AN INVESTIGATION INTO THE SENSITIVITY OF DIFFERENTIAL RATINGS OF PERCEIVED EXERTION (dRPE) AS A TOOL TO MEASURE INTERNAL TRAINING LOAD IN TEAM SPORT PLAYERS

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ABSTRACT

Monitoring the internal response to training load in team sports has the potential to improve performance and reduce the risk of injury. A solution to monitor the internal load of individuals is to collect a subjective rating of perceived exertion (RPE). However, RPE may be theoretically limited by its approach in combing a variety of inputs into one gestalt score. To overcome this limitation, recent advances in monitoring have led to the development of a differential rating of perceived exertion (dRPE) which has the potential to provide a more sensitive evaluation of internal load. The aim of the current study was to investigate the ability of dRPE to detect changes in the physiological demands associated with different deceleration profiles in high-intensity running protocols.

Thirteen male team sport players completed four exercise protocols (Dec5m, Dec15m, Dec5/15m and Dec15/5m) which involved 20 repetitions of a 30 metre high-intensity run but with different deceleration profiles. Ratings of muscular exertion (RPE_L) and feelings of breathlessness (RPE_B) were recorded after every repetition. In addition to dRPE the external load of the protocols was measured using 10 Hz GPS devices (Optimeye S5, Firmware 7.38, Catapult Sports, Melbourne, Australia) and measures of muscle soreness and neuromuscular fatigue were assessed.

Total distance ($p = 0.615$) and average maximum velocity ($p = 0.360$) was consistent between the protocols. Peak deceleration was greater in the Dec5m protocol compared to the Dec15m protocol ($p = 0.005$). Changes in RPE_L and RPE_B increased substantially from the first to the last repetition during all the protocols. However, the rate of change in RPE_L and RPE_B from the first to the last repetition between the protocols ranged from likely trivial to most likely trivial. Comparisons of neuromuscular function measures were unclear for most of the time points. There was a very likely increase in muscle soreness in the Dec5m protocol compared to the Dec15m protocol 48 hours post protocol.

In conclusion, dRPE might not be a sensitive enough measure to detect small differences in the muscular and respiratory demands of the protocols and cohort used in this study. However, the lack of sensitivity may be exercise/sport and/or population dependant.

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LIST OF ABBREVIATIONS

ANOVA – Analysis of variance

AU – Arbitrary unit

CI – Confidence Interval

cm – Centimetre

CNS – Central nervous system

CR10® – Borg category-ratio 10 (deciMax®) scale

CR100® – Borg category-ratio 100 (centiMax®) scale

CV – Coefficient of variation

Dec5m – Exercise protocol involving twenty repetitions of a 30m sprint with a 5m deceleration

Dec15m – Exercise protocol involving twenty repetitions of a 30m sprint with a 15m deceleration

Dec5/15m – Exercise protocol involving twenty repetitions of a 30m sprint with alternating 5m and 15m decelerations respectively

Dec15/5m – Exercise protocol involving twenty repetitions of a 30m sprint with alternating 15m and 5m decelerations respectively

dRPE – Differential ratings of perceived exertion

GPS – Global positioning system

HDOP – Horizontal dilution of precision

kg – Kilogram

LIST – Loughborough intermittent shuttle test

m – Metre

MEMS – Microelectrical mechanical systems

m/s – Metres per second

MPID – Minimum practically important difference

RPE – Ratings of perceived exertion

RPE_B – Ratings of perceived breathlessness

RPE_L – Ratings of perceived leg muscle exertion

RPE_T – Ratings of perceived technical demand

RPE_U – Ratings of perceived upper body muscle exertion

Sec – Seconds

SD – Standard deviation

sRPE – Session ratings of perceived exertion

SWC – Smallest worthwhile change

TRIMP – Training impulse

$\dot{V}O_2$ – Oxygen update

$\dot{V}O_2$ Max – Maximal Oxygen update

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The physical demands of team sports are well documented (Mohr *et al.*, 2003; Hoff, 2005; Stølen *et al.*, 2005; Bangsbo *et al.*, 2006; Macutkiewicz and Sunderland, 2011; Cummins *et al.*, 2013; Varley *et al.*, 2014) and have been described as including bouts of high-intensity linear and multidirectional activity combined with lower intensity rest periods (Bangsbo *et al.*, 2006). However, there are noticeable differences in activity profiles between sports due to reasons such as pitch or court size, duration played and the number of substitutions permitted. As well as this, positional differences within the same sport exist with some positions requiring a greater number of maximal intensity periods than others (Di Salvo *et al.*, 2007; Cummins *et al.*, 2013). More recently, the activity profile which typifies soccer and rugby union has been observed to change as a function of time (Barnes *et al.*, 2014; Bush *et al.*, 2015; Curran and Carling, 2018). For example, in soccer, high intensity running has increased by 30-35% during the 2006-2013 seasons and meterage per minute has increased in rugby union (Barnes *et al.*, 2014; Curran and Carling, 2018). There has also been an increase in the competitive calendar meaning that team sport players are required to play a greater number of matches across the week (Soligard *et al.*, 2016).

These aforementioned factors all contribute to the complexity of team sports. Therefore, the high demands of competitive match-play make preparation strategies for individual players an important consideration for top level performance. One important consideration that supports optimal preparation strategies is to monitor the training load completed by the players as such processes can increase the chance of achieving the desired performance outcomes (Borresen and Lambert, 2009). As well as this it can also reduce the risk of training load induced injuries and non-functional over-reaching (Halson, 2014). Monitoring training load in team sports frequently involves the analysis of both external and internal loads placed on individual players. External loads are the activities which are completed by an athlete in training sessions and matches (e.g. the total distance covered and/or high-speed distance and the number of acceleration and decelerations) (Wallace *et al.*, 2008). Solutions to monitor external loads performed during training or competition tend to be through the use of microtechnology, such as microelectrical mechanical systems (MEMS), global positioning systems (GPS) or through the use of video tracking technologies. However, limitations do exist with these technologies. Firstly, there are the costs involved with these systems, limitations within the technology itself and the expertise required to analyse the data. All of which make them inaccessible for some teams (Impellizzeri *et al.*, 2005). Most importantly though, external load measures only provide information on what activities a player has completed which could be the same between players if all players were prescribed the same training load. However, how individuals react to this external load can vary between individuals (internal load) and it is this response which is important when attempting to achieve the desired physiological adaptations. Therefore, as the external loads do not provide any indication on how the players are responding to the prescribed training load it is extremely important to monitor the internal load alongside the external load (Impellizzeri *et al.*, 2019).

A players internal load represents the psychophysiological (biochemical) and mechanical stress (stress on tendon, muscle, cartilage and bone) response to an exercise stimulus (Impellizzeri *et al.*, 2005; Vanrenterghem *et al.*, 2017). The importance of analysing the internal response of each individual player is due to the fact that these responses are dependent on the inherent characteristics of the individual such as genetic background, age and starting fitness level (Bouchard and Rankinen, 2001; Impellizzeri *et al.*, 2005; Gil-Rey *et al.*, 2015a). Also, individuals can have different responses to the same stimulus due to other reasons such as fatigue, illness or psychological wellbeing (Bourdon *et al.*, 2017; Impellizzeri *et al.*, 2019). Therefore, monitoring internal load is extremely important as this is what determines whether there is an increase or decrease in performance.

There are many solutions to monitor the internal load of team sports players. These include objective measures such as heart rate parameters, blood lactate and salivary measures and subjective measures such as ratings of perceived exertion (RPE). Ratings of perceived exertion is a quick, valid and non-invasive measure of an individual's internal load. To date, the definition of perceived exertion, which is deemed to be the most accurate is 'the conscious sensation of how hard, heavy, and strenuous a physical task is' (Marcora, 2010). Ratings of perceived exertion can be collected post session with ease, as athletes can complete this rating with minimal instruction using either the CR10® or CR100® point scale (Foster *et al.*, 2001). To enable longitudinal monitoring of a player's perception of effort Foster *et al*., (2001) proposed a method for assessing internal load known as a session rating of perceived exertion (sRPE).

Session ratings of perceived exertion are calculated as overall RPE multiplied by session duration. Session RPE integrates a variety of information (Los Arcos *et al.*, 2014a) into one standalone gestalt score (Weston, 2013). This single number measured in arbitrary units (AU) is representative of the volume and intensity of the whole training session (Foster *et al.*, 2001; Impellizzeri *et al.*, 2004). Studies have shown that sRPE is a valid method in quantifying training load in Australian Soccer (Scott *et al.*, 2013), soccer (Impellizzeri *et al.*, 2004; Alexiou and Coutts, 2008) and basketball (Foster *et al.*, 2001). However, using sRPE does have its limitations. In addition to the practical issues of ensuring that the data collected is accurate, sRPE may also be theoretically limited by its approach in combing a variety of inputs into one gestalt score. This will mean that a breakdown of what specific demands experienced by the athlete and how they contribute to this one score is impossible to determine. The lack of specific information prevents such data fully assisting with the prescription of training loads and recovery for individual players. Recent advances in monitoring have led to the development of a differential rating of perceived exertion (dRPE) score which may overcome this limitation.

Similar to RPE, dRPE is a quick and non-invasive measure of internal load. This perception of effort rating has the potential to provide a more sensitive evaluation of internal load by having separate ratings for sub-components of RPE associated with specific physiological events (Robertson and Noble, 1997). These specific aspects of the response to exercise are rated separately, thereby providing an opportunity to understand the individual's subjective interpretation of the exercise stress. For example, athletes can be asked to provide separate scores for ratings of perceived leg muscle exertion (RPE_L) and ratings of perceived breathlessness (RPE_B). The rationale to investigate the use of dRPE as a means of monitoring internal load in team sports was due to the earlier observations that RPE's remained stable during competitive matches (Weston, 2013) but with a large disparity in external load. This suggests that the measure of internal load (RPE) may not be providing a true representation of the physiological stress imposed on the athletes under differing external loads. Therefore, a global RPE is potentially masking the weighting of what else contributes to this internal load (Robertson and Noble, 1997). Such contributors include psychological factors, peripheral and central signals, performance milieu and exertional symptoms (Robertson and Noble, 1997). Therefore, it can be assumed that the weighting of the psychophysiological signals (signal dominance) alters between matches but this is unclear when only collecting one global measure of perceived exertion.

The concept of differential ratings of perceived exertion was initially investigated within a laboratory where perceptual signal dominance has been shown to be dependent on training experience and exercise mode such as running on a treadmill or cycling on a cycle ergometer. However despite this proof of concept model there are notable differences between the external loads elicited from these protocols and the external loads of team sport training and matches, which is where further research is needed to understand the usefulness of dRPE within team sports. Since then, studies have investigated the application of dRPE within team sports during competitive matches (Yanci *et al.*, 2014; Weston *et al.*, 2015; Los Arcos *et al.*, 2016; Zurutuza *et al.*, 2017), different training modalities (Los Arcos *et al.*, 2013; Gil-Rey *et al.*, 2015b; Mclaren *et al.*, 2017; McLaren *et al.*, 2018) and the influence of playing duration (Los Arcos *et al.*, 2014b) and position (Barrett *et al.*, 2018; Birdsey *et al.*, 2019) on players dRPE.

Although these studies demonstrate that dRPE has the ability to provide a more sensitive evaluation of an individual’s internal load, further proof of concept research is required. For a monitoring tool to be deemed valid and reliable it requires different types of research to be designed and completed before confidence in this measure can be confirmed (Halperin *et al.*, 2015). Initial studies on dRPE were conducted within a controlled laboratory environment but for the reasons stated above these studies had their limitations as to the application to team sports. Other studies outlined above have taken the concept of dRPE straight from a controlled setting, where the exercise mode was either a treadmill or a cycle ergometer and used it within a very uncontrolled applied setting. It could be argued that a proof of concept study which investigates the use of dRPE during team specific movements, an approach that has both ecological and suitable control, would be useful in adding to the research that evaluates the potential use of dRPE. Therefore, this study looks to bridge the gap between the laboratory studies and the applied studies to provide further insight into the usefulness of dRPE as a monitoring tool in team sports. This study will look to assess the sensitivity of dRPE to detect changes in exercise protocols with varying deceleration profiles due to the recent research which has suggested that high intensity decelerations can act as mediators in inducing both neuromuscular fatigue and tissue damage (Harper and Kiely, 2018) which has the potential to increase the risk of training load induced injuries (Halson, 2014; Vanrenterghem *et al.,* 2017). Therefore, if dRPE, specifically RPE_L is sensitive enough then the mechanical load of exercise protocols can be assessed.

1.2 AIMS AND OBJECTIVES

The aim of the current study was to investigate the ability of dRPE to detect changes in the physiological demands associated with different deceleration profiles in high-intensity running protocols. The objectives of the study were to:

1. Analyse changes in RPE_L and RPE_B scores between four protocols with varying deceleration profiles.
2. Compare objective and subjective measures of exertion between the four protocols to assess the appropriateness of the protocol manipulation.

This study had the following hypothesis based on the above aim:

1. Completing the protocol with the shortest deceleration zone would increase RPE_L and RPE_B scores in team sport players. As well as this, this protocol would also show the greatest decrease in neuromuscular function and an increase in muscular soreness post protocol.

CHAPTER 2

LITERATURE REVIEW

2.1 THE PHYSICAL DEMANDS OF TEAM SPORTS

The physical demands experienced in team sports are varied and complex, including both tactical and technical requirements combined. Team sports are categorized broadly by bouts of high-intensity linear and multidirectional activity combined with longer low intensity recovery periods (Bangsbo *et al.*, 2006). Whilst team sports can be generally classified in this way, a number of factors impact this generic activity profile to create more individualized challenges to a player's physiology. For example, positional differences within the same sport do exist and, as such, the activity profile will be different with some positions requiring increased periods of maximal activities than others (Di Salvo *et al.*, 2007; Cummins *et al.*, 2013). Further, the activity profile of team sports also varies as a function of the sport due to reasons such as pitch or court size, duration played, and the number of substitutions allowed. To expand upon these points, during competitive soccer, rugby league and Australian Football matches, elite players will cover a total distance of between 8 to 13 kilometers (Hoff, 2005; Stølen *et al.*, 2005; Bangsbo *et al.*, 2006), 6 to 8 kilometers (Varley *et al.*, 2014) and 11 to 13.5 kilometers (Cummins *et al.*, 2013) respectively. In contrast, international female field hockey players cover the least total distance with values of between 5 and 7 kilometers (Macutkiewicz and Sunderland, 2011). These differences are potentially a result of factors such as pitch size, number of players and rule changes allowing for unlimited substitutions, which results in a greater number of players utilized and reduced playing time compared to soccer (Macutkiewicz and Sunderland, 2011). The ranges in total distance reported within the literature above highlights firstly that each sport is unique and has its own physical requirements and secondly, that within the different sports there are positional differences. The aforementioned team sport requirements all contribute to the complexity and physical demands associated with individual competitions, therefore, creating a need to individualize player preparation.

When considering the disparities in the total volume of training load completed between sports, differences in how the total volume is constructed in terms of the percentage of time spent at different velocity thresholds are also evident. Sprinting has been found to constitute between 1 and 11% of the total distance covered in a soccer match (Mohr *et al.*, 2003), 1.5% in field hockey (Macutkiewicz and Sunderland, 2011), 2.5% in Australian football and approximately 5% in rugby league (Varley *et al.*, 2014). The intermittent exercise pattern observed in team sports also leads to multiple short bursts of maximal activities such as accelerating, decelerating, changing of direction and cutting (Bishop and Girard, 2013). A systematic review has shown that non-contact team-sport athletes (soccer, field hockey, basketball and volleyball) can change activity 500-3000 times during a match. These activity changes seem to be most frequent in basketball (every 1-2 seconds) (Taylor *et al.*, 2017) with changes occurring every 3-4 seconds in soccer and hockey (Taylor *et al.*, 2017). This research demonstrates that team sports involve a large quantity of non-linear movement which can produce a substantial mechanical stress of the soft tissues resulting in a greater energetic cost (Vanrenterghem *et al.*, 2017).

Recent research has suggested that the activity profile which typifies team sports is not constant but rather changes as a function of time (Barnes *et al.*, 2014; Bush *et al.*, 2015; Curran and Carling, 2018). For example, Barnes *et al.*, (2014) found that over a 7-season period in the English Premier League (2006-2013) high intensity running and sprinting distance had substantially increased by 30-35%. In rugby union the volume, measured by total distance, and the intensity, measured by meterage per minute, was also found to have increased, probably as the result of trial law changes in matches (Curran and Carling, 2018). In addition to these in-game increases in demands, commercial obligations have also seen the competitive calendar increase meaning that players are having to compete more regularly across the week (Soligard *et al.*, 2016). Players who also compete internationally face additional loads associated with the increase in the number and demands of international games across both the domestic season and the off season (Thorpe *et al.*, 2017). Due to the complexity of team sports, backroom staff are employed in an attempt to prepare players for these demands. Specific roles, such as that of the sports scientist, helps ensure that team sport players are appropriately prepared for both their specific positional demands as well as being prepared to compete regularly in games at optimal levels (Thorpe *et al.*, 2017). One of the roles of a sports scientist is to be able design effective preparation strategies to assist with the prescription of training and recovery loads to maximize performance.

2.2 MONITORING IN TEAM SPORTS

2.2.1 OVERVIEW

There are numerous different types of monitoring tools which exist within team sports. However, the focus of this chapter is on monitoring tools which can be used to analyze training load. Training load has been defined as ‘the sport and non-sport burden (single or multiple physiological, psychological or mechanical stressors) as a stimulus that is applied to human biological systems (including subcellular elements, a single cell, tissues, one or multiple organ systems, or the individual’ (Soligard *et al.*, 2016). The importance of training load monitoring is that it allows practitioners to evaluate the exercise completed (external load) and how individuals have consequently reacted to the exercise (internal load) (Halson, 2014). This information can then be utilized to inform future training and recovery loads with the aim of improving performance. The process by which performance is enhanced is through the systematic repetition of appropriate prescribed training loads (Impellizzeri *et al.*, 2019). If players are exposed to suitable external loads there is then the potential to increase chronic physiological adaptations (Vanrenterghem *et al.*, 2017; Impellizzeri *et al.*, 2019) and the chance of achieving the desired performance outcomes (Borresen and Lambert, 2009). However, excessive prescribed training loads can increase fatigue and increase the risk of training load induced injuries and non-functional overreaching (Halson, 2014; Vanrenterghem *et al.*, 2017). The timing and magnitude of a stimulus can also be suboptimal, which can lead to a loss in the desired adaptations (Impellizzeri *et al.*, 2019). This highlights the importance of an appropriate monitoring tool to help ensure the desired response is achieved in training to prevent the problems of too much and/or too little load occurring (Vanrenterghem *et al.*, 2017).

