performance (Lyons *et al.* 2006). In contrast to previous research which has reported improvements in reaction times following exercise but used simple verbal response or pressing of a key, in the current study both the fatiguing and the reaction tasks were performed by the legs. It has been suggested that fatigue primarily occurs in the periphery (McKenna 2003). Considering the fatiguing task used in the present study, it is possible that increases in decision-making time for the 1<sup>st</sup> trial of each rRAT can be attributed to peripheral impairments such as reduced acetylcholine, potassium, ATP and phosphocreatine (PCr) in the muscles, hence increasing motor time of reaction (McMorris and Graydon 2000). This is also supported by McMorris *et al.* (2005) who suggested that slower reaction time following exercise might be caused by a build-up of lactate and break down of neurotransmitters in the peripheral nervous system. Although the lack of correlation between BLa and decision

time ( $r = 0.138$ ,  $P = 0.295$ ) does not suggest that lactate has an effect on decision time, it has to be taken into account that blood lactate concentrations were taken following the 3<sup>rd</sup> trial of each rRAT. Fig. 3 shows a significant decrease in decision-making time from the 1<sup>st</sup> to the 3<sup>rd</sup> trial of each rRAT. The mean time between trial 1 and trial 3 of each rRAT was 65 seconds, allowing for some amount of recovery and replenishment to occur. Following repeated sprints, about 3 minutes are needed in order for PCr to be fully replenished and in about 30s PCr levels are less than 50% replenished (Dawson 1997) potentially explaining as well why no changes in sprint performance were observed. In addition, Kjaer (1989) added that replenishment of chemicals following exercise is particularly fast in trained athletes, therefore, the effect of reduction of peripheral neurotransmitters may have affected only the first trial of each rRAT.

Tomprowski and Ellis (1986) also suggested that physical fitness, in terms of aerobic capacity has an effect on cognitive performance for chronic exercise and that fitter individuals could perform better than less fit individuals. Furthermore, Fleury *et al.* (1981) stated that physical fitness is an important factor, as it determines the ability of an individual to resist disturbances provoked by different types of fatigue. The central processing of information in an individual with lesser exercise tolerance would be impaired and their performance in cognitive tasks would be decreased in comparison to fitter individuals (Lyons 2011). McMorris and Graydon (1996) support this by claiming that fit performers who can adapt better to continuously changing conditions and can cope better with physiological stress, are also able to suppress the negative effect of fatigue. In regard to the effect of aerobic capacity on cognitive performance during acute exercise, sport specific research is limited. In the present study no interaction was found between aerobic capacity as a measure of physical fitness and decline in decision-making time ( $P$

= 0.951). In addition, Pearson product moment correlation reported no correlation between decision time and  $\dot{V}O_2\text{max}$  ( $r = 0.224$ ,  $P = 0.059$ ). However, pattern of neural activation associated with a particular task, is also quickly restored to normal levels after the cessation of the task and it takes few minutes only to normalize any exercise-induced changes in neural activity which might explain the absence of link between aerobic capacity and decrements in cognitive performance (Dietrich and Sparling 2004). In addition, it has to be kept in mind that in the present study the level of fatigue was moderate and the physiological stress placed on the participants was not as great as during an actual match, possibly due to the simulation protocol not mimicking match demands accurately enough, due to lack of contact.

The influence of physical qualities on reactive agility performance has been previously explored, with Sheppard *et al.* (2006) and Gabbett, Kelly and Sheppard (2008) being the first ones to investigate the relationship between speed, change of direction and reactive agility. Gabbett, Kelly and Sheppard (2008) used a similar RAT to the one from the present study and found significant relationships between the 5 m, 10 m, and 20 m sprint times and performances on the 505 test, L-run and modified 505 test. This is in contrast to previous research (Young, Dowell and Scarlett 2001) which found a weak to moderate association between linear sprinting speed and change of direction speed. Furthermore, the relationship between the L-run and 5 m, 10 m, and 20 m sprint times observed by Gabbett, Kelly and Sheppard (2008) was stronger ( $r = 0.57\text{--}0.73$ ) than that observed for the 505 ( $r = 0.52\text{--}0.58$ ) and modified 505 ( $r = 0.61\text{--}0.62$ ) tests. There was also a significant moderate correlation ( $r = 0.40\text{--}0.58$ ) between all change of direction speed tests and reactive agility movement times (referred to as ST in the present study), suggesting that movement times are influenced by the change of direction speed of