Monitoring training load in team sports requires the analysis of both external and internal loads to evaluate the training outcome. Based on the theoretical framework of the training process it is suggested that there are two factors which will impact the internal response to an exercise bout and, as such, determine the training outcome (Figure 2.1) (Impellizzeri *et al.*, 2005). These two factors include the individual characteristics of the players and the organisation, quantity and quality of the external load performed (Impellizzeri *et al.*, 2005). This integrated approach of assessing both the external load completed and the internal response to the training is important to provide an insight into how the athletes are coping with the training stress (Bourdon *et al.*, 2017).

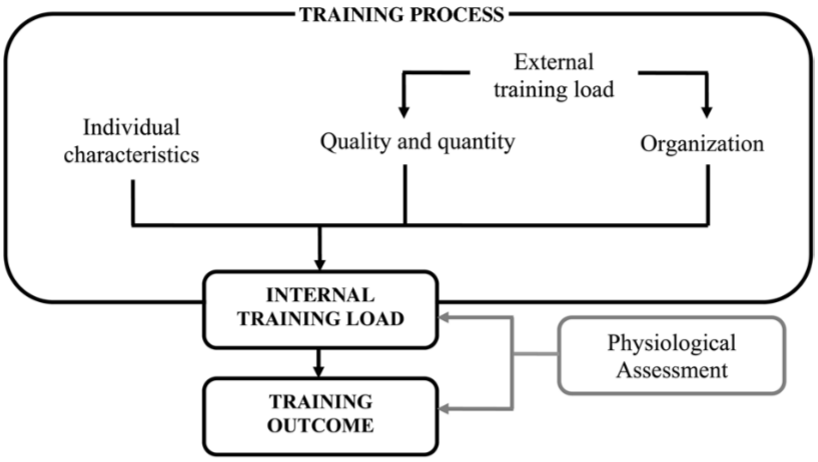

Figure 2.1. Theoretical framework of the training process. The training outcome is a result of the internal training load. The internal load is a result of the individual characteristics of the players and the quality, quantity and organisation of the performed external load. Taken from (Impellizzeri *et al.*, 2005).

2.2.2 EXTERNAL LOAD MEASURES IN TEAM SPORTS

External loads are the activities that are completed by an athlete (e.g. the total distance covered, distance covered at high-speed and the number of accelerations as examples). During training these loads can be controlled to some extent as they are often prescribed by a multidisciplinary team beforehand to ensure that the tactical, technical and physical goals of a specific training session are met to elicit a positive response (Impellizzeri *et al.*, 2019). However, competition creates a challenge as the external load is the output of the match and due to the nature of competition these loads are difficult to pre-determine as there are many factors which can affect this output (score line, formation, possession). Practitioners may try to control these loads by substituting a player on or off the pitch to reduce playing time and consequently the external load. This is most common when a player is returning from injury and they are being exposed to competitive match loads early on in their rehabilitation. Aside from on-pitch load, external load can also be the training completed in the gym during resistance-based programmes. The external load during this type of training would be monitored through the sets, reps and weight lifted (Impellizzeri *et al.*, 2019). Therefore, it is important to have a monitoring tool or tools to measure the external load during training, matches and in the gym so you can get a true representation of the overall exercise load completed by each player, which otherwise may be unknown (Impellizzeri *et al.*, 2019). Although there is not a gold standard solution to monitor the external load completed on the pitch (Impellizzeri *et al.*, 2019) solutions tend to be through the use of microtechnology, such as microelectrical mechanical systems (MEMS), global positioning systems (GPS) or through the use of video tracking technologies. Advances in technology now allow practitioners to access real time data during training and matches so any necessary changes to a players training load can be adjusted proactively. During gym-based sessions technologies which can assess power output and detect the number of repetitions performed are becoming increasingly popular.

Even though external load measures have been deemed as an important tool, limitations of external load measures do exist. Limitations include the financial cost associated with these systems, limitations of wearable technology itself and the expertise required to analyse the data which makes them inaccessible for some teams (Impellizzeri *et al.*, 2005). Aside from this, external load measures are limited as they only provide information on what training a player has completed. The external load completed could theoretically be the same between players during training sessions if every player completed the same drills with no consideration for the individual needs and the different positional demands of the sport (Impellizzeri *et al.*, 2005). However, the response (internal load) to this exercise can vary markedly between individuals and this response is what will determine whether there is the desired physiological adaptation or not (Bouchard and Rankinen, 2001; Impellizzeri *et al.*, 2005; Gil-Rey *et al.*, 2015a). Therefore, as the external loads do not provide any indication on how the players are responding to the prescribed training load it is extremely important to monitor the internal load alongside the external load (Impellizzeri *et al.*, 2019).

2.2.3 INTERNAL LOAD MEASURES IN TEAM SPORTS

Internal load is a representation of the psychophysiological (biochemical) and mechanical stress (stress on tendon, muscle, cartilage and bone) placed on an individual in response to an exercise stimulus (Impellizzeri *et al.*, 2005; Vanrenterghem *et al.*, 2017). The internal response to external loads are dependent on the inherent characteristics of the individual's under consideration such as age, genetic background and the individuals starting fitness level (Bouchard and Rankinen, 2001; Impellizzeri *et al.*, 2005; Gil-Rey *et al.*, 2015a). It is these inherent characteristics which will stimulate a physiological response that can be vastly different between individuals (Gil-Rey *et al.*, 2015a). Not only do the inherent characteristics differ between participants but the internal load response to the same exercise stimulus can vary markedly between the same individual on different days due to the individuals state of fatigue, illness or psychological wellbeing (Bourdon *et al.*, 2017; Impellizzeri *et al.*, 2019). Impellizzeri *et al.*, (2019) suggested that the internal load should always be incorporated within a monitoring system as this is what determines the training outcome (either improving or limiting performance) and, therefore, practitioners should be monitoring this for each individual (Figure 2.1).

Internal load is most commonly measured through the use of heart rate parameters collected from transmitter belts and/or the collection of a subjective rating of the perception of effort (Halson, 2014). Heart rate transmitter belts are worn during training and competition which allows a range of internal load metrics to be collected and subsequently analysed. Examples of some of these parameters are maximal heart rate, average heart rate and time spent in different heart rate zones (Halson, 2014). Post training analysis often includes calculations known as training impulse (TRIMP) where training duration is multiplied by a delta heart rate exercise ratio and a gender specific multiplying factor (Banister, 1991) to provide a global indication of the volume and intensity of the session (Alexiou and Coutts, 2008; Borresen and Lambert, 2009). Limitations do exist when utilizing heart rate measures as a method to monitor the internal load response to the exercise completed in team sports. Heart rate measures were initially validated based on the linear relationship between heart rate and $\dot{V}O_2$ during steady state exercise (Impellizzeri *et al.*, 2005). However, team sports are intermittent in nature and due to the heart rate response to changes in activity there is the potential that the heart rate response may be underestimated (Alexiou and Coutts, 2008; Impellizzeri et al., 2005). As well as this, there is also the possibility that due to the nature of team sports such as rugby that there may be heart rate trace dropouts when a heart rate belt has been displaced due to contact with another player and, as such, affect the data collected. Missing data can have huge consequences when monitoring the internal response to the training load as you cannot be certain as to the response to exercise (Foster *et al.*, 2001). Therefore, heart rate measures may not be the most valid and may be practically limited when attempting to understand how players are adapting to the prescribed training load (Alexiou and Coutts, 2008).

Other measures of internal load are available such as blood lactate and salivary measures. However, these measures are not as easily implemented within team sport training (Halson, 2014). Similarly to heart rate measures, blood lactate and salivary measures require specialist equipment in order to be able to collect this data, which comes at a financial cost meaning it is not accessible for all teams to utilise (Impellizzeri *et al.,* 2005). Secondly, alongside the financial cost, these measures of internal load require a skilled practitioner in order to be able to take these measures off a player. Collecting blood lactate and salivary measures also takes time and is, therefore, not feasible to be done after each training session has finished especially when the number of practitioners are limited (Halson, 2014; Impellizzeri *et al.,* 2005). Therefore, these measures are more suited within laboratory practices or within sports where there are fewer number of players.

Aside from the theoretical and practical limitations of using heart rate, blood lactate and salivary measures, internal load has been described as the biochemical and the mechanical stress of exercise. Collecting heart rate, blood lactate and salivary measures alone do not provide an insight into the mechanical stresses of the soft tissues (Vanrenterghem *et al.*, 2017) and, therefore, is potentially not a true representation of the internal load. The activity profile of team sports causes mechanical stresses on muscles, tendons and cartilages as a result of having to absorb and produce large forces during activities such as cutting (Vanrenterghem *et al.*, 2017). The resulting factor of this mechanical stress is that there will either be a positive or negative adaptation of the musculoskeletal system (Vanrenterghem *et al.*, 2017). Due to the importance of trying to elicit a positive adaptation within players to reduce the risk of injury and to enhance performance, it is important to have a monitoring tool which can monitor both the biochemical and mechanical stresses of exercise. An alternate measure of internal load is the concept termed ratings of perceived exertion (RPE). This measure has the potential to encompass the biomechanical and mechanical stress of exercise and is a quick, valid and a non-invasive measure of an individual's internal load (Halson, 2014; Vanrenterghem *et al.*, 2017).

2.3 RATINGS OF PERCEIVED EXERTION

2.3.1 OVERVIEW AND DEFINITIONS OF RATINGS OF PERCEIVED EXERTION

Ratings of perceived exertion (RPE) are an alternative method to heart rate, blood and salivary measures to quantify the internal response to team sport training and competition (Foster *et al.*, 2001; Impellizzeri *et al.*, 2005). Borg (1962) first initiated the use of RPE in exercise in 1962 and since then it has become the most popular scale used in sport and exercise science to provide an indication of the 'demands of exercise' (Faulkner and Eston, 2008). Unlike heart rate, blood and salivary measures, which are objective measures of internal load, RPE is a subjective rating of how hard the players found a training session or competition based on the score provided using a reference scale (Foster *et al.,* 2001). The original RPE scale was a 15-grade category scale (6-20) which was designed initially for steady-state aerobic exercise on a cycle ergometer as ratings were found to increase linearly with heart rate and oxygen consumption (Borg, 1962; Pageaux, 2016). This scale has been validated against objective measures of internal load (Pageaux, 2016). The values ranging from 6 to 20 were designed to symbolize heart rates ranging from 60 to 200 beats per minute. For example, a value of 9 on the scale would equate to 90 beats per minute. However, due to the limitations of category scales, in this case the placing of the verbal anchors does not create an interval scale (Borg, 1982). For example, you cannot compare responses as a rating of 12 does not suggest it was double the intensity of a value of 6. This led to the development of the more recent CR10® scale which is a category scale but with ratio properties (Borg, 1982). This meaning that a rating of 5 on the scale represents half of the intensity of a rating of 10. This scale along with the most recent CR100® scale are discussed in greater detail below.

The original definition of perceived exertion was defined as 'the feeling of how heavy, strenuous and laborious exercise is' (Borg, 1962). Borg (1962) proposed that overall perceived exertion is a gestalt which consists of 'sensations from the organs of circulation and respiration, from the muscles, the skin, the joints and force' alongside perceptions of 'pedal resistance, effort, fatigue, strain exertion, heat, pressure, pain or anxiety'. Upon reflection, Robertson and Noble (1997) disagreed with the original definition of perceived exertion as they did not think it was reflective of all these other sensations outlined by Borg (1962). As a result of this critique, perceived exertion was then defined by Robertson and Noble (1997) as 'the subjective intensity of effort, strain, discomfort, and/or fatigue that is experienced during physical exercise'.

However, more recently, this definition of perceived exertion has been challenged due to the different constructs included (Marcora, 2010; Pageaux, 2016). The constructs of effort, strain, discomfort and fatigue all have unique definitions associated with them which can potentially affect the rating provided by the participant if they are all included. For example, discomfort is described as a 'slight pain or something that causes one to feel uncomfortable' (The Oxford Dictionary). Research has shown that humans can differentiate between sensations of effort and discomfort during exercise, which suggests that they are two separate constructs with discomfort requiring its own psychophysical scale (Pageaux, 2016). Within a practical setting, if this definition were to be utilized within team sports it would require players to combine multiple sensations aside from effort into one gestalt score. As a result of this, it will be impossible for the practitioner to determine how feelings of effort, strain and discomfort etc. contributed to this score. This would hinder the analysis of how players are coping with training and competition stress (Pageaux, 2016) which is important for training interventions and periodization. For this reason, the definition of perceived exertion, which is now deemed to be the most accurate, which only includes sensations related to effort is 'the conscious sensation of how hard, heavy, and strenuous a physical task is' (Marcora, 2010). Given the above, future studies which aim to investigate internal training loads within sports and practitioners working within the field should use this definition (Pageaux, 2016).

2.3.2 THEORETICAL MODELS OF RATINGS OF PERCEIVED EXERTION

Despite its popularity and usefulness, how RPE's are created in the brain are not completely understood. Although it is widely acknowledged that RPE's are a result of the neuronal process of the sensory signals and that there are many factors involved in this process, the exact process of the sensory signals involved remains debated

(Pageaux, 2016; Haddad *et al.*, 2017). To date, there are four theoretical models which attempt to explain how RPE's are derived. The four models which will be outlined in this section are the afferent feedback model, corollary discharge model, the combined model and the global explanatory model.

The afferent feedback model suggests that perceived exertion is a result of a complex integration of different inputs into the central nervous system (CNS) (Figure 2.2) (Marcora, 2009; Haddad *et al.*, 2017). These inputs include afferent information from cardiopulmonary (heart rate, oxygen update and respiratory/ventilatory rate) and peripheral/metabolic (blood lactate, muscle damage, core and skin temperature) regions (Hampson *et al.*, 2001). It is thought that this afferent information from the cardiopulmonary, peripheral/metabolic regions is responsible for the development of fatigue and, therefore, plays a role in changes in pacing strategies by limiting peripheral fatigue (Gabbett *et al.*, 2015; Hutchinson, 2019). The mechanism in which this happens is suggested to be down to group III and IV afferent fibres within the skeletal muscle which are responsible for projecting this peripheral afferent information via the spinal cord to the sensory cortex in the brain (Amann *et al.*, 2010). Although the exact mechanism is still unclear, this model suggests that the integration of these different inputs influences perceived exertion indirectly and unconsciously due to heart rate and blood lactate increasing with an increase in exercise intensity (Hampson *et al.*, 2001). Whilst there are studies in support of this model, they are not without limitations (Amann *et al.*, 2010; Gagnon *et al.*, 2012) due to the definition of perception of effort having either not been outlined in the methodology or including sensations other than effort (E.g. discomfort, strain and fatigue). Therefore, the conclusions which can be drawn from these studies may be limited due to the reasons associated with combining different sensations within one definition as outlined above (Pageaux, 2016). For example, when multiple sensations are combined into one global score you cannot be certain of the weightings of each of these sensations on how they contributed to this score. If a player had pain during a training session, they may provide a higher RPE which would indicate a high internal load. However, the physiological response to the external load completed may have been relatively low (Pageaux, 2016). In this scenario it would make any analysis post training session impossible to determine.

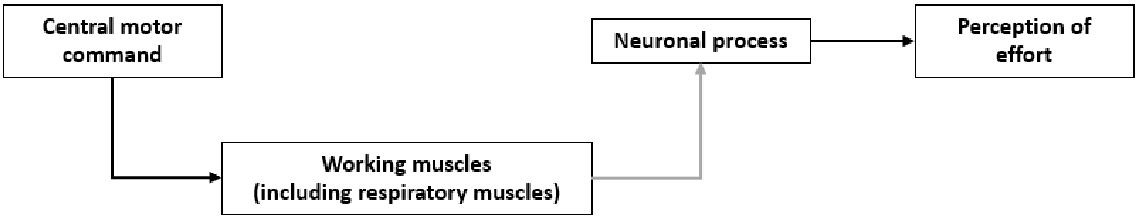

Figure 2.2. The afferent feedback model which aims to demonstrate the generation of perception of effort because of afferent feedback (grey line). Reproduced from Pageaux (2016).

In contrast to the afferent feedback model, the corollary discharge model proposes that perceived exertion is independent from any afferent feedback from the cardiopulmonary and peripheral/metabolic regions (Figure 2.3) (Hampson *et al.*, 2001; Marcora, 2009; Haddad *et al.*, 2017). This implies that afferent feedback is not responsible for generating the feeling of perceived exertion (Pageaux, 2016) but instead, it is centrally generated as a result of forwarding neuronal processes of the corollary discharge (a copy of a motor command that is sent to the muscles to produce movement) to the somatosensory areas of the cerebral cortex (Marcora, 2009). Unlike the afferent feedback model, the corollary discharge model is well accepted within research as there are numerous studies in support of this model (Pageaux, 2016). Whilst this model suggests that afferent feedback is not responsible for generating feelings of effort, it has been suggested that afferent feedback might actually be responsible for other sensations such as feelings of pain and or discomfort (Pageaux, 2016). Therefore, these two models may be responsible for generating different feelings. The afferent feedback model may be responsible for generating feelings of discomfort and the corollary discharge model feelings of perceived effort. This clarifies the importance of utilizing the correct definition within research and practice so that the different sensations are not combined as they are different constructs which potentially utilize different theoretical models.

Incorporating both the afferent feedback and the corollary discharge model produces a model called the combined model (Figure 2.4). As the name implies, this model suggests that perceived exertion is a result of a combination of both afferent feedback and corollary discharge (Abbiss *et al.*, 2015; Pageaux, 2016). Currently, this model has only been suggested theoretically with no studies currently having tested it

(Pageaux, 2016). Based on the assumptions that afferent feedback is potentially responsible for feelings of discomfort and not of that of effort, it does not seem plausible that this model is valid. This is due to the fact that when utilizing the definition of perceived exertion as 'the conscious sensation of how hard, heavy, and strenuous a physical task is' (Marcora, 2010), you do not want to include sensations of discomfort and, therefore, you potentially do not require any afferent feedback. However, further research is required to test this theory (Pageaux, 2016).

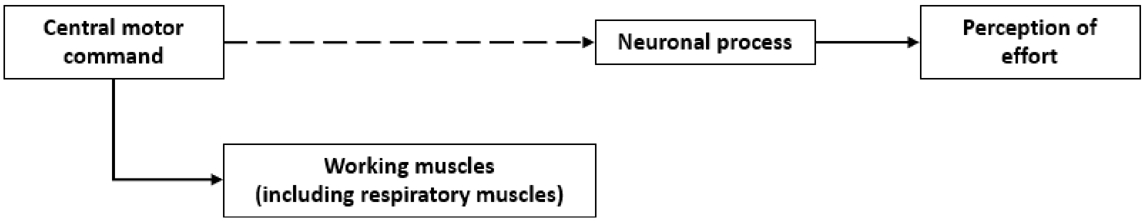

Figure 2.3. The corollary discharge model which attempts to explain that perceived exertion is due to the forwarding of neuronal processes of the corollary discharge (dotted line). Reproduced from Pageaux (2016).