athletes (Gabbett, Kelly and Sheppard 2008). In contrast, in the present study, no relationship was observed between ST during the RATs and L-run times (Table VI), except for a moderate negative relationship between RAT4 ST and L-run time ( $r = -0.593$ ,  $P < 0.05$ ). However, an interesting finding is that ST for RAT3 was moderately related to 10m sprint speed ( $r = 0.584$ ,  $P < 0.05$ ) and strongly related to 30m sprint speed ( $r = 0.701$ ,  $P < 0.05$ ), suggesting that sprint speed was a factor influencing ST during the RAT immediately following the first half of the RLMSP. In terms of DT, the only relationship displayed was between RAT2 DT and L-run ( $r = 0.643$ ,  $P < 0.05$ ). Since there was a lack of a significant relationship between reactive agility decision times and L-run times for the rest of the RATs, changes in reactive agility performance for RAT2 cannot be solely attributed to change of direction speed. This is supported by Gabbett, Kelly and Sheppard (2006) who also suggest that reactive agility performance is likely to be affected by other factors, such as perceptual processes (visual scanning, anticipation, pattern recognition and situational knowledge) in addition to, or other than change of direction speed. Furthermore, Gabbett, Kelly and Sheppard (2008) reported that while linear speed was related to change of direction speed, the lack of a relationship between reactive agility decision time and change of direction speed confirms that reactive agility tests assess a different quality to pre-planned change of direction speed tests. In addition to this, Sheppard *et al.* (2006) also reported a significant relationship ( $r = 0.74$ ,  $P < 0.05$ ) between linear speed and change of direction speed, but reactive agility and change of direction speed performance were unrelated. In the present study, a negative moderate relationship between 5m sprint speed and L-run was reported ( $r = -0.604$ ,  $P < 0.05$ ). Collectively, these findings are in support of the fact that reactive agility performance could be affected by both physical (e.g., linear speed, strength, change of direction speed) and

perceptual/decision-making factors (Young, James and Montgomery 2002). This suggests again that changes in DT performance seen in the present study are unlikely to be explained by a single event or process.

Trying to unfold the mechanisms underlying the results of the study is challenging and identification of one specific mechanism appears highly unlikely. The possibility of the current findings fitting within a theoretical framework was also explored in relation to the cognitive processes associated with premotor time. As previously stated, researchers have been trying to explain the relationship between exercise, arousal and performance, putting forward various theories (Yerkes and Dodson 1908; Easterbrook 1959; Kahneman 1973). The inverted-U theory (Yerkes and Dodson 1908) and the Cue Utilisation Theory (Easterbrook 1959) both predict that moderate levels of arousal would elicit optimal performance. The majority of the research on the effect of exercise on cognitive performance outside the sporting environment has been in favour of these theories (Tomprowski and Ellis 1986). Arousal levels or a state of arousal can be indicated by HR (Kennedy and Scholey 2000). HR during exercise increases to meet the body's requirement for oxygen and to maintain adequate motor functioning by supplying the muscles with oxygenated blood. Poels *et al.* (2008) suggested that the blood flow to the brain also increases, information processing improves and results in decreased reaction time, explaining the relationship between moderate exercise and optimal cognitive functioning. This has been supported by Abicht *et al.* (2014) who reported that increases in HR corresponded to decreases (improved) reaction time. In the present study, there was a negative correlation between HR and DT (Table IV), however it was a weak correlation ( $r = -0.383$ ,  $P < 0.001$ ) and only 15% of the change in DT could be explained

by HR. The changes in total DT following moderate exercise were not significantly different between the different time points, which is not in agreement with the inverted-U theory and the Cue Utilisation Theory. McMorris *et al.* (2004) suggested that arousal is induced through exercise; it may be that the heart rates obtained are poor predictors because the emotional and physical responses interact in such a way that heart rate becomes an unreliable predictor of arousal. Since arousal was not measured in any other way throughout the present study, fitting the current results within a theoretical framework that looks at the relationship between arousal and exercise is only being explored.