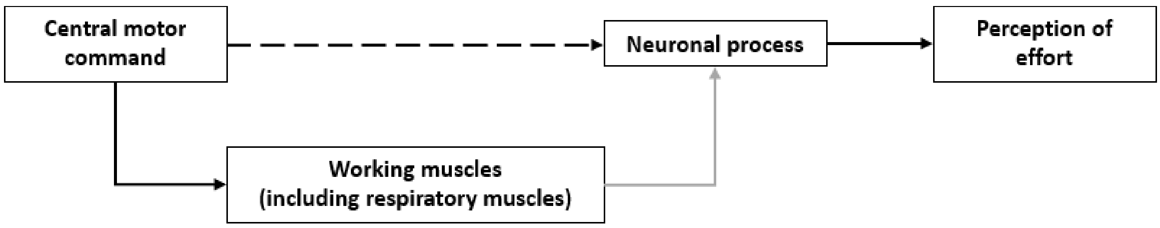

Figure 2.4. The combined model which aims to explain that the generation of perception of effort is a result of both afferent feedback and corollary discharge. Reproduced from Pageaux (2016).

The global explanatory model (Figure 2.5) is similar to the corollary discharge model as it is thought that increases in central and peripheral muscle tension (tension-producing properties of the muscle) results in a greater corollary discharge (Robertson and Noble, 1997). This physiological signal mediator is responsible for initially sculpting the intensity of the perceptual response (Robertson and Noble, 1997). Once the efferent copy of the central command is sent to the sensory cortex the signal from here enters a perceptual reference filter where it gets matched with previous events based on intensity, experiences and knowledge allowing a perceptual response to be created (Robertson and Noble, 1997; Abbiss *et al.*, 2015). For example, a player may use their previous experiences of perceived exertion from competitive matches to compare their current feelings. The difference between this model and that of the corollary discharge model is that the global explanatory model also figuratively demonstrates how psychological, performance and exertional signals are sent to the sensory cortex and subsequently used in the perceptual reference filter to moderate RPE (Robertson and Noble, 1997; Eston, 2012). Examples of psychological factors include the current mood state, motivation and fatigue levels of the athlete. Whereas, the performance milieu is defined as the competition strategy, which in team sports may be the current score line and duration of the match left. The feeling of breathlessness, muscle soreness and sweating are what this model considers examples of exertional signals.

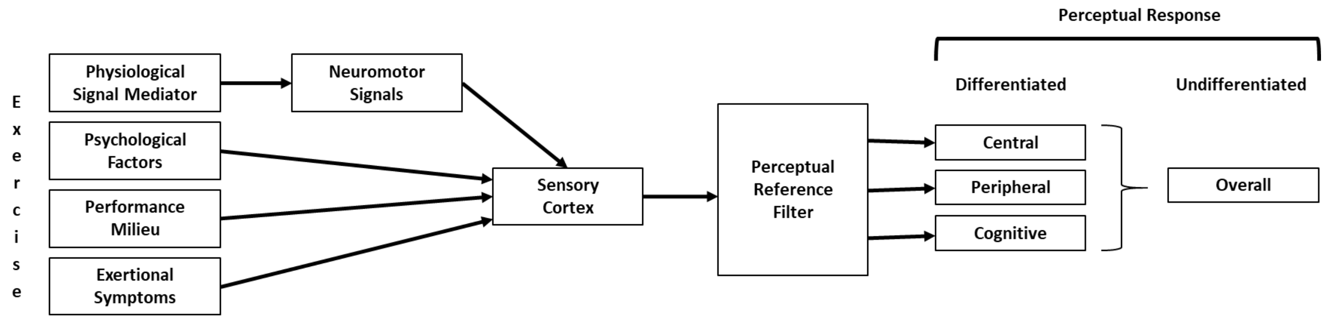

Figure 2.5. The global explanatory model of perceived exertion visualising how during exercise physiological, psychological, performance and exertional signals enter the sensory cortex and subsequently the perceptual reference filter which generates a perceptual response. Reproduced from Robertson and Noble (1997).

The theoretical models outlined above demonstrate the complexity involved in generating an RPE. However, this area is still not completely understood and agreed upon and, therefore, requires further research to establish the exact mechanism in the process of perception of effort generation (Pageaux, 2016). Although it is currently not conclusive, it is still important that practitioners are aware of the potential theoretical models which explain how players generate their effort score as it seems to be a complex process. Some individuals may find generating a RPE a challenging process due to the lack of previous experiences to compare their current feelings to, which may cause an under or over representation of perceived exertion. Not only is it important as a practitioner to understand the theoretical models, it is also key to have knowledge of how measurement and methodological considerations are key to ensure the data collected is both reliable and valid.

2.4 MEASUREMENT AND METHODOLOGICAL CONSIDERATIONS OF RATINGS OF PERCEIVED EXERTION

To ensure the validity and reliability of the measurement there are standardized instructions and methodological approaches which need to be adhered to (Impellizzeri *et al.,* 2004; Pageaux, 2016). Such methodological considerations include the familiarization of the participants to the use of the scale, the timing of RPE collection and the type of scale used (Halperin and Emanuel, 2019; Pageaux, 2016). The following two sections will proceed to outline the instructions for use, explain the importance of having valid and reliable methods within sports science monitoring and the correct methodology for the use of RPE within team sports.

2.4.1 INSTRUCTIONS FOR THE COLLECTION OF RATINGS OF PERCEIVED EXERTION

Besides the theoretical reasons, ratings of perceived exertion are a popular method to monitor internal training load within team sports since it is quick, cheap and non-invasive (Impellizzeri et al., 2004). Although the concept of collecting a subjective rating of perceived exertion from players can appear to be relatively simple as it only requires players to provide a score post training (Foster *et al.,* 2001), it does require a strict set of instructions for use to ensure the validity and reliability of the data collected (Pageaux, 2016). The standardized instructions for the use of RPE for both the practitioner and the player can be found within the literature and are outlined below (Borg, 1998; Pageaux, 2016). The literature suggests that these instructions for the player should include a definition of RPE alongside a description on how to provide a rating of effort when the scale is presented to them post training or competition (Borg, 1998; Pageaux, 2016). This description should clearly outline that the rating they are about to provide does not include any feelings of discomfort and/or pain and only that of effort (for the reasons described above, see the section 'definition of ratings of perceived exertion‘) (Borg, 1998; Pageaux, 2016) as shown in the example of the instructions which were provided to the participants in this study (Figure 2.6). Once the player has read the definition they are asked to first read the verbal expression on the scale in front of them and then to report the corresponding number according to their perception of effort (Pageaux, 2016). To avoid a ceiling effect, players can rate a value greater than maximal on the scale if they need to as what they deem as maximal for them can change over time due to fitness and/or fatigue levels. Practitioners should ensure that when collecting RPE’s from players that each player does this individually and away from everyone else so that the score is not influenced by other players perceptions and, therefore, is only representative of themselves.

Despite the literature outlining clearly how to collect RPE’s and with researchers emphasizing the importance of clear and accurate instructions when using RPE within an applied setting (Borg, 1998), these instructions are often overlooked. Diverting from these instructions will impact the validity of the data collected within team sports (Halperin and Emanuel, 2019). If these data collection protocols are not observed, the data collected will have potentially little relevance and usefulness within a practical setting. To overcome this, aside from following the standardized instructions within the literature, players should be educated on the reasons for the use of this type of monitoring tool to ensure they provide a rating which is representative of how hard they found the session and not what they think the session should have been. The players should be aware that this subjective score is collected from them to help enhance their performance and reduce the risk of injury. If players are appropriately educated, this may well allow for a true representation of how a player is coping with training and competition loads, which will aid with the prescription of future training stimuluses to enhance performance.

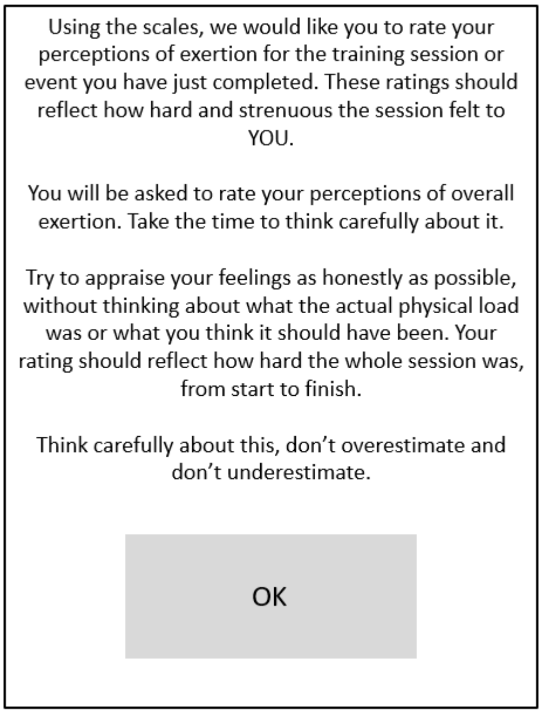

Figure 2.6. Example interface of the bespoke RPE app used in this study which displays the instructions provided to the participants before an RPE was collected.

2.4.2 METHODOLOGICAL CONSIDERATIONS OF RATINGS OF PERCEIVED EXERTION

When considering which monitoring tool to utilize within team sports it is essential to ensure that they are both valid and reliable (Currell and Jeukendrup, 2008). These two factors are not independent of each other, but, in fact, interact with each other (Currell and Jeukendrup, 2008). Validity is broadly termed 'the degree to which the test measures what it purports to measure' (Lohr, 2002) and is an umbrella term which underneath it has a number of different types of validity. There are a magnitude of different monitoring tools across team sports and such tests must be validated before using them within practice. It often requires several different studies which are in support of each other before a monitoring tool can be deemed valid and, as such, improve the quality of the literature and professional practice (Impellizzeri and Marcora, 2009). Validity research often requires different types of research design or different projects before people can be confident in the measure. When conducting research to validate a monitoring tool it is most often investigated first in a controlled setting to minimise the effect of confounding variables (Halperin *et al.*, 2015). This is known as internal validity. When a measure is deemed to be valid within a controlled setting you can then take this monitoring tool into an applied setting, such as for use within team sports (Halperin *et al.*, 2015). This is known as external validity. Whilst the validity of a test ensures that the outcome of a test is what it is intended to measure, reliability is defined as 'the consistency of measurements, or of an individual's performance, on a test' (Atkinson and Nevill, 1998). Whilst it is realistic that regardless of the test there will always be a small amount of random error, practitioners must decide what amount of systematic error is deemed acceptable when using a test (Atkinson and Nevill, 1998). A monitoring tool or test must be deemed reliable before it is deemed valid as it cannot be valid unless it has consistent measurements (Atkinson and Nevill, 1998; Lamb *et al.*, 1999).

With more than 200 RPE studies having been published between 2000 and 2008 alone, the validity and reliability of RPE has been confirmed (Faulkner and Eston, 2008). However, regardless of whether RPE has been deemed valid and reliable within the literature, if the correct methods and/or instructions for use are not followed when using it within team sports then the data collected may not be valid or reliable (Halperin and Emanuel, 2019). Therefore, it is extremely important to follow the methodologies outlined within research when looking to implement this performance monitoring tool within team sports. The first methodological consideration to ensure valid and reliable RPE data is the concept of familiarisation (Eston *et al.*, 2015). Within research, familiarisation trials tend to be performed with the aim of reducing learning effects (Hopkins, 2000). The importance of familiarising participants with the RPE scale prior to use in this case is to avoid any over or underestimated RPE's (Pageaux, 2016). The literature has outlined the correct methodological approach for familiarising participants with the RPE scale (Impellizzeri *et al.*, 2004; Pageaux, 2016). When working with team sport players, the literature suggests that players should be exposed to a range of different training intensities along a spectrum associated with their physical capacities (Impellizzeri *et al.*, 2004; Pageaux, 2016). An example protocol to do this would be to get the players to perform an incremental test as this would allow the association between RPE scores at different exercise intensities (Impellizzeri *et al.*, 2004). The concept behind this is that by familiarising participants with the RPE scale, they will be able to have a point of reference to provide their current RPE against (Impellizzeri *et al.*, 2004; Pageaux, 2016). This is based on the concept of memory-anchoring (i.e. maximal exertion related to the highest effort experienced) and exercise-anchoring (i.e. exertion experienced at exhaustion during an incremental test) (Pageaux, 2016). This approach can be related back to the global explanatory model (Figure 2.5) as the development of an expansive perceptual reference filter will develop a large 'database' for the individual to compare the current exercise stimulus to, hence, enabling a more confident evaluation of the internal training load (Robertson and Noble, 1997). If the players perceptual reference filter is small due to limited exposure to conflicting exercise intensities, then the subjective rating may be under or overrepresented of the true demand of the external load as they do not have any past feelings to relate to. Although the literature has outlined the importance, differences in familiarisation protocols are evident within the literature with some authors expressing their concern over the lack of familiarisation which has taken place (Lamb *et al.*, 1999). As the literature outlines, clear instructions should be given and the correct methodological approaches should be followed, including suitable familiarisation, when utilising RPE. However, Lamb *et al.*, (1999) has suggested that participants within studies are often deemed to having understood the RPE scale once they have been introduced to it via the set instructions but without any familiarisation. An example of the lack of familiarisation can be found during a study which looked at the timing of RPE collection post a resistance training protocol (Singh *et al.*, 2007). During this study, the participants only did one familiarisation session (Singh *et al.*, 2007), whereas, during a different study, participants taking part in a boxing study were familiarised with the RPE scale over 20 different sessions which all varied in intensity (Uchida *et al.*, 2014). Therefore, the participants in the boxing study would have a larger perceptual reference filter in which the importance of this was outlined above and the RPE's from the resistance protocol may be under or overestimated which will not be useful when attempting to periodize training.

The second methodological issue which can affect the validity of RPE is the timing of the RPE collection post exercise. Whilst there is a clear consensus that ratings of perceived exertion are collected post exercise, there is still some disagreement regarding the gold standard time at which this subjective rating should be collected. It was first suggested that RPE should be collected 30 min post exercise as this time period allows the score to be reflective of the whole session rather than the intensity of the last activity which was performed (Foster *et al.*, 2001; Impellizzeri *et al.*, 2004). Such approaches may not, however, be practically convenient (Singh *et al.*, 2007). To provide some insight into the importance of this issue Uchida *et al.*, (2014) investigated whether there were any differences in collecting RPE at different time points (10 minutes versus 30 minutes) post an Olympic boxing training routine. No statistical difference between RPE scores collected 10 minutes and 30 minutes post sessions were observed suggesting that RPE can be collected as early as 10 minutes post session without the last activity influencing the rating (Uchida *et al.*, 2014). In direct contrast to this finding Mclaren *et al.*, (2016) found a moderate to large latency effect for differential ratings of perceived (dRPE) exertion subcomponents when comparing the scores immediately after the end of maximal incremental exercise and those 30 minutes post exercise. In agreement with Mclaren *et al.*, (2016), Singh *et al.*, (2007) also found a significant difference between RPE collected within the first 10 minutes of completing a resistance programme and 30 minutes after. Methodological differences, such as the use of different collection time points, exercise modes and different familiarisation protocols between these studies, may explain the differences observed in the outcome. Overall, as a result of these initial studies, further research is required which investigates a larger range of time points post exercise using different exercise modes before the optimum timing of RPE collecting can be established. However, it seems plausible that if you want to gain an understanding of the internal load to specific drills then RPE's can be collected immediately after the specific drill has finished. This would then be reflective of that drill. Until further research has been conducted, to gain an understanding of the internal response to the whole training session these measures should be collected 30 minutes post termination of exercise (McLaren *et al.,* 2016).

The third methodological issue to be mindful of when utilising the use of RPE as a method to monitor internal load is the type of scale used. There are numerous scales reported within the literature but typically, when studies are investigating perceived exertion, the Borg scale is most commonly used. Although studies have reported that they have used the Borg scale, it is fairly common to see modifications to it (Halperin and Emanuel, 2019). Examples of such modifications observed have been alterations to the scale, verbal anchors and user instructions (Halperin and Emanuel, 2019). However, these modifications can have serious consequences on the accuracy of the data collected as RPE was validated using a specific scale and any alterations to this scale can affect the validity and reliability of the data collected as the modified scales have not been validated within the literature. One such modification is the exclusion of a dot (•) on the CR10® scale. This dot represents that although the number 10 on the scale refers to 'extremely strong' participants can rate higher than this if they perceive the exercise bout to be higher and, in fact, 'absolute maximum' (Halperin and Emanuel, 2019). Without the inclusion of the dot (•) and the correct instructions, participants may deem 'extremely strong' to be the highest value they can provide and as a result of this you would get a ceiling effect. The inclusion of the dot (•) provides players the opportunity to rate higher if they deem it to be and this ensures that the internal response is never underestimated allowing for a true representation of the load.

Within team sports the sRPE method has most commonly been measured using the CR10® scale (Figure 2.7). The CR10® scale is a category ratio scale meaning that participants provide a perceived exertion score based off the verbal anchors on the numeric ratio scale (Borg, 2007). The popularity of this scale is most likely due to the vast amount of research investigating its validity and reliability and its simplicity (Borg, 2007). However, more recently a new centiMax scale has been proposed (Borg and Borg, 2002). This centiMax scale is known as the CR100® scale and its design was to allow for a more finely graded scale which athletes could use to rate their perceived exertion (Figure 2.7) (Borg and Kaijser, 2006; Scott *et al.*, 2013). The CR100® scale is still a category ratio scale which has verbal anchors placed at whole numbers on the scale (Borg and Borg, 2002). However, as this scale has numerical values from 0 to 100 arbitrary units (AU) it has an advantage of less clustering around verbal anchors (Figure 2.7) compared to the CR10® scale. In support of this, when investigating the percentage of RPE values reported which were positioned at the same location as the verbal anchors, Borg and Kaijser, (2006) and Fanchini *et al.*, (2016) found a higher percentage when using the CR10® scale (37% and 49% respectively) compared to 25% and 26% when using the CR100® scale. This suggests that the CR100® scale could provide a more sensitive measure of internal load during team sport training (Fanchini *et al.*, 2016). Recently, this scale has been validated for use as a monitoring tool in Australian rules football (Scott *et al.*, 2013) and top-level soccer players (Fanchini *et al.*, 2016).

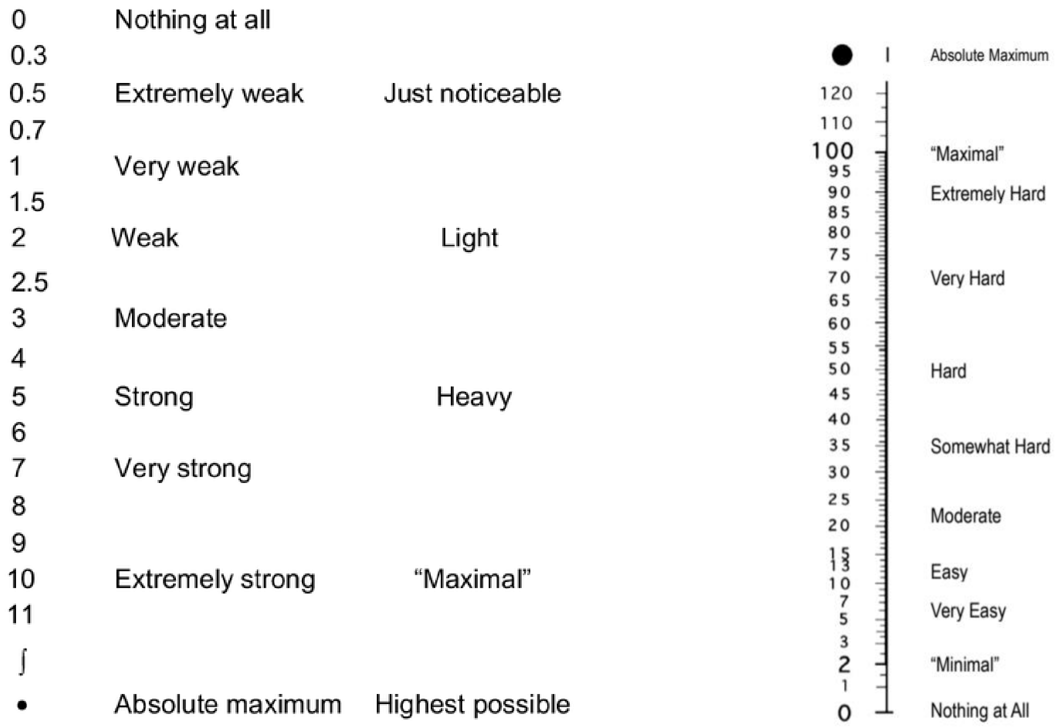

Figure 2.7. Borg's CR10® and CR100® scale shown retrospectively.

2.5 THE APPLICATION OF RATINGS OF PERCEIVED EXERTION IN TEAM SPORTS

Ratings of perceived exertion can be applied in team sports to determine training load using a method first developed by Foster *et al.*, (2001). This method is known as session ratings of perceived exertion (sRPE) and is representative of the volume and intensity of the whole training session or competition (Foster *et al.*, 2001; Impellizzeri *et al.*, 2004; Haddad *et al.*, 2017). Session ratings of perceived exertion are collected in the same way as RPE's by ensuring that the standardized instructions and methodological considerations are adhered to but the score provided by the players is now multiplied by the session duration to produce a single arbitrary number (AU) (Foster *et al.,* 2001). This method is an effective and popular tool in quantifying and managing individual training load in team sports with 95% of sports scientists working in the English Rugby Union Premier league agreeing with this (West *et al.*, 2019). The sRPE method is useful as it allows practitioners to monitor the internal response to single training sessions or competitions or it can be used for longitudinal analysis. Both of which will aid with training load periodization resulting in an increased performance and a decrease in injury risk (Lockie *et al.*, 2012; Haddad *et al.*, 2017). Studies have supported its use by demonstrating that sRPE is a valid method in quantifying training load in team sports such as Australian rules football (Scott *et al.*, 2013), soccer (Impellizzeri *et al.*, 2004; Alexiou and Coutts, 2008) and basketball (Foster *et al.*, 2001).

Session ratings of perceived exertion represents a global indicator of how hard players found the training session or competition (Casamichana *et al.*, 2013). However, training load within team sports is predominately pre-planned by external load metrics and, as such, you only know the internal response to the external load after the session has been completed. Therefore, when utilizing RPE as a monitoring tool within team sports it is important to understand the factors, such as external load, which may have influenced the RPE generated (Gallo *et al.*, 2015; Gaudino *et al.*, 2015). This knowledge has the potential then to help with the prescription of these pre-planned loads. Research has investigated the factors impacting sRPE in semi-professional soccer (Casamichana *et al.*, 2013), elite soccer (Gaudino *et al.*, 2015), Australian football (Gallo *et al.*, 2015) and rugby league (Lovell *et al.*, 2013). In semi-professional soccer sRPE was largely correlated with total distance ($r = 0.74$) and player load ($r = 0.76$) (Casamichana *et al.*, 2013). Alternatively, high-speed running ($r = 0.114$) and the number of impacts ($r = 0.45$) and accelerations ($r = 0.37$) best predicted sRPE during elite soccer training (Gaudino *et al.*, 2015). In elite rugby it was total distance and high-speed running which had a very large ($r = 0.82$) and large ($r = 0.62$) correlations respectively with sRPE (Lovell *et al.*, 2013). Similarly, in Australian football there was a very large ($r = 0.88$) correlation in total distance with sRPE but also a very large correlation with player load (Gallo *et al.*, 2015). The differences observed may be due to the sport, differences in training modalities or the use of different RPE scales and methodologies (Lovell *et al.*, 2013). However, there seems to be a consensus that a combination of different external load metrics such as total distance, high-speed running and player load bests predicts sRPE rather than one individual measure alone (Lovell *et al.*, 2013; Gaudino *et al.*, 2015).

Whilst this knowledge is useful, there is a considerable amount of evidence which suggests that the internal response to training is multifactorial (Borg, 2007) and not just a result of the external load performed. One such factor which influences a player's global RPE which needs to be taken into consideration is the individuals inherent characteristics (Bouchard and Rankinen, 2001; Impellizzeri *et al.*, 2005; Gil-Rey *et al.*, 2015b). The above studies investigated the average response across the teams to the external load performed but this failed to take into consideration how each player responded. When working within team sports, each player needs to be treated as an individual to ensure that their performance is maximised. As such, prescribing training loads based purely off the external loads may cause a training imbalance for some players as different players will respond differently to the exercise perfromed (Gallo *et al.*, 2015). However, one of the challenges of team sport training is that the majority of the time the players will be training together in order to work on the tactical and technical aspects of the game. This makes prescribing team training based on each of the inviduals internal physiological measures extremelly challenging (Gallo *et al.*, 2015). Therefore, combining the external load with a knowledge of the individual characteristics (e.g. age, fitness levels, position, genetic background) when planning training sessions will assist with achieving the desired goals (Gallo *et al.*, 2015). In conclusion, sRPE might be somewhat limited due to the generation of RPE's involving the complex integration of so many different factors.

2.6 THEORETICAL LIMITATIONS OF THE USE OF RATINGS OF PERCEIVED EXERTION IN TEAM SPORTS

Theoretical limitations do exist with sRPE. Firstly, there are the practical issues of ensuring that the data collection is accurate and valid as outlined above. Secondly, sRPE may be theoretically limited by its approach in combining a variety of inputs into one gestalt score. The gestalt framework in which a combination of a multitude of physiological and psychological sensations are combined to produce one score is potentially not sufficient enough to represent the range of perceptual signals athletes experience during training and matches (Hutchinson and Tenenbaum, 2006). For example, Weston, (2013) identified that RPE's remained fairly stable and, as such, lacked sensitivity during competitive soccer matches when the external loads varied considerably. To support this statement a study in youth soccer players found that during matches RPE's remained stable in U14 (8.4 ± 0.2), U16 (8.5 ± 0.4) and U18 (8.4 ± 0.6) age groups (Wrigley *et al.*, 2012). With RPE's being fairly consistent across different matches Gregson *et al.*, (2010) investigated between match variability of high-speed activity in soccer. It was found that there was a high coefficient of variation (16-30%) in high speed activities between matches. With such a large difference in these activities between matches this suggests that players do not consistently produce the same activity profile each match. There can be a number of reasons for this large discrepancy such as playing formation, possession of the ball and score line. The fact that RPE's have been found to remain stable during competitive matches suggests that even though there is a large difference in high speed running activities (external load) there may be other factors apart from the physiological signals which are affecting the production of an RPE at the end of the match (Figure 2.5) (Robertson and Noble, 1997). As a consequence of this the breakdown of what specific demands experienced by the athlete and how they contribute to this one score is impossible to determine.

The lack of specific information on the demands of training and competitions when providing a global RPE prevents such data fully assisting with the prescription of training loads and recovery for individual players (Weston, 2013). To overcome this limitation recent advances in monitoring have led to the development of a differential rating of perceived exertion (dRPE). Differential ratings of perceived exertion represent the psychophysiological signals independently which has the potential to provide a more sensitive evaluation of the biochemical and mechanical stress (Weston, 2013; Vanrenterghem *et al.*, 2017). This construct is best represented in Figure 2.5 where the differentiated perceptual response to the right-hand side of the model is split into central, peripheral and cognitive signals (Robertson and Noble, 1997).

2.7 DIFFERENTIAL RATINGS OF PERCEIVED EXERTION

2.7.1 OVERVIEW

The concept of differential ratings of perceived exertion (dRPE) is not novel (Pandolf and Noble, 1973; Pandolf *et al.*, 1975; Seip *et al.*, 1991; Robertson and Noble, 1997; Faulkner and Eston, 2007). However, it has been only relatively recently that research in dRPE has been investigated in an applied team sport setting. In this next chapter, the literature review will explore the earlier laboratory studies investigating dRPE and provide a rationale as to why utilizing dRPE as a monitoring tool may be important in team sports and, as such, warrants further investigation. This section will conclude with a summary and the aims of the current study.

The theoretical model of dRPE suggests that separate perceptual signals (central, peripheral and technical) are associated to specific physiological events (Robertson and Noble, 1997). Therefore, dRPE has the potential to provide a more sensitive evaluation of the internal load by having separate ratings for the subcomponents of

RPE related to the specific underlying physiological responses (Bolgar *et al.,* 2010). Differential ratings of perceived exertion are collected with the same methodological considerations as RPE's although now, players are instructed to provide separate ratings for feelings of legs or upper body muscle exertion, feeling of breathlessness and a cognitive or technical demand. These differing events may cause a player to experience different feelings based on each perceptual signal. For example, during exercise the peripheral perceptual signals are a result of the movement of muscles and joints, which can be localized for either the legs (RPE_L) or upper body (RPE_U) dependent on the exercise mode (Bolgar *et al.*, 2010). The peripheral signal is thought to be driven by changes in physiological conditions, such as metabolic acidosis, availability of energy substrate and blood flow (Robertson and Noble, 1997). Central exertional signals driven by an increase in ventilation and oxygen uptake (Robertson and Noble, 1997) are rated on how hard the exercise mode feels on the individual's perception of heart rate and feeling of breathlessness (RPE_B) during the exercise bout. Recent research in team sports has also investigated a technical or cognitive (RPE_T) demand during training and competitive matches (Weston, Siegler, Bahnert, Mcbrien, *et al.*, 2015; Mclaren, Smith, *et al.*, 2017). This cognitive exertional signal has the potential to provide information as feedback to the coaches on the understanding of the players during skill-based training and its application on match day in team sports (Weston, Siegler, Bahnert, Mcbrien, *et al.*, 2015). Overall, the greater depth of information gained from having individual ratings for each of the subcomponents outlined above has the potential to help practitioners two-fold. Firstly, it will assist practitioners in a greater understanding of an individual's internal load response to the prescribed training loads. Secondly, this information will help assess whether the aims of the session were met, which will assist with future periodization of training and recovery loads.

2.7.2 DRPE PROOF OF CONCEPT STUDIES

Differential ratings of perceived exertion provide an opportunity to understand an individual's subjective interpretation of the exercise stress by indicating which signal was more intense than another during a given task (Robertson and Noble, 1997; Bolgar *et al.*, 2010). When one signal, whether this is peripheral, central or technical, is rated higher than another it is termed as perceptual signal dominance (Robertson and Noble, 1997; Bolgar *et al.*, 2010). However, it may also be possible that during certain training typologies that the peripheral, central and technical demands of the session were equal and, as such, no dominant signal was present. The concept of differential ratings of perceived exertion was initially investigated within a laboratory where perceptual signal dominance can vary dependent on training experience and exercise mode. Research has shown peripheral signal dominance (RPE_L) during cycle ergometer protocols in male university soccer players (Mclaren *et al.*, 2016), male recreationally active college students (Robertson *et al.*, 1979), in sedentary males (Pandolf *et al.*, 1975), in trained females at high cycling intensities (Bolgar *et al.*, 2010) and in both males and females with high and low fitness levels (Faulkner and Eston, 2007). However, perceptual signal dominance is not as apparent in treadmill-based exercise as it is in cycling. A study investigating the sensitivity of dRPE as a measure of internal load during a maximal incremental treadmill protocol found that male university soccer players rated the central perceptual signal higher than the peripheral signal post protocol suggesting a central signal dominance (Mclaren *et al.*, 2016). Conversely, in trained and recreationally active women there was not a significant difference between any of the dRPE components after completing a modified Bruce protocol (Bolgar *et al.*, 2010) and, as such, no signal dominance was highlighted. The findings of Bolgar *et al.*, (2010) are in agreement with Seip *et al.*, (1991) and Rutkowski *et al.*, (2004) who did not report any perceptual signal dominance during a treadmill walk/run test in both habitual and sedentary male runners and 10-year old children suggesting that it was equally demanding for all components of RPE. The differences observed between cycling and treadmill running might be due to the fact that as running is a weight baring exercise, whereas cycling is a non-weight baring exercise, running utilizes more muscle mass than cycling (Millet *et al.*, 2009). Therefore, participants may find treadmill running harder on the whole body sensory integration process (Bolgar *et al.*, 2010) making it equally demanding on both the peripheral and central signals compared to cycling which seems to be dominated by lower body muscular demands.

The above laboratory-based studies provide a proof of concept to support the use of dRPE as it demonstrates that dRPE is sensitive enough to detect changes in perceptual demands between different exercise modes and intensities. As the internal response to external loads is very individualised based on the participants inherent characteristics (age, fitness levels, genetic background (Bouchard and Rankinen, 2001; Impellizzeri *et al.*, 2005; Gil-Rey *et al.*, 2015a), the use of dRPE can be extremely valuable in providing information on how individuals are responding. For example, during a 4x4 small-sided game in soccer the percentage of maximum heart rate for the players was 87.9 ± 4.6 which demonstrates the variability in individuals heart rate during a training drill (Impellizzeri *et al.*, 2005). If a global RPE was collected, then practitioners would not understand how the psychophysiological signals were constructed for different exercise modes and intensities. Despite this proof of concept model there are notable differences between the external loads elicited from these protocols and the external loads of team sport training and matches, which is where further research is needed to understand the usefulness of dRPE within team sports. It has been suggested that the physical demands of team sports are hard to reproduce within a laboratory (Lakomy and Haydon, 2004). The team sports of interest in this study are running based activities with multiple elements of performance such as accelerating, slowing down and cutting (Lakomy and Haydon, 2004). The increase in eccentric muscular demands during change of direction and decelerating activities may have the potential to increase the peripheral perceptual signal as opposed to linear running on a treadmill.

2.8 THE APPLICATION OF DRPE IN TEAM SPORTS

2.8.1 THE RATIONALE FOR THE USE OF DRPE IN TEAM SPORTS

One of the original rationales to investigate the use of dRPE as a means of monitoring internal load in team sports was due to the earlier observations that RPE's remained stable during competitive matches (Weston, 2013) but with a large disparity in external load. Coefficients of variation (CV) of 5-10% in sRPE have been reported between matches (Weston *et al.*, 2015; McLaren *et al.*, 2016) and in youth soccer players RPE's have been reported at U14 (8.4 ± 0.2), U16 (8.5 ± 0.4) and U18 (8.4 ± 0.6) age groups to be substantially similar (Wrigley *et al.*, 2012). However, despite RPE remaining relatively consistent across competitive matches a large CV of 16-32% in high speed running and a CV of 19-58% in sprinting during matches have been reported (Gregson *et al.*, 2010; McLaren *et al.*, 2016). One suggestion for the fact that the measure of internal load (RPE) may not be providing a true representation of the physiological stress imposed on the athletes under differing external loads is that a global score of RPE is potentially masking the weighting of what else contributes to this internal load

(Robertson and Noble, 1997). Such contributors include psychological factors, peripheral and central signals, performance milieu and exertional symptoms (Robertson and Noble, 1997). Therefore, it can be assumed that the weighting of the psychophysiological signals (signal dominance) alters between matches but this is unclear when only collecting one global measure of perceived exertion. For example, psychological and performance factors, such as losing to a team which is at the top of the league, may present a higher cognitive load than when a team is winning comfortably (Barrett et al., 2018). Or a soccer player within a team who has spent the majority of time out of possession may have a greater awareness of heavy breathing due to having to spend a large proportion of the match tracking back and defending. As such, Weston, (2013) identified that it would potentially be of a greater value to monitor the central, peripheral and tactical demands of match play separately in team sports instead of collecting one gestalt score. Therefore, based on the theories of the original rationale there is currently a need to investigate the use of dRPE within team sports as relatively little has been researched so far in this area of monitoring.

2.8.2 THE APPLICATION OF DRPE TO COMPETITIVE TEAM SPORT MATCHES

To date, studies have investigated the application of dRPE within team sports during competitive matches (Yanci *et al.*, 2014; Weston *et al.*, 2015; Los Arcos *et al.*, 2016; Zurutuza *et al.*, 2017), different training modalities (Los Arcos *et al.*, 2013; Gil-Rey *et al.*, 2015b; Mclaren *et al.*, 2017; McLaren *et al.*, 2018) and the influence of playing duration (Los Arcos *et al.*, 2014b) and position (Barrett *et al.*, 2018; Birdsey *et al.*, 2019) on players dRPE. One of the first studies to be conducted was by Weston *et al.*, (2015) who investigated the dRPE response to Australian Football League matches. Differences between RPE_L (91.5 AU ± 9.8 AU) and RPE_B (89.0 AU ± 11.0 AU) were found to be substantial (*likely* small - 3.5% ± 1.5%). Muscular (RPE_L), breathlessness (RPE_B) and technical/cognitive (RPE_T) ratings of perceived exertion combined explained 76% of the total variance in an overall global RPE score for the whole match. In agreement with this study, Yanci *et al* (2014) also observed significantly higher ($p = 0.000$) RPE_L (6.9 AU ± 1.3 AU) scores compared to RPE_B (6.6 AU ± 1.1 AU) when players completed a full competitive soccer match. These two studies suggest that the peripheral and central demands of team sport competition are perceived differently (Mclaren *et al.*, 2017), which provides a unique insight into the perceptual demands which would otherwise be combined into one global score.