The present findings that the decision-making performance immediately following exercise cessation worsened may be explained in terms of the Multi-Dimensional Allocation of Resources Theory by Kahneman (1973). Kahneman (1973) stated that attentional resource capacity can vary depending on how demanding the cognitive task is - if the task is perceived as appealing, the participant will put more resources in that task processing capacity. As responding to a visual task is simple and not as challenging as being faced by an opponent in a 1-on-1 scenario, not enough attentional resources were required. This resource allocation can possibly explain why no effect of exercise on cognition was observed in previous research in comparison to the present study (Tomprowski 2003). Furthermore, in a real match situation, the addition of a cognitive component such as identification and development of strategies as well as anxiety and pressures to score or prevent opposition from scoring is likely to cause a shift in the allocation of attentional resources and amplify the negative effect of fatigue on cognitive performance observed in the present study.

Supplementary resource allocation is closely linked with the transient hypofrontality hypothesis, recently proposed to explain the relationship between acute exercise and cognition (Dietrich 2003). It is based on the fact that the brain has a limited information processing capacity (Broadbent 1958) and needs to continuously evaluate costs in order for efficient information processing to be assured. During exercise and sport, when there is a strain on metabolic resources, the brain has to account for the sustained large activation of motor and sensory systems through lowering activity in other neural structures (Vissing, Anderson and Diemer 1996). According to the transient hypofrontality hypothesis, brain regions, such as areas of the frontal lobe, which do not play a vital role in performing the exercise, are temporary inhibited. Brains' resources are therefore redistributed to areas sustaining the workload (Dietrich and Sparling 2004). In terms of exercise intensity, coded by the rate of firing of the neurons, low workload is not sufficient to strain metabolically motor and sensory structures and cause such a shift. Similarly, high workload cannot challenge the brains' resources as it cannot be sustained long enough by the cardiovascular system (Dietrich and Sparling 2004). The condition most likely to cause a shift in resource allocation is exercise of moderate intensity. It is characterized by a large increase in firing rates of neurons in neural tissue and can be maintained long enough to put a strain on metabolic needs (Dietrich and Sparling 2004). The intensity during the RLMSP in the present study was moderate, as confirmed by HR, RPE and blood values, thus enough to put a strain on the relatively limited reservoir of metabolic resources available. In order for the workload throughout the protocol to be sustained, the brain is likely to have downregulated neural structures that were not key to the exercise performed and could be disengaged, such as the frontal lobe. As the frontal lobe is involved in higher-cognitive functions, with the ventromedial region playing an



important role in decision-making (Spinella, Yang and Lester 2004), this could provide another possible explanation to why decision-making immediately following cessation of the RLMSP was impaired.

The possibility that the decline in decision-making performance during the first trial of the rRATs can be attributed to a single process or mechanism is unlikely and now appears naïve.

### **5.3 Sprint Time**

There were no significant changes in sprint time throughout the protocol. This is in contrast with previous research by Small *et al.* (2009) who examined changes in sprint performance during a Soccer-specific Aerobic Field Test. Results showed that sprint time significantly increased during both halves of the fatiguing protocol. Krstrup *et al.* (2010) also reported slower sprint time following competitive games in elite female soccer, which is consistent with previous research (Mohr *et al.* 2004; Krstrup *et al.* 2006) that found repeated sprint performance to deteriorate significantly during competitive games. Similarly, in contact sports such as Rugby and Australian Football, sprint performance was impaired over time throughout a simulated game protocol (Singh *et al.* 2010). This disagreement is likely to be due to a potential disadvantage in the design of the simulation/fatiguing protocol used in the present study. The protocol ends with Part B, which simulates when ball is out of play and promotes recovery. Therefore, prior to the rRATs at the end of each half, participants would have already started recovering, which may explain why no decreases in sprinting performance were observed. In addition, Johnston and Gabbett (2001) reported that the addition of tackling significantly decreased

sprint performance in Rugby League players due to large increases in physiological responses. Contact was not reflected in the current RLMSPP and so the physiological demand on the players might be underestimated. However, the recovery period at the end of Part B is still representative of a match situation, especially for the backs. These players typically spend most of the time jogging or walking around, not involved in defence/contact, and suddenly faced with decision-making situations.