Research also suggests that duration played may have an effect on the different perceptual demands of competition. Los Arcos *et al.*, (2014) found that professional soccer players who played greater than 70 minutes rated RPE_L (~7.4 AU) significantly higher ($p \leq 0.05$) than RPE_B (~6.4 AU), which is in agreement with the two studies above. However, for the soccer players who played between 20 and 45 minutes RPE_L (~4.3 AU) and RPE_B (~4.7 AU) were very similar and for players who played less than 20 minutes RPE_L (~3.3 AU) was significantly lower ($p < 0.01$) than RPE_B (~4.4 AU). This unique insight into the effect of duration on dRPE can assist with the prescription of 'top up' sessions for substitutions. For example, if a player has played for less than 20 minutes the Sports Scientist may look to increase the muscular demand of a training session post-match to try and provide a similar stimulus to that of a full match. Interestingly, research has also investigated the differences in dRPE when playing against teams in varying league table positions (Barrett *et al.*, 2018). Substantial changes in RPE_L and RPE_T compared to RPE_B have been reported during matches played against teams placed at the top of the league compared to the middle and bottom. However, the result of the match and whether the match was played at home or away did not provide any substantial differences in dRPE (Barrett *et al.*, 2018). These studies provide a novel insight into the peripheral, central and technical demands of team sports which may else be disguised by a global RPE score.

Aside from research suggesting that the perceptual demands of team sports are unique, which can also be affected by playing duration and the quality of the opposition, there are some studies which suggests that the perceptual demands of team sports are equal. A study on forty young professional soccer players playing in a first-division Spanish league between 2011 to 2013 found trivial differences (ES = –0.17 ± 0.63, unclear 17/39/46) between sRPE_L and sRPE_B for players playing an entire match (> 90 minutes) (Los Arcos *et al.*, 2016). Agreeing with this study, Zurutuza *et al.*, (2017) found no difference between RPE_L (6.8 AU ± 1.3 AU) and RPE_B (6.5 AU ± 1.2 AU) during soccer matches in semi-professional soccer players. Although it could be argued that in this case dRPE adds no additional information to the fact that the peripheral and cognitive demands were equal, in itself is useful information as this can assist with periodizing the week in the lead up to competition which would otherwise remain unknown if a global RPE was collected. On the other hand, in the

Los Arcos *et al*., (2016) study there were large between-match variabilities of 18.2% ± 6.2% and 19.4% ± 9.3% for RPE_B and RPE_L scores respectively for players who played 90 minutes. This demonstrates the high variability of dRPE during matches as a result of the variable external loads (Gregson *et al.*, 2010; McLaren *et al.*, 2016), which suggests that during some matches and on an individual level there may have been instances where there was a signal dominance.

2.8.3 THE INFLUENCE OF PLAYING POSITION DURING COMPETITIVE MATCHES

It is well documented that positional differences in external loads exist in team sports and, as such, you may expect the internal load to differ positionally as a result of the work completed. To date, only two studies have been published investigating the differences in dRPE between playing positions. One study in competitive netball matches (Birdsey *et al.*, 2019) and one in competitive soccer matches (Barrett *et al.*, 2018). International netball players who played in mid-court positions rated sRPE, RPE_L, RPE_B, RPE_U (upper body muscular exertion) and RPE_T higher than those players playing in goal-based positions (Birdsey *et al.*, 2019). This is in support of the external demands of these positions as it has been reported that mid-court positions have a greater player load per minute (instantaneous acceleration in three planes of movement) than goal-based positions (Young *et al.*, 2016) and these positions spend the most time being active during matches compared to goal keepers and goal shooters (Chandler *et al.*, 2014). In netball the differences between the external loads and, as such, the internal load is most likely due to the positional restraints which exist in this sport. For example, goal shooters and goal keepers are only allowed in their own attacking/defensive thirds respectively but mid-court positions (excluding the centre) are allowed in the centre third and the attacking/defensive thirds and, therefore, have the opportunity to cover greater distance and are involved in both attacking and defending aspects of the game. During professional soccer matches full backs rated RPE_L, RPE_B and RPE_T substantially higher than all other positions and central midfielders rated RPE_L higher than attackers (Barrett *et al.*, 2018). This is potentially down to the fact that full backs have been reported to cover the greatest percentage of high intensity running in relation to total distance covered with the shortest recovery duration between these actions (Carling *et al.*, 2012). This information provides further support in the usefulness of dRPE as it is sensitive enough to identify differences in perceptual demands. Identifying the different internal loads associated with different positions can further assist with the prescription of training and recovery loads to ensure that each individual is prepared for their positional demands.

2.8.4 THE APPLICATION OF DRPE TO TEAM SPORT TRAINING

Team sport training consists of different training typologies to produce the desired tactical, technical, and physiological response in preparation for competition. These training typologies will have specific physiological demands associated with them dependent on the desired outcome of the training session and, as such, it might be expected that the different types of training sessions may elicit different dRPE responses. Weekly training loads during rugby union pre-season training were found to be likely moderate (10.1%; ±8.4%) between sRPE_B (18413 ± 2632 AU) and sRPE_L (20560 ± 1778 AU) (McLaren *et al.*, 2018). There were also differences in sRPE_L and sRPE_B during training in young soccer players with sRPE_L being rated higher (Gil-Rey *et al.*, 2015b). During professional youth soccer training at a Spanish club, strength training which involved vertical and horizontal orientated exercises combined with technical and tactical training were rated harder ($p < 0.01$) for RPE_L and RPE_B than other types of training (endurance/technical/tactical and technical/tactical) (Los Arcos *et al.*, 2013). In support of this a difference in dRPE between training typologies was also found during professional rugby union training (Mclaren *et al.*, 2017). These studies demonstrate that different training sessions elicit different perceptual demands as reported by the players (McLaren *et al*., 2017) and, as such, providing detailed information around the demands of each training session or individual drills.

Not all research has found a signal dominance in dRPE during team sport training. No substantial difference between RPE_L and RPE_B were found during soccer training in session derived training loads (sRPE_L and sRPE_B) (Los Arcos *et al.*, 2013, 2014a, 2017), weekly soccer training loads as a percentage of a match (Zurutuza *et al.*, 2017) or weekly training loads during the off-season in rugby union (McLaren *et al.*, 2018). Whilst some training sessions might elicit equal peripheral and central demands, differences between these two signals may not have been observed in the studies investigating session derived training loads (sRPE_L and sRPE_B) as these loads were accumulated and analyzed over weekly blocks. This type of analysis has the potential to mask specific individual training sessions in which a difference in peripheral and central responses may have been observed due to the physiological demands of the different training typologies you would expect to have been completed in the week leading to competition (McLaren *et al.*, 2018).

Although these studies demonstrate that dRPE has the ability to provide a more sensitive evaluation of an individual's internal load, further proof of concept research is required. As mentioned previously, for a monitoring tool to be deemed valid and reliable it requires different types of research design before confidence in this measure can be confirmed (Halperin *et al.*, 2015). Initial studies were conducted within a controlled laboratory environment but for the reasons stated above these studies had their limitations as to the application to team sports. However, the studies outlined above have taken the concept of dRPE straight from a controlled setting where the exercise mode was either a treadmill or a cycle ergometer and used it within an applied setting. It could be argued that a proof of concept study which investigates the use of dRPE during team specific movements has not been conducted. Therefore, this study looks to bridge the gap between the laboratory studies and the applied studies to provide further insight into the usefulness of dRPE as a monitoring tool in team sports.

2.9 PROTOCOL DESIGN

The activity profile which typifies team sports has shown that the number of decelerations performed within match activity are greater than that of accelerations in soccer, rugby sevens and rugby union (Harper and Kiely, 2018; Harper *et al.,* 2019). Within soccer decelerations have been shown to occur 2.9 times more frequently than accelerations (de Hoyo *et al.,* 2016). Very high intensity decelerations (> -3.5 m/s^2) have been reported in American football, rugby sevens, rugby union and soccer (Harper *et al.,* 2019) as a result of rapidly slowing down over a short distance (Harper and Kiely, 2018). The frequency and magnitude of these decelerations requires powerful eccentric contractions which leads to mechanical stress on the musculoskeletal system (Vanrenterghem *et al.,* 2017). It has been suggested that high intensity decelerations can act as mediators in inducing both neuromuscular fatigue and tissue damage (Harper and Kiely, 2018) which has the potential to increase the risk of training load induced injuries (Halson, 2014; Vanrenterghem *et al.,* 2017).

Therefore, it seems appropriate that the load induced from decelerations should be monitored.

As previously outlined, dRPE has the potential to monitor the subjective internal response to different subcomponents of RPE. One of these being a lower body muscular load (RPE_L). Due to the seemingly importance of monitoring mechanical load as described above this study attempted to assess the sensitivity of dRPE to detect changes in exercise protocols which manipulated deceleration distances by focusing on RPE_L and RPE_B. The protocol was designed to replicate the demands of team sports within a controlled environment. The protocol consisted of 20 repetitions of a 30 metre acceleration with either a five metre or 15 metre deceleration. A five metre deceleration was included to elicit the greatest eccentric contractions as this produced similar peak deceleration values reported as very high intensity decelerations within the literature (> -3.5 m/s^2) (Harper *et al.,* 2019). This distance also best reflects the deceleration distance covdered in team sports (Lakomy and Haydon, 2004; Howatson and Milak, 2009). Decelerating over 5 metres during twenty repetitions equates to 100 metres of high intensity decelerating distance. This is in line with deceleration distances reported within soccer matches where a range of 103 to 225 metres have been reported (Akenhead *et al.,* 2013). In an attempt to have a protocol which required less intense eccentric contractions a 15 metre deceleration was also included. An acceleration distance of 30 metres was chosen as this is similar to sprinting distance observed in team sports (Lakomy and Haydon, 2004; Howatson and Milak, 2009).

To objectively describe the requirements of each of the protocols, global positioning systems (GPS) were used as they have been shown to be a valid and reliable method to quantify high intensity accelerations and decelerations (Harper *et al.,* 2019; Vanrenterghem *et al.,* 2017). The ability to objectively describe the protocols ensures that the manipulation of the deceleration distances (independent variable) could be assessed. Performance tests such as jump tests have been used in previous research to assess neuromuscular function after team sport match play (Castillo *et al.,* 2017). Whilst vertical jump tests have been used most commonly as a measure of neuromuscular function, other jump tests do exist such as the horizontal jump which is also known as the broad jump. Due to the nature of the protocol used in this study, to assess neuromuscular function a horizontal jump was used. The rationale for using this type of performance test was due to that fact that acceleration and deceleration-based protocols require strength in the horizontal axis (Yanci *et al.,* 2014) so it seems logical to assess neuromuscular function during a horizontal jump which utilizes the same muscle group as when performing the exercise (Castillo *et al.,* 2017). This is because these muscles are more likely to fatigue than those used in vertical movements.

CHAPTER 3

METHODS

3.1 RESEARCH APPROACH

In an attempt to evaluate the sensitivity of dRPE as a tool to monitor internal load in team sports the ability of dRPE to detect changes in the physiological demands associated with different deceleration profiles in high-intensity running protocols was assessed. The research question was operationalised by the design of exercise protocols which attempted to increase the 'muscular load' (RPE_L) associated with the exercise task by changing the extent of the deceleration distances in each protocol.

3.2 PARTICIPANTS

Sixteen male team sport players (age: 19 ± 2 y; stature: 1.81 ± 0.07 m; body mass: 77 ± 9 kg) were recruited for this study. Three participants were removed from analysis as they did not complete all the protocols meaning that 13 participants completed everything . All participants were healthy and free from injury at the time of the study and were currently training three times a week and competing one to two times a week in competitive regional football and field hockey matches. Prior to any data collection the participants were provided with an information sheet that provided the details of the study design. The participants had the opportunity to ask any questions before giving written consent and were instructed that they were free to withdraw at any point. The study had been granted ethical approval via local University Ethics Committee in accordance with the Declaration of Helsinki. The participants were asked to refrain from any physical activity 24 hours before completing the protocols and 48 hours post protocol. Outside of this time the participants were asked to keep a training diary which was submitted after each training session. Participants filled out the training diary to include data on the type and duration of the activity completed and to provide a numerical value on the CR100® scale for each of the dRPE components (RPE_L and RPE_B) associated with this exercise. This information was logged in an Excel spreadsheet (Microsoft Excel 2016, Microsoft Corp, Redmond, USA) for further analysis.

3.3 EXPERIMENTAL DESIGN

Sixteen team sport players were randomised into one of four groups; the order of the protocols to be completed were counterbalanced using the Latin square design. The experimental design of the study involved the participants completing a familiarisation trial followed by the four different protocols. All of the protocols apart from the familiarisation trial consisted of twenty reps of a 30 metre sprint with either 20 repetitions of a five metre deceleration zone (Dec5m), a 15 metre deceleration zone (Dec15m) or a protocol which involved alternating the deceleration zones between the five metre and 15 metre zones (ten repetitions of each deceleration in total). One of the alternating protocols started with a five metre deceleration which was followed by a 15 metre deceleration on the next repetition (Dec5/15m) and the other alternating protocol started with a 15 metre deceleration and was then followed by a five metre deceleration (Dec15/5m). The familiarisation trial consisted of 10 repetitions of a 20 metre acceleration followed by a 10 metre deceleration. Figure 3.1 illustrates these protocols figuratively. Each participant completed the five trials over five visits with each trial separated by one week. Testing took place at the same time of the day and the same day of the week each week and was conducted on the same sand dressed artificial grass pitch. Differential ratings of perceived exertion for leg muscle exertion (RPE_L) and breathlessness (RPE_B) were recorded after every rep during all the protocols to investigate the subjective internal load associated with the exercise bout. In addition to dRPE the external load of the protocols was measured using 10 Hz GPS devices (Optimeye S5, Firmware 7.38, Catapult Sports, Melbourne, Australia). This data was collected in an attempt to objectively describe the requirements of each protocol. This enabled an evaluation of the independent variables (i.e. deceleration demands) as well providing confirmation of the control of other important exercise descriptors (e.g. volume and intensity). Neuromuscular function was also monitored pre, at the mid-point and at the end of the protocol using a horizontal jump in an attempt to examine the impact of each exercise protocol on performance. Muscle soreness was assessed using a subjective wellness questionnaire where the participants rated their muscle soreness pre, post, 24 hours and 48 hours post protocol using a 5-point Likert Scale. Both neuromuscular function and muscle soreness provided data on the overall physiological consequences of completing the protocols thereby providing additional information for the evaluation of the usefulness of dRPE. The timings of these measures can be seen in Figure 3.2.

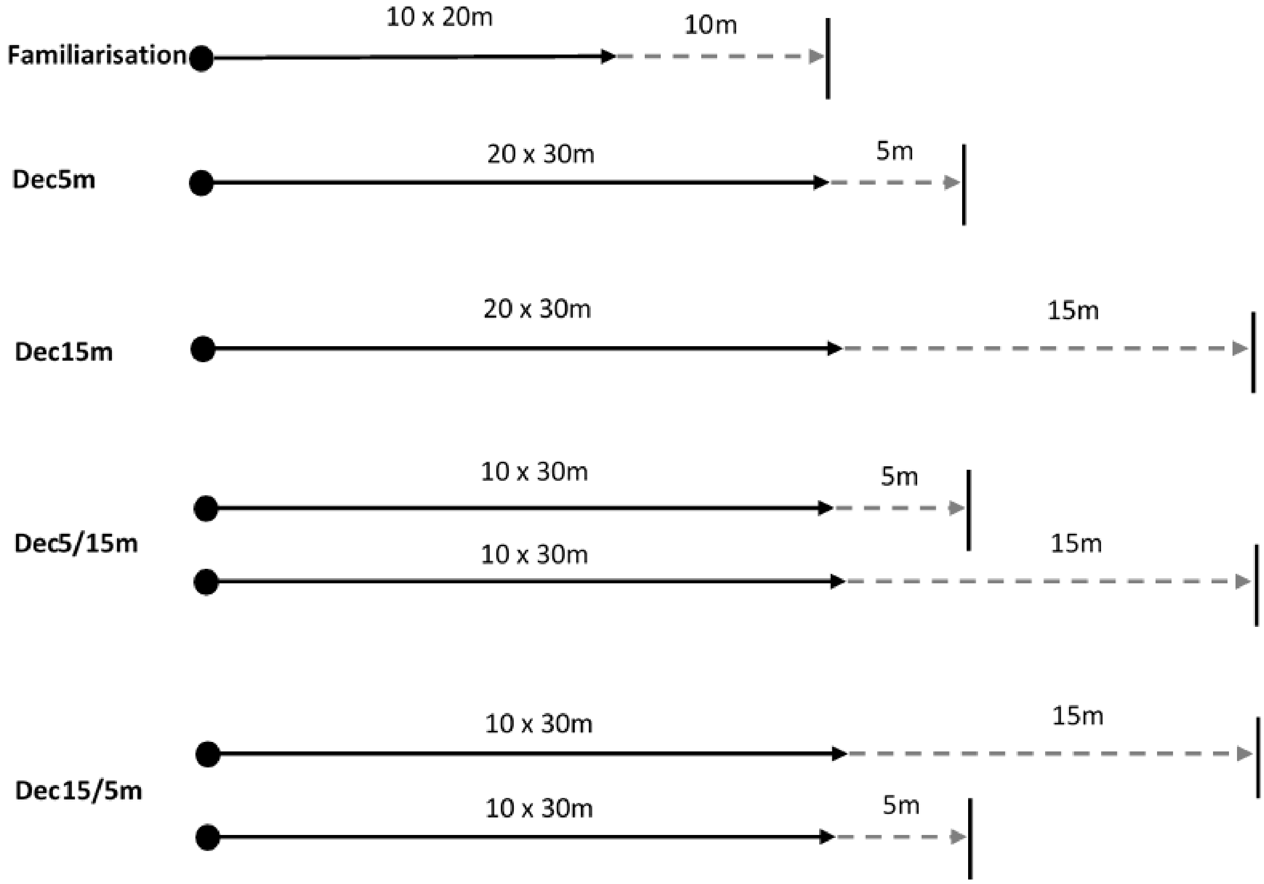

Figure 3.1. Schematic of the five different protocols. ● represents the start of the acceleration. – – – – ▸ represents the deceleration zone. | represents where the participants had to come to a complete stop. The familiarisation trial involved the participants completing 10 repetitions of a 20 metre acceleration with a 10 metre deceleration. The Dec5m and Dec15m protocols involved 20 repetitions of a 30 metre acceleration with either 20 repetitions of a five metre or 15 metre deceleration respectively. The Dec5/15m and the Dec15/5m protocols consisted of 20 repetitions of a 30 metre acceleration but the deceleration distance was alternated between the five metre and 15 metre for the Dec5/15m protocol and between 15 metre and five metre for the Dec15/5m protocol.

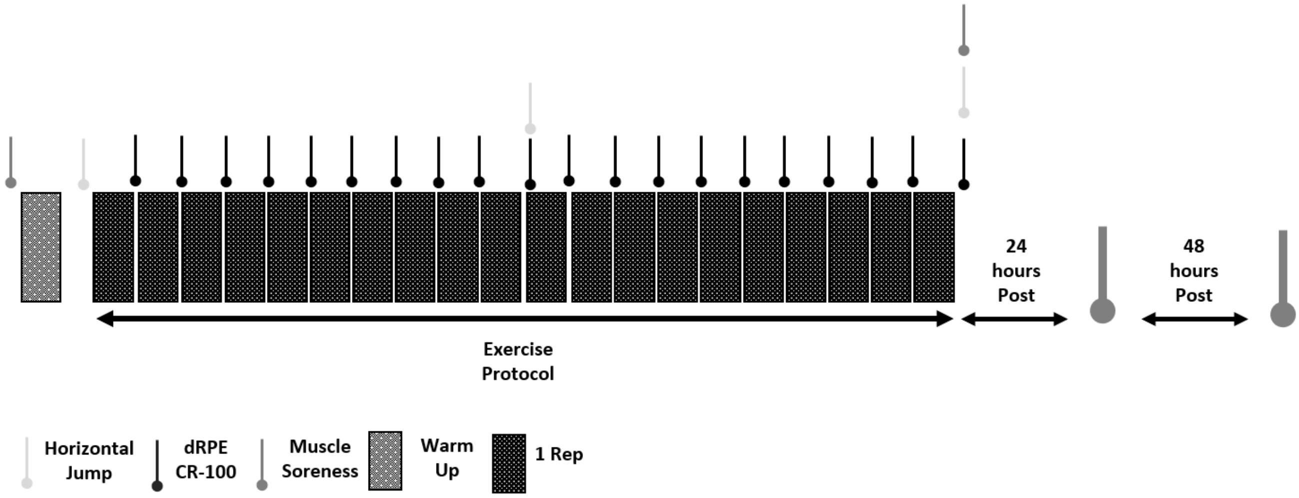

Figure 3.2. Schematic representation of the measures used in each protocol and when these measures took place.

3.4 EXPERIMENTAL PROCEDURES

3.4.1. FAMILIARISATION TRIAL

The aim of the familiarisation trial was to expose the participants to all of the methodologies included in the study. This involved collecting the participants maximum velocity, trialling a modified protocol and familiarising them with methods to collect dRPE, horizontal jump and muscle soreness. To obtain the participants maximum velocity the participants were required to complete three 30 metre sprints. This was to ensure that during the main protocols the participants were completing each rep within 95% of their maximum velocity. After the participants completed the sprints they were also familiarised with the horizontal jump test. This familiarisation trial had two main purposes. Firstly, it was to accustom the participants with the procedure and secondly it was to alleviate any learning effects that may impact the data collected in the experimental trials (Scott and Docherty, 2004). The familiarisation protocol for the horizontal jump was similar to that as previously described by Scott and Docherty (2004). The participants repeated the horizontal jump until they were consistently jumping within a band of scores which represented 95% of each rep. If the score was outside of this range the participant repeated another jump until this consistency was established. Once this standard had been reached it was assumed that the learning effects had been removed and on subsequent protocols the participants only had to perform one rep pre, at the mid-point and post protocol. On average it took the participants 4 ± 1 jumps to be familiarised. Following on from this the participants completed the familiarisation trial which consisted of 10 reps of a 20 metre acceleration with a 10 metre deceleration zone. This was designed to allow the participants to experience and understand how and when the measurements of dRPE collection, muscle soreness and horizontal jump would be take place. To control the eccentric muscular demand required to decelerate during each rep the participants were instructed to stop with both hips facing forward and both feet on the line with their knees flexed in an 'athletic position'. A rest period of three minutes between reps was utilised to allow the participants to finish the rep, walk back to where the bespoke dRPE application was kept and to perform a horizontal jump when required (on the 10th repetition). The participants rated their perception of effort after each rep to get used to the bespoke computer application. The participants also scored their muscle soreness pre and post protocol using a 5-point Likert scale.

3.4.2 EXERCISE PROTOCOLS

A standardised warm up was completed before all of the protocols began. As the protocols had different deceleration distances the total distance (45 metre) for each rep regardless of protocol was controlled. Controlling the distance of each rep and, therefore, the volume, required the participants to walk from the five metre stopping point to the end of the 15 metre deceleration zone when the reps involved a five metre deceleration. This allowed for external load analysis via the use of GPS microsensors to investigate how the different deceleration distances effected the external load. The intensity of the protocols was controlled by informing the participants that each rep needed to be performed at 95% of their maximum velocity obtained during the familiarisation session. The rest period between the reps were standardised at three minutes to allow the participants to complete the dRPE computer application and to perform a horizontal jump after the 10th rep. The split times during the deceleration period were recorded using timing gates to analyse the consistency between the reps.

3.5 PROCEDURES

3.5.1 NEUROMUSCULAR FUNCTION

A horizontal jump was used to investigate how the different protocols had an impact on neuromuscular function. Measurements were taken after a standardised warm up before the protocol began, after 10 reps and at the end of the protocol (Figure 3.2). Participants were instructed to place their toes behind a permanent pitch marking and using a countermovement action, using their arms and legs, jump as far as they could horizontally. The participants had to stay upright when they landed, and measurements were taken from the start line to the back of the furthest heel using a tape measure along the floor and a meter ruler at 90 degrees to the tape measure. The researchers were confident that the participants had learnt the protocol during the familiarisation protocol and, therefore, any learning effects had been alleviated so only one jump was needed to be performed at each of the above measurement points.

3.5.2 COLLECTION OF DIFFERENTIAL RATINGS OF PERCEIVED EXERTION (dRPE)

As previously described by Mclaren *et al.*, (2017) dRPE was collected using a bespoke computer application on a 7-inch android device (Amazon Fire, Quanta Computer, Taipei, Taiwan) one minute after each rep (Figure 3.2). The one-minute period post rep was to allow the participants to walk back to the start where the device was kept. The participants were presented with the android device after each rep and they logged in with their unique participant number. The computer application started with a description of what the participants should think about before answering each question and the participants were encouraged to read this each time they provided a rating. The participants were asked to rate their perception of breathlessness (RPE_B) and perception of leg muscle exertion (RPE_L) for each sprint on the touchscreen interface (Figure 3.3). The scale used was a numerically blinded CR100® scale (Borg and Borg, 2002) with English verbal anchors. The CR100® scale was used rather than the CR10® scale as it provides a more accurate and precise measure of internal load (Fanchini *et al.*, 2016). Each participant could not see the other participants scores. Each score was stored in a cloud-based spread sheet (Microsoft Excel 2016, Microsoft Corp, Redmond, USA) for further analysis.

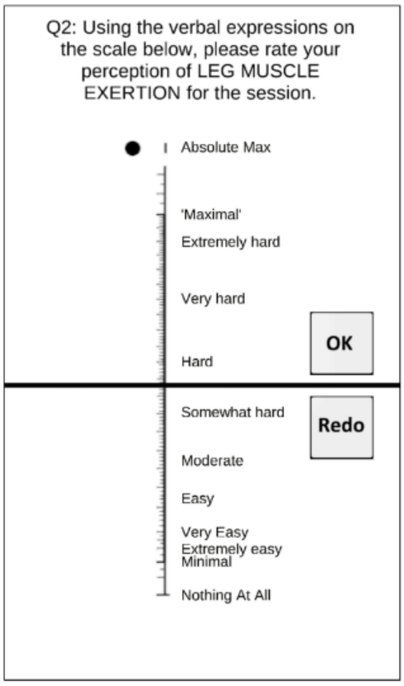

Figure 3.3. An example of the touchscreen interface on the bespoke dRPE computer application.

3.5.3 EXTERNAL AND INTERNAL LOAD MEASURES

The approach to measure external load was to use 10Hz GPS devices (Optimeye S5, Firmware 7.38, Catapult Sports, Melbourne, Australia). An indication of internal load was provided using heart rate monitors (Polar T31 Coded, Polar Electro OY, Kempele, Finland). The GPS devices were placed in a customised tight-fitting vest between the scapulae to reduce any unwanted movement which would affect the accelerometer data as outlined by the manufacturer (Harley *et al.*, 2010). During all the trials the participants wore the same GPS device which were only allocated to one participant to avoid inter-unit error (Jennings *et al.*, 2010). To ensure the GPS devices had satellite 'lock' (Malone *et al.*, 2017) prior to any data collection the devices were turned on and left in the middle of the artificial pitch. Data collection only commenced when this was achieved as indicated by a slow green flashing light on the interface of the device. The number of satellites the devices were connected to during the data collection was 11.3 ± 1.3 and the positional quality was 84.6 ± 4.5%. It has been suggested that the quality of data is reduced when the GPS devices are connected to less than 6 satellites and that a horizontal dilution of precision (HDOP) value of less than 1 is ideal (Malone *et al.*, 2017). Horizontal dilution of precision is an indication of the spacing of the satellites which can affect the accuracy and quality of the signal (Jennings *et al.*, 2010; Malone *et al.*, 2017). The HDOP value during data collection was 0.8 ± 0.1. Data was discarded if there were less than six satellites connected and a HDOP of >1.5 during the data collection. No data met this criterion so, therefore, no data had to be discarded. The bias was 1.3%. All raw data was exported from the Openfield Cloud based system into Excel (Microsoft Excel 2016, Microsoft Corp, Redmond, USA) for further analysis.

3.5.4 ACCELERATION AND DECELERATION MEASURES

To control for the intensity of each rep the participants were instructed to aim to perform each rep at 95% of their maximum velocity. On average the participants completed each rep within 94.9 ± 2.3% of their maximum velocity. To record the 30 metre sprint times for each rep during each exercise protocol timing gates (Brower Timing Systems, Draper, Utah, USA) were used. The position of the timing gates can be seen in Figure 3.4. Timing gates were placed one metre behind the two stopping distances to get the split times during the deceleration period in order to control the rate of deceleration. The timing gates were placed one metre behind the stopping line at five metre and 15 metre so that the participants would not set the timing gate off when they were stopped in a deceleration position. The participants were requested to stop in a traditional deceleration position with both feet inline.

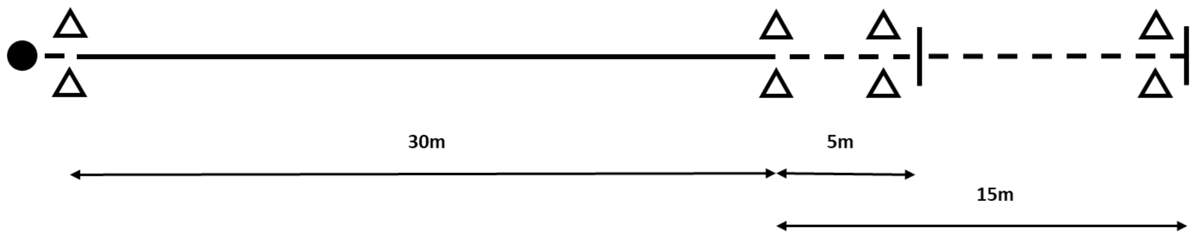

Figure 3.4. Diagram to show the placement of the timing gates and the setup of the protocol. ● indicates the start of the protocol. The timing gates are represented as the △ and the --- is the five metre and 15 metre deceleration period with the two different stopping lines.

3.5.5 MUSCLE SORENESS

Changes in muscle soreness pre and post protocol were measured to investigate if the protocols which had a shorter deceleration distance resulted in increased muscle damage. Using a 5-point Likert scale (0.5-point increments) (Table 3.1) the participants were asked to rate their muscle soreness pre, immediately post and 24 and 48 hours post protocols. A muscle soreness rating were also taken immediately before each protocol to get a baseline value of the participants subjective feeling of muscle soreness prior to completion of a protocol. This scale (Table 3.1) was adapted from Mclean *et al.*, (2010) well-being questionnaire based on the previous recommendations of Hooper and Mackinnon (1995).

Table 3.1. Example of the 5-point Likert scale used in this study.

Muscle Soreness	
1	Very sore
2	Increase in soreness/tightness
3	Normal
4	Feeling good
5	Feeling great

3.6 STATISTICAL ANALYSIS

3.6.1 DIFFERENTIAL RATINGS OF PERCEIVED EXERTION

Differential ratings of perceived exertion (sRPE, RPE_L and RPE_B) were log transformed and then the standardised mean differences with 95% confidence intervals (CI) between protocols were calculated (SPSS v24, IBM Corp, Armonk, NY, USA). Differences between the protocols for each of the dRPE components were examined using paired samples t-tests. The magnitude of the chance that the true value of the effect statistic was substantially positive, negative or trivial was interpreted using an anchor-based approach of 20 AU which represented the substantial change required to increase to the next verbal anchor on the CR100® scale across each protocol. Within protocol changes in sRPE, RPE_L and RPE_B were individually linearly regressed to examine the rate of change in sRPE, RPE_L and RPE_B from start to finish. Magnitude based inferences were then applied using the same anchor-based approach of 20 AU. Magnitude based inferences were interpreted using the following scale (Batterham and Hopkins, 2006): 25-75% - possibly, 75-95% - likely, 95-99.5% - very likely and 99.5-100% - most likely. A difference was deemed unclear if the confidence limit overlapped a substantial increase and a substantial decrease threshold by ≥ 2.5%.

3.6.2 NEUROMUSCULAR FUNCTION

Analysis of pre-post neuromuscular measures between the protocols were performed and standardised mean differences with 95% confidence intervals were calculated using Hopkins (2006) pre-post crossover analysis spreadsheet. Magnitude based inferences were then subsequently applied to the between protocol analyses using the smallest worthwhile change (SWC) in horizontal jump performance as the threshold value (Hopkins, 2002).

3.6.3 MUSCLE SORENESS

Between protocol muscle soreness measures were log transformed and the standardised mean differences with 95% confidence intervals between protocols were calculated using the same pre-post crossover analysis spreadsheet (Hopkins, 2006) as previously described. The magnitude of effects were interpreted using a threshold percentage of 3% as this has previously been shown to be the minimum practically important difference (MPID) for a change in muscle soreness (Thorpe, 2015).

3.6.4 SPRINT PERFORMANCE

The between and within protocol changes in 30m sprint performance across the 20 repetitions were calculated using the same methods as outlined above with dRPE. The magnitude of the chance that the true value of the effect statistic was substantially positive, negative or trivial was interpreted using the smallest worthwhile change (SWC) in 30m sprint performance as the threshold (Hopkins, 2002).

3.6.5 EXTERNAL LOAD

A one-way ANOVA was used to determine any significant differences between the protocols for the external load variables. Where a statistically significant difference in group means occurred a post hoc test (Tukey) was then used to determine which protocols differed from each other.

CHAPTER 4

RESULTS

4.1 EXTERNAL LOAD

4.1.1 PEAK DECELERATION

The protocols were designed to have varying deceleration distances with the aim of impacting the eccentric load of the lower body with the Dec5m protocol having the shortest deceleration zone. The peak deceleration for the Dec5m protocol was significantly greater than the peak deceleration for the Dec15m protocol ($p = 0.005$) as a result of this shorter deceleration (Figure 4.1). Similarly, during the alternating protocols (Dec5/15m and Dec15/5m) the five metre repetitions also had a greater deceleration than the 15 metre repetitions ($p < 0.0005$). The five metre repetitions had a peak deceleration of -4.14 ± 0.10 m/s^2 and -4.09 ± 0.12 m/s^2 for the Dec5/15m and Dec15/5m protocols respectively whereas the 15 metre repetitions had a peak deceleration of -3.41 ± 0.11 m/s^2 and -3.12 ± 0.14 m/s^2 respectively.

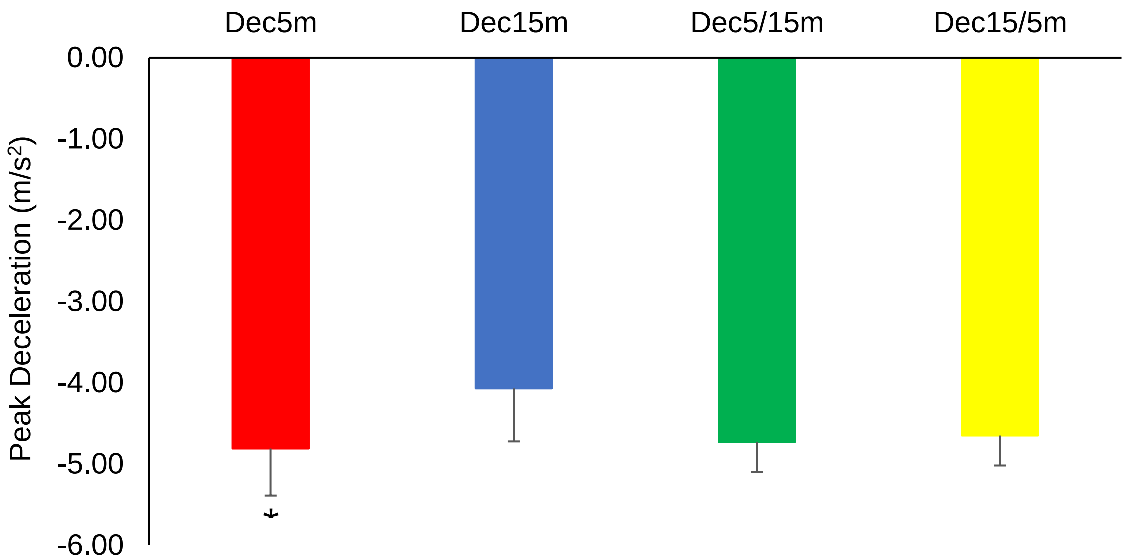

Figure 4.1. Peak deceleration (mean ± SD) across each of the protocols (* indicates a statistically significant difference in comparison to the Dec15m protocol ($p = 0.005$)).

4.1.2 TOTAL DISTANCE

The distance the participants covered during each repetition of the protocols was controlled by making each run the same distance in length. This was to ensure that the volume was the same across the protocols. The total distance measured through MEMS was consistent between the protocols demonstrating that this was controlled ($p = 0.615$) (Figure 4.2).

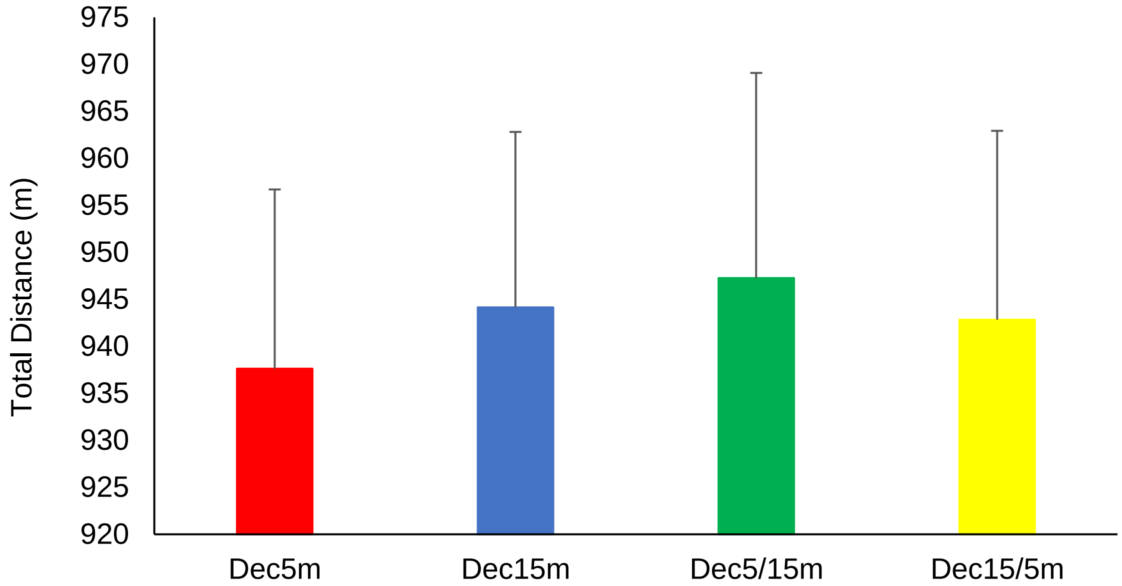

Figure 4.2. Total distance (mean ± SD) completed across each of the protocols.