According to Dynamic Systems Theory, movement coordination to achieve a set goal represents a complex dynamic interaction between the behaviour of the neuromuscular, neural and cognitive systems and the individual's motivation to perform the task within the constraints placed before them (Missiuna *et al.* 2001). These constraints can be organismic, environmental or task and are defined as boundaries that limit motion (Newell 1986). Organismic constraints refer to factors internal to the individual that cannot be changed, such as biological, physiological or psychological factors (e.g. speed, stride length). External influences such as weather or surface qualities are defined as environmental constraints. For example, the correct decision in terms of task achievement would be very different when playing on a muddy pitch to that when playing on a hard pitch (McMorris 2004). Some of these constraints can be modified/changed in order to minimize the influences of the environment on movement coordination, however others, such as opposition team tactics, cannot be changed. Task constraints involve the properties of the task itself. For example, in Rugby League rules of the game can be perceived as constraints as they require players to abstain from passing forwards hence forcing them to search for opportunities to pass sideways. The interaction of internal characteristics, environmental influences and properties of the task determines optimal

coordination pattern for any given task (Newell 1986). In the present study, many of these constraints were removed or diminished – ambient and pitch conditions were controlled, opposition and team tactics were excluded from the decision-making task and players were presented with a 1-on-1 scenario, hence movement performance of the given task was not significantly affected and sprint performance did not significantly change. Reducing the amount of decisions that players were faced with, might not be as challenging as what they would experience during a real game. During real game condition, players will be faced with a number of environmental and task constraints that would require them to make multiple decisions, therefore it is likely that the protocol used underestimated decision-making.

#### **5.4 Blood glucose**

Blood glucose concentration levels at rest were  $4.26 \pm 1.20 \text{ mmol.l}^{-1}$  remained elevated during the 1<sup>st</sup> half of the game and half time ( $4.52 \pm 1.68 \text{ mmol.l}^{-1}$ ), and then decreased during the 2<sup>nd</sup> half ( $3.99 \pm 1.66 \text{ mmol.l}^{-1}$ ), with further decline in values to  $3.58 \pm 1.34 \text{ mmol.l}^{-1}$  following the last RAT. Supporting this finding, Bergeron (1991) reported a downward trend of glucose concentration levels in a tennis game. In contrast, Krstrup *et al.* (2006) reported that glucose concentrations were maintained at high level throughout a soccer match. It was suggested that glucose was maintained at high levels during the game through compensatory mechanisms in order to account for the decline in muscle glycogen. The possible mechanisms included elevated levels of free-fatty acids concentration, mainly during the 2<sup>nd</sup> half, elevated levels of glycerol and an increase in the utilization of muscle triglycerides in the 2<sup>nd</sup> half as a result of increased catecholamine

levels (Krustrup *et al.* 2006). Differences are likely to be due to the fact that the present study, although a simulation of a match, lacked stress factors such as match importance, management, supporters and the effects of the catecholamines on blood glucose were minimal.

The findings from the present study suggest that the rate of glucose released from the liver is not enough to compensate for the use of blood glucose throughout a game. Future studies which investigate whether ingestion of suitable carbohydrates and/or caffeine during prolonged play would be favourable to sustain glucose levels are needed.

As the brain relies on glucose as its main source of energy, several aspects of brain function, such as cognition, have been shown to be affected by changes in glucose. Research has shown that the development of hypoglycaemia negatively influences some components of cognitive function. Severe hypoglycaemia ( $2.6 \text{ mmol.l}^{-1}$ ) was found to cause a significant decline in performance of cognitive tasks (reaction time) in healthy individuals (Evans *et al.* 2000). Furthermore, following a 20 minute recovery period until euglycemia was restored ( $5 \text{ mmol.l}^{-1}$ ), reaction times remained impaired. Even modest hypoglycaemia, of glucose levels of  $2.8 \text{ mmol.l}^{-1}$ , has been reported to affect cognitive performance, complex more than simple cognitive skills (Maran *et al.* 2000). The number of studies examining the effect on cognition of glucose values within the normal physiological range is limited. In a study by Bandelow *et al.* (2010) soccer players were asked to complete a cognitive test battery before, in the half time and after matches. The players also underwent measurements of glucose before and after the match. Results