4.1.3 HIGH SPEED DISTANCE AND SPRINT DISTANCE

Table 4.1 shows the total average high-speed running and sprint distance for each protocol. There was no significant difference between protocols in high speed running distance ($p = 0.402$). However, there was a significant difference in sprint distance with the Dec15m protocol having a greater distance spent above seven metres per second compared to the Dec5m protocol ($p = 0.005$).

Table 4.1. High-speed running and sprinting distance (mean ± SD) during each protocol.

	Dec5m	**Dec15m**	**Dec5/15m**	**Dec15/5m**
Total High-Speed Running Distance (m) (5.5-7.0 m/s)	230 ± 56	266 ± 87	223 ± 64	236 ± 49
Total Sprinting Distance (m) (>7.0 m/s)	300 ± 72	425 ± 113 *****	399 ± 88	376 ± 66

* Statistically significant difference in comparison to the Dec5m protocol (p = 0.005).

4.1.4 THIRTY METRE SPRINT PERFORMANCE

The average maximum velocity measured with MEMS was consistent across all the protocols demonstrating that the intensity was controlled ($p = 0.360$) (Figure 4.3). However, the within protocol changes in 30 metre sprint performance times (measured using timing gates) from the first to the last repetitions (Figure 4.4; Table 4.2) were *likely* increased for the Dec5m ($p = 0.025$), Dec15m ($p = 0.008$) and Dec15/5m ($p = 0.015$) protocols. The Dec5/15m ($p = 0.143$) protocol was *possibly* increased in the 30 metre sprint performance times over the 20 repetitions. Nevertheless, the between protocol differences in 30 metre sprint performances times over the 20 repetitions were *unclear* for all the protocols demonstrating consistency of effort across the protocols (Table 4.3).

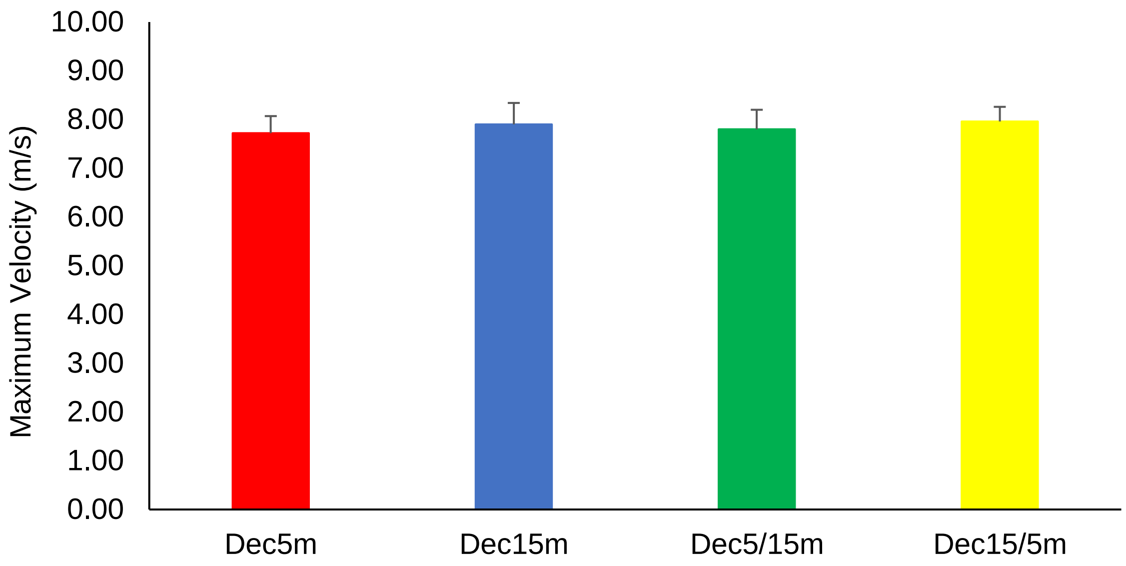

Figure 4.3. Maximum velocity (mean ± SD) across each of the protocols.

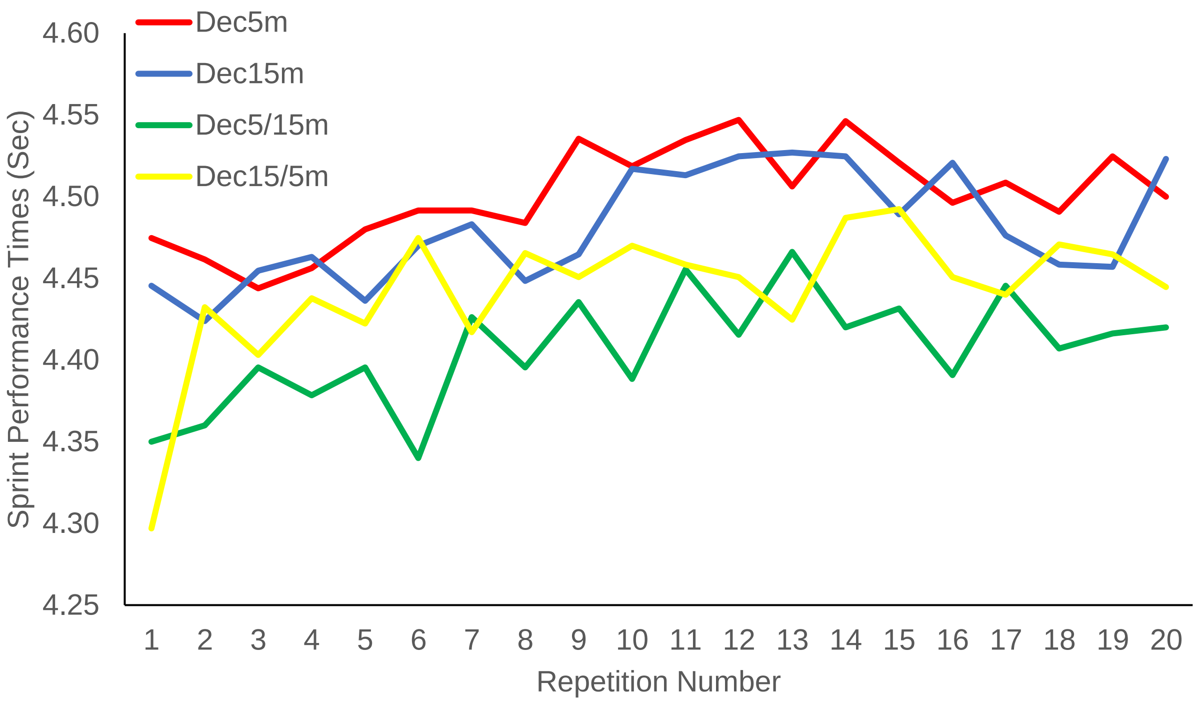

Figure 4.4. Mean sprint performance times for each repetition across each protocol.

Table 4.2. Within protocol mean difference, correlations (95% Confidence Intervals) and effect statistics for changes in 30 metre sprint performance across the 20 repetitions.

Protocols	Mean Difference (s)	95% Confidence Interval	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m	0.053	0.01 to 0.09	0.025	85/15/0.1	Likely Increase
Dec15m	0.065	0.02 to 0.11	0.008	94/6/0	Likely Increase
Dec5/5m	0.043	-0.02 to 0.1	0.143	68/31/1	Possibly Increase
Dec15/5m	0.075	0.02 to 0.13	0.015	94/6/0.1	Likely Increase

Table 4.3. Between-protocol difference, correlations (95% Confidence Intervals) and effect statistics for changes in 30 metre sprint performance across the 20 repetitions.

Protocols	Mean Difference (s)	95% Confidence Interval	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	-0.012	-0.1 to 0.081	0.782	17/49/34	Unclear
Dec5m – Dec5/15m	0.008	-0.08 to 0.09	0.850	29/54/18	Unclear
Dec5m – Dec15/5m	-0.026	-0.10 to 0.04	0.433	5/50/45	Unclear
Dec15m – Dec5/15m	0.020	-0.06 to 0.1	0.603	39/51/10	Unclear
Dec15m – Dec15/5m	-0.014	-0.13 to 0.17	0.784	44/31/25	Unclear
Dec5/15m – Dec15/5m	-0.034	-0.12 to 0.057	0.437	8/39/53	Unclear

4.2 DIFFERENTIAL RATINGS OF PERCEIVED EXERTION

The overall mean ± SD for dRPE (RPE_L and RPE_B) after the first and last repetition across each protocol are displayed in Table 4.4. The mean ± SD for RPE_L and RPE_B after every repetition during each protocol are displayed in Figures 4.5 and 4.6 respectively.

Table 4.4. The mean ± SD for RPE_L and RPE_B for repetition one and twenty across each protocol.

Protocol	Rep Number	RPE_L (AU)	RPE_B (AU)
Dec5m	1	23 ± 13	21 ± 14
	20	60 ± 29	50 ± 30
Dec15m	1	23 ± 21	23 ± 21
	20	58 ± 28	53 ± 27
Dec5/15m	1	26 ± 18	27 ± 18
	20	48 ± 23	47 ± 26
Dec15/5m	1	24 ± 24	29 ± 26
	20	48 ± 28	48 ± 28

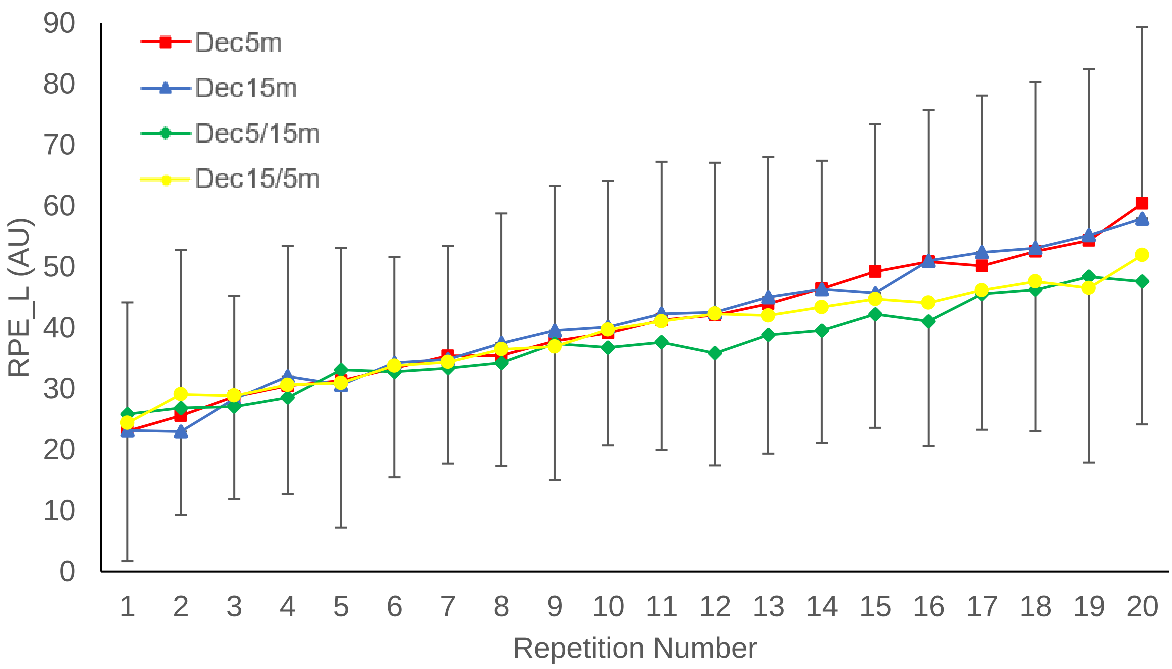

Figure 4.5. RPE_L (mean ± SD) values for each repetition across each protocol.

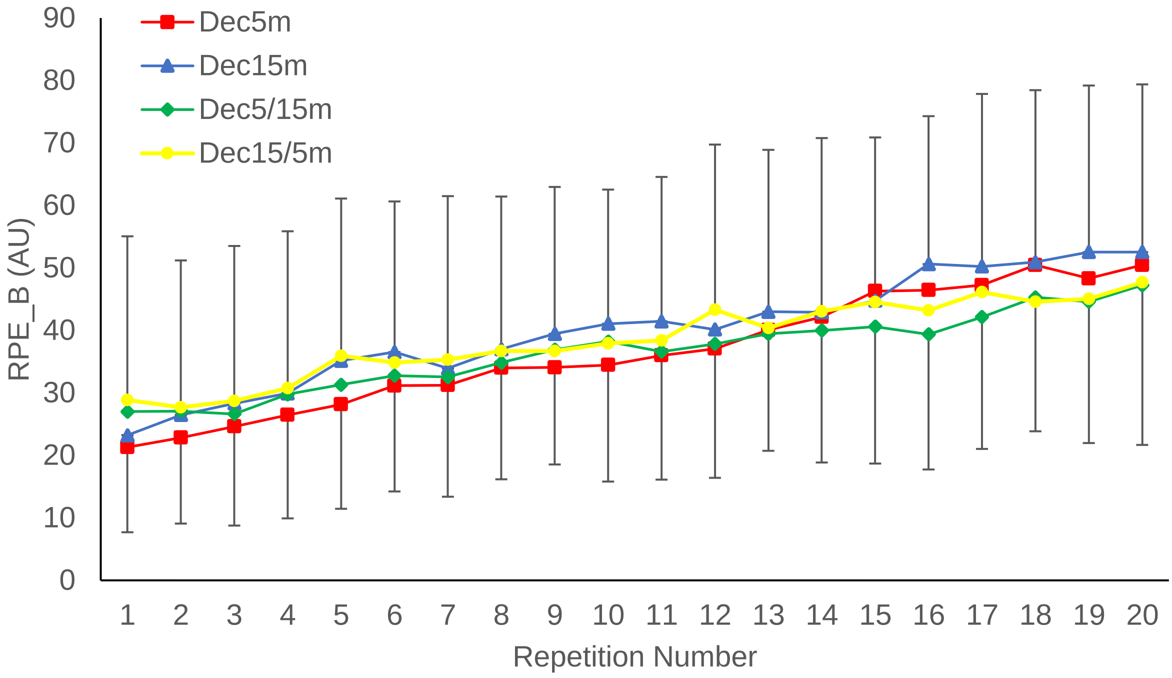

Figure 4.6. RPE_B (mean ± SD) values for each repetition across each protocol.

Using an anchor-based approach the changes in RPE_L within the Dec5m (Effect statistic 35 ± 95% confidence limits 2.1, $p < 0.0005$), Dec15m (35 ± 2.3, $p < 0.0005$) and Dec15/5m (25 ± 2.3, $p < 0.0005$) protocols were *most likely* increased from the first to the last repetition (Figure 4.7). Changes in RPE_L within the Dec5/15m protocol were *very likely* increased from the first to the last repetition (23 ± 2.3, $p < 0.0005$) (Figure 4.7). The rate of change in RPE_L between the protocols are displayed in Table 4.5. The rate of change in RPE_L from the first to the last repetition between the Dec5m and Dec15m ($p = 0.995$) and the Dec5/15m and Dec15/5m ($p = 0.539$) protocols was *most likely* trivial. There was a *Likely* trivial rate of change in RPE_L between the Dec5m and Dec5/15m ($p = 0.033$), the Dec15m and Dec5/15m ($p = 0.141$) and the Dec15m and Dec15/5m ($p = 0.210$) protocols. The rate of change in RPE_L between the Dec5m and Dec5/15m ($p = 0.070$) protocols was *very likely* trivial.

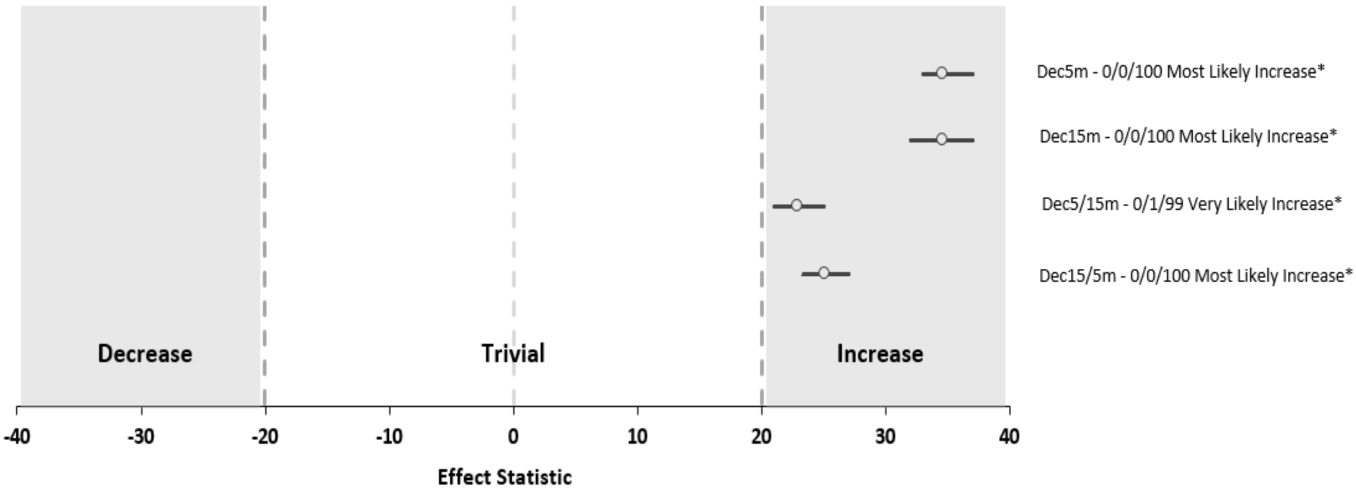

Figure 4.7. Within protocol correlations (95% Confidence Intervals) and effect statistics for RPE_L using an anchored based approach. Numbers shown are quantitative chances (%) that the true value is a substantial decrease, trivial or a substantial increase. * denotes a significant effect on condition (P<0.0005).

Table 4.5. Between-protocol mean difference, correlations (95% Confidence Intervals) and effect statistics for RPE_L using an anchor-based approach (20 AU).