showed high association between glucose and faster fine motor speed, faster complex visual discrimination and faster memory scanning. However, higher glucose was negatively associated with a decrease in accuracy in the working memory scanning test. Thus suggesting although high glucose levels within the normal range have a positive effect of response speed, it is at the cost of accuracy and increased number of errors, particularly on complex decision tasks (Bandelow *et al.* 2010). Hogervorst *et al.* (2008) reported that caffeine in a performance bar significantly improved complex cognitive ability during and after cycling exercise. This finding suggested that caffeine ingestion might be a strategy to counteract the negative effect of higher glucose values, further research, incorporating complex decision-making scenarios in the sport-specific setting for team sports is warranted.

## **5.5 Limitations**

The study was designed in such a way as to enable researchers to conduct it in the appropriate field setting and to examine the immediate effect of fatigue on performance. The effect of fatigue on decision-making could have been underestimated due to absence of real physical contact during the fatiguing protocol, which is acknowledged by Sykes *et al.* (2013). Consequently, muscles in the upper body were not as fatigued as the muscle groups of the lower body. In a typical game of Rugby League players are involved in between 24 to 47 physical collisions (Gabbett, Jenkins and Abernethy 2011) depending on position, which contribute significantly to physical demands of the sport (Austin, Gabbett and Jenkins 2011). It has been documented that physical collisions and associated muscle damage due to the blunt force trauma, lead to reductions in upper body

neuromuscular function (Johnston *et al.* 2013). This is also suggesting that fatigue might have been underestimated. However, the introduction of contact would have increased the risk of injury and also would have made it difficult to control the intensity at which it was performed (Sykes *et al.* 2013). Up to date, a Rugby League simulation protocol that takes into account the above mentioned factors does not exist, hence the selection of the current protocol. Future research should consider the development of a protocol that is Rugby League- specific and truly replicates match patterns and contact demands.

Another limitation of the present study is the small sample size of participants who were from the same club. Hence, the results may reflect the physiological statuses of this particular group and be applicable only to amateur players. To confirm the findings, data should be obtained from a range of different clubs and compared across different levels of play.

Currently, the findings of the present study need further exploration in different groups to confirm its results. A reactive agility test that is more reflective of a tackle situation and that discriminates between premotor and motor time is needed. Future research should include neuroscience techniques and biochemical measurements to investigate brain function, in particularly prefrontal activity (McMorris *et al.* 2015), to quantify response to fatigue and different environmental sport-related stressors. However, to do this in sport-specific and ecologically valid way would be very difficult.

## 6 Conclusion

The present study employed a sport specific protocol and observed no differences in reactive agility at different time points of the protocol, which did not support the study hypothesis. However, an increase in decision time during the first trial of the repeated RATs immediately following exercise cessation was reported. This is in contrast to prior laboratory based work (Audiffren, Tomporowski and Zagrodnik 2008; Davranche *et al.* 2006; Davranche *et al.* 2005, Hüttermann and Memmert 2014). The findings from the present study contribute to the body of knowledge on the relationship between fatigue and decision-making in sport. The decline in decision-making performance immediately following exercise cessation is likely to be magnified during real match conditions. The results of this study may have implications for Rugby League coaches and strength and conditioning coaches at amateur level of the sport. In particular, it might be beneficial if game-specific high-intensity repeated efforts are incorporated into training, as they are representative of the most demanding parts of a game. Immediately following that, reactive agility drills should be performed in order to encourage the development of decision-making skills under conditions of fatigue and minimize the effect of fatigue on the skill. If this is incorporated into regular training sessions it may translate to players coping better with the physical demands of match-play and improved performance. Future work should be directed towards investigating the effect of high levels of fatigue on cognitive performance, through measuring brain function and using protocols and tasks that are highly reliable and ecologically valid and include physical collisions.

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## **8 Appendices**

### **8.3 Appendix A- The L-run**

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**Figure 7. Schematic illustration of the L-run agility test. (Gabbett *et al.* 2008b)**

#### **8.4 Appendix B – The RLMSP**

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**Figure 8. Schematic representation of the exercise pattern of the rugby league match simulation protocol (Sykes *et al.* 2013)**