Protocols	Mean Difference (AU)	95% Confidence Interval	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	0.03	-11 to 11	0.995	0/100/0	Most Likely Trivial
Dec5m – Dec5/15m	11.7	1.1 to 22	0.033	6/94/0	Likely Trivial
Dec5m – Dec15/5m	9.7	-0.91 to 20	0.070	3/97/0	Very Likely Trivial
Dec15m – Dec5/15m	11.7	-4.5 to 28	0.141	14/86/0	Likely Trivial
Dec15m – Dec15/5m	9.7	-6.3 to 26	0.210	9/91/0	Likely Trivial
Dec5/15m – Dec15/5m	-2.0	-8.8 to 4.8	0.539	0/100/0	Most Likely Trivial

The within protocol changes in RPE_B from the first to the last repetition were *most likely* increased for the Dec5m (31 ± 2.2, p <0.0005) and Dec15m (30 ± 3.2, p <0.0005) protocols and were *possibly* increased for the Dec5/15m (20 ± 2.1, p <0.0005) and Dec15/5m (20 ± 2.6, p <0.0005) protocols (Figure 4.8). Table 4.6 displays the between protocol differences in RPE_B. Changes in RPE_B from the first to the last repetition between the Dec5m and Dec15m (p = 0.510) and the Dec5/15m and Dec15/5m (p = 976) protocols were *most likely* trivial. The Dec5m and Dec5/15m (p = 0.011), the Dec15m and Dec5/15m (p = 0.080) and the Dec15m and Dec15/5m (p = 0.136) protocols were all *very likely* trivial. The changes in RPE_B between the Dec5m and Dec15/5m (p = 0.067) was *likely* trivial.

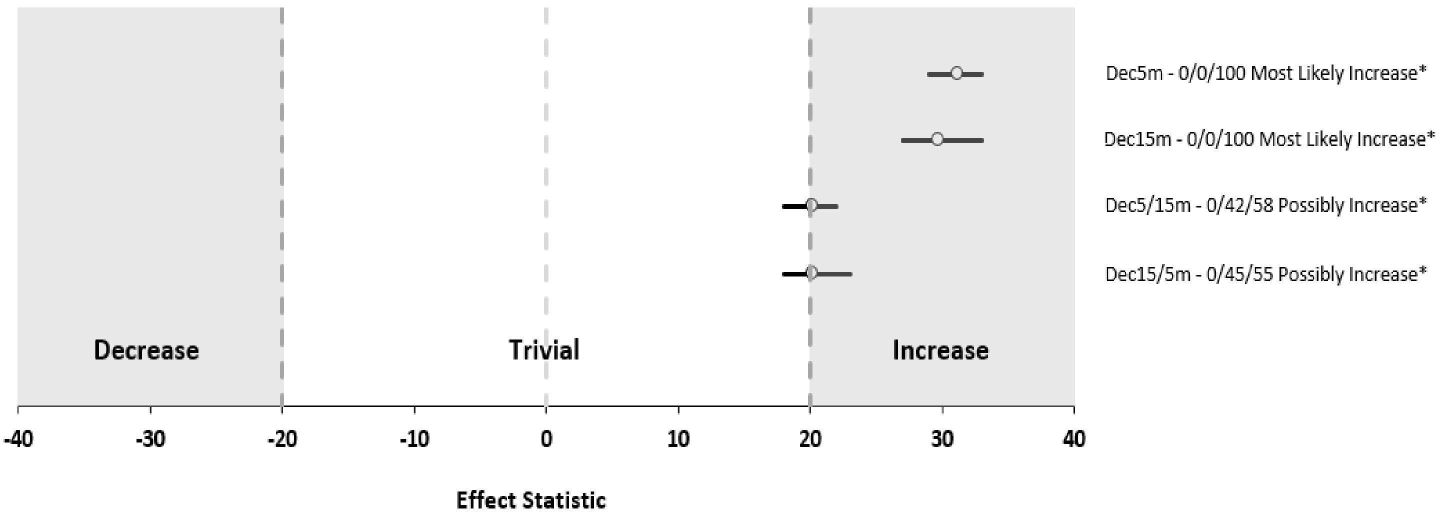

Figure 4.8. Within protocol correlations (95% Confidence Intervals) and effect statistics for RPE_B using an anchored based approach. Numbers shown are quantitative chances (%) that the true value is a substantial decrease, trivial or a substantial increase. * denotes a significant effect on condition (P<0.0005).

Table 4.6. Between-protocol mean difference, correlations (95% Confidence Intervals) and effect statistics for RPE_B using an anchor-based approach (20 AU).

Protocols	Mean Difference (AU)	95% Confidence Interval	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	2.4	-5.2 to 9.9	0.510	0/100/0	Most Likely Trivial
Dec5m – Dec5/15m	11.1	3.1 to 19	0.011	2/98/0	Very Likely Trivial
Dec5m – Dec15/5m	11.2	-0.92 to 23	0.067	7/93/0	Likely Trivial
Dec15m – Dec5/15m	8.8	-1.2 to 19	0.080	2/99/0	Very Likely Trivial
Dec15m – Dec15/5m	8.9	-3.2 to 21	0.136	3/97/0	Very Likely Trivial
Dec5/15m – Dec15/5m	0.1	-6.9 to 7.1	0.976	0/100/0	Most Likely Trivial

4.3 NEUROMUSCULAR FUNCTION

Neuromuscular function was assessed immediately pre-protocol (pre), after the participants had completed 10 repetitions (mid) and immediately post-protocol (post) using a horizontal jump (Figure 4.9). The difference in neuromuscular function from the mid-point to pre-protocol were *unclear* for the Dec5m to Dec15m ($p = 0.700$), Dec5m to Dec5/15m ($p = 0.902$), Dec5m to Dec15/5m ($p = 0.771$), Dec15m to Dec5/15m ($p = 0.726$), Dec15m to Dec15/5m ($p = 0.890$) and Dec5/15m to Dec15/5m ($p = 0.747$) protocol comparisons (Table 4.7). The differences in post neuromuscular measures compared to those collected at the mid-point (Table 4.8) were *unclear* for the Dec5m to Dec15m ($p = 0.733$), Dec5m to Dec15/5m ($p = 0.898$), Dec15 to Dec5/15m ($p = 0.410$) and Dec15m to Dec15/5m ($p = 0.689$) comparisons. Measures collected at these time points between the Dec5m and Dec5/15m were *possibly* increase ($p = 0.242$) and a *possible* decrease in neuromuscular function was observed for the Dec5/15m to Dec15/5m ($p = 0.193$) protocols. The neuromuscular measures collected post-protocol compared to pre-protocol measures were *unclear* for the Dec5m to Dec15m ($p = 0.534$), Dec5m to Dec5/15m ($p = 0.498$), Dec5m to Dec15/5m ($p = 0.867$), Dec15m to Dec5/15m ($p = 0.761$), Dec15m to Dec15/5m ($p = 0.606$) and Dec5/15m to Dec15/5m ($p = 0.521$) comparisons (Table 4.9).

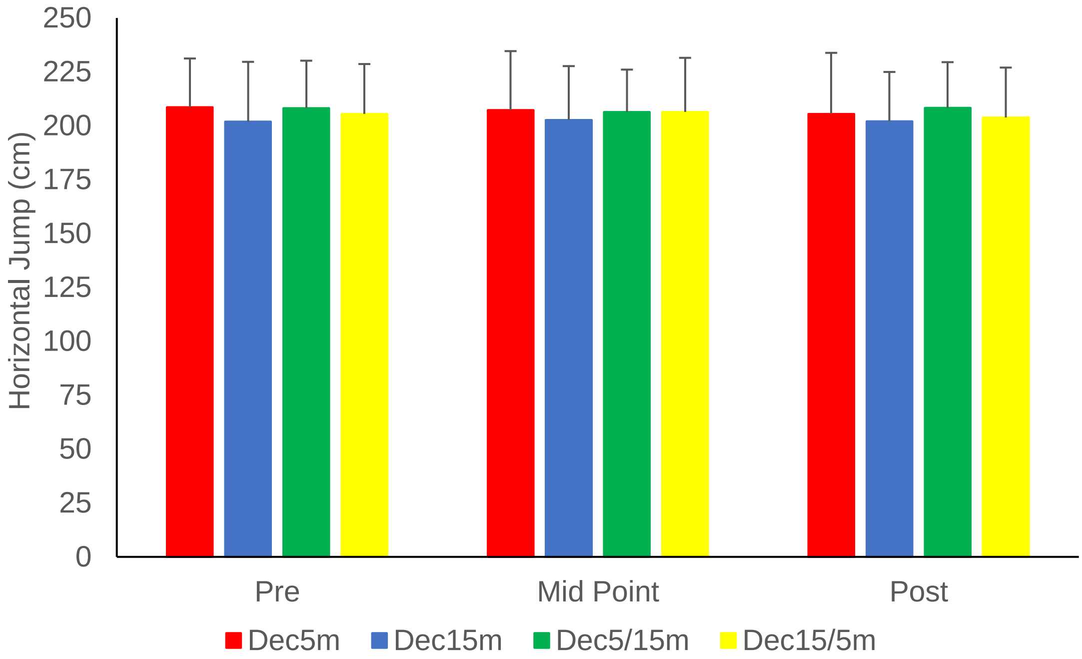

Figure 4.9. Horizontal jump measures (mean ± SD) for each protocol collected pre, at the mid-point and post protocol.

Table 4.7. Mid to pre between protocol changes in neuromuscular function, mean difference, correlations (95% Confidence Intervals) and effect statistics.

Protocols	Mean Difference (cm)	95% Confidence Interval	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	1.8	-8.3 to 12.0	0.700	32/56/12	Unclear
Dec5m – Dec5/15m	-0.5	-9.5 to 8.4	0.902	15/65/20	Unclear
Dec5m – Dec15/5m	1.4	-9.2 to 12.1	0.771	30/55/14	Unclear
Dec15m – Dec5/15m	-1.3	-9.4 to 6.8	0.726	9/67/24	Unclear
Dec15m – Dec15/5m	-0.4	-7.1 to 56.2	0.890	9/78/13	Unclear
Dec5/15m – Dec15/5m	1.5	-8.7 to 11.7	0.747	30/57/13	Unclear

Table 4.8. Post to mid between protocol changes in neuromuscular function, mean difference, correlations (95% Confidence Intervals) and effect statistics.

Protocols	Mean Difference (cm)	95% Confidence Interval	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	1.0	-5.4 to 7.4	0.733	16/78/6	Unclear
Dec5m – Dec5/15m	3.7	-2.9 to 10.3	0.242	46/52/1	Possibly Increase
Dec5m – Dec15/5m	-0.5	-9.1 to 8.0	0.898	13/67/19	Unclear
Dec15m – Dec5/15m	2.6	-4.0 to 9.2	0.410	32/65/3	Unclear
Dec15m – Dec15/5m	-1.3	-8.3 to 5.7	0.689	6/73/21	Unclear
Dec5/15m – Dec15/5m	-4.2	-10.8 to 2.4	0.193	1/47/52	Possible Decrease

Table 4.9. Post to pre between protocol changes in neuromuscular function, mean difference, correlations (95% Confidence Intervals) and effect statistics.

Protocols	Mean Difference (cm)	95% Confidence Interval	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	2.8	-6.9 to 12.5	0.534	40/53/7	Unclear
Dec5m – Dec5/15m	3.2	-6.9 to 13.3	0.498	43/50/7	Unclear
Dec5m – Dec15/5m	0.9	-11.0 to 12.9	0.867	29/52/19	Unclear
Dec15m – Dec5/15m	1.2	-7.3 to 10.1	0.761	25/64/11	Unclear
Dec15m – Dec15/5m	-1.7	-8.9 to 5.4	0.606	5/70/25	Unclear
Dec5/15m – Dec15/5m	-2.6	-11.4 to 6.1	0.521	6/57/37	Unclear

4.4 MUSCLE SORENESS

Muscle soreness was assessed prior to the protocol starting (pre), upon completion of the protocol (post) and 24 and 48 hours post-protocol (Figure 4.10). The between-protocol differences in post to pre muscle soreness measures (Table 4.10) were *unclear* for the Dec5m to Dec15m (p = 0.130), Dec15m to Dec15/5m (p = 0.506) and Dec5/15 to Dec15/5m (p = 0.478) protocols. However, the Dec5m to Dec5/15m was a *most likely* increase (p = 0.0003), Dec5m to Dec15/5m (p = 0.019) was a *very likely* increase and Dec15m to Dec15/5m (p = 0.062) was a *likely* increase.

Twenty-four hours post to pre-protocol changes in muscle soreness (Table 4.11) between the Dec5m to Dec15m (p = 0.080), Dec5m to Dec 5/15m (p = 0.163), Dec15m to Dec5/15m (p = 0.875), Dec15m to Dec15/5m (p = 0.470) and Dec5/15m to Dec15/5m (p = 0.329) protocols were *unclear.* On the other hand, there was a *very likely* increase in muscle soreness between the Dec5m and Dec15/5m protocols.

The between protocol differences in muscle soreness 48 hours post to pre-protocol (Table 4.12) were *unclear* for the following comparisons; Dec5m to Dec5/15m (p = 0.755), Dec5m to Dec15/5m (p = 0.198), Dec15m to Dec5/15m (p = 0.157), Dec15m to Dec15/5m (p = 0.569) and Dec5/15m to Dec15/5m (p = 0.372). However, between the Dec5m and Dec15m (p = 0.050) protocols there was a *very likely* increase in muscle soreness.

The between protocol differences in muscle soreness 24 hours post to immediately post-protocol (Table 4.13) were *unclear* for the Dec5m to Dec15m (p = 0.131), Dec5m to Dec15/5m (p = 0.459), Dec15m to Dec5/15m (p = 0.386), Dec15m to Dec15/5m (p = 0.484) and Dec5/15m to Dec15/5m (p = 0.128). Conversely, there was a *likely* increase in muscle soreness between the Dec5m and Dec5/15m (p = 0.071) protocols.

Forty-eight hours post to immediately post between-protocol changes in muscle soreness (Table 4.14) were *unclear* for the Dec5m to Dec5/15m (p = 0.321), Dec5m to Dec15/5m (p = 0.258), Dec15m to Dec15/5m (p = 0.484) and Dec5/15m to Dec15/5m (p = 0.159) protocols. However, there was a *likely* increase in muscle soreness between the Dec5m and Dec15m (p = 0.070) protocols and a *very likely* decrease between the Dec15m and Dec5/15m (p = 0.041) protocols.

The between-protocol changes in muscle soreness 48 hours post to 24 hours post (Table 4.15) were *unclear* for all of the protocol comparisons; Dec5m to Dec15m (p = 0.905), Dec5m to Dec5/15m (p = 0.312), Dec5m to Dec15/5m (p = 0.659), Dec15m to Dec5/15m (p = 0.434), Dec15m to Dec15/5m (p = 0.248) and Dec5/15m to Dec15/5m (p = 0.502).

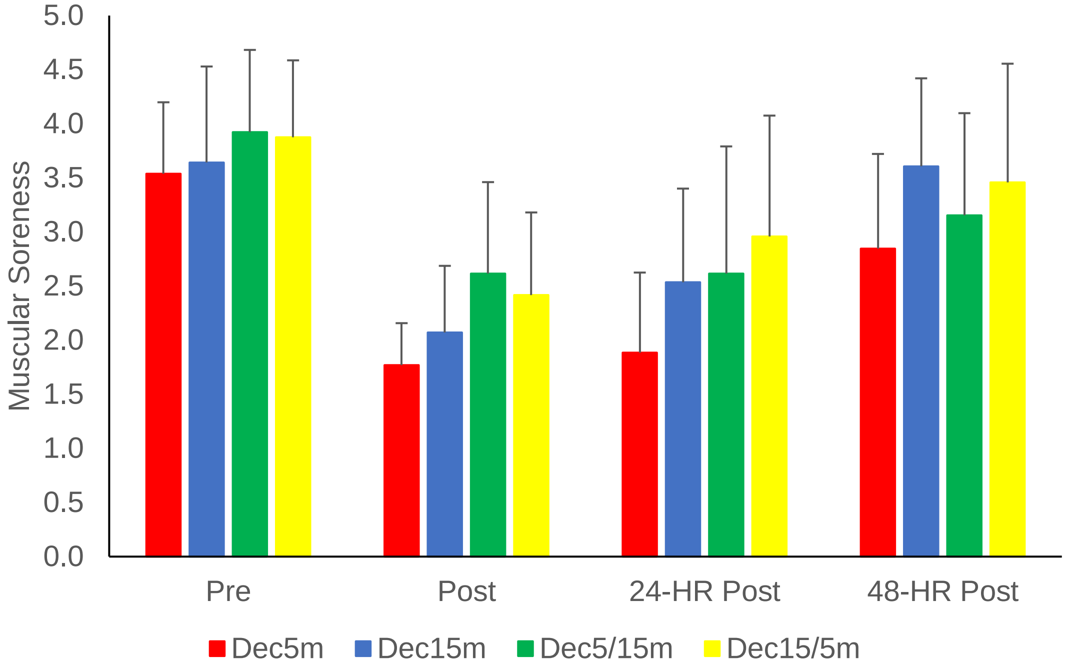

Figure 4.10. Muscular soreness (mean ± SD) for each protocol collected pre, post, 24-hours and 48-hours post protocol.

Table 4.10. Post to pre between protocol changes in muscle soreness, mean different, correlations (95% Confidence Intervals) and effect statistics.

Protocols	Mean Difference (%)	95% Confidence Interval (%)	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	14.8	-4.7 to 38.3	0.130	89/8/4	Unclear
Dec5m – Dec5/15m	43	23.3 to 65.8	0.0003	100/0/0	Most Likely Increase
Dec5m – Dec15/5m	26.5	4.8 to 52.7	0.019	98/1/1	Very Likely Increase
Dec15m – Dec5/15m	21.6	-1.2 to 49.6	0.062	95/4/2	Likely Increase
Dec15m – Dec15/5m	8.6	-16.5 to 41.2	0.506	67/15/18	Unclear
Dec5/15m – Dec15/5m	-8.5	-30.0 to 19.5	0.478	17/14/68	Unclear

Table 4.11. Twenty-four hours post to pre between protocol changes in muscle soreness, mean different, correlations (95% Confidence Intervals) and effect statistics.

Protocols	Mean Difference (%)	95% Confidence Interval (%)	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	33.3	-4.0 to 85.1	0.080	94/3/3	Unclear
Dec5m – Dec5/15m	25.0	-10.0 to 73.7	0.163	89/5/6	Unclear
Dec5m – Dec15/5m	42.4	9.7 to 84.8	0.012	99/1/0	Very Likely Increase
Dec15m – Dec5/15m	-3.0	-36.3 to 47.7	0.875	38/12/50	Unclear
Dec15m – Dec15/5m	10.8	-18.0 to 49.7	0.470	70/13/18	Unclear
Dec5/15m – Dec15/5m	17.6	-17.0 to 66.9	0.329	79/9/13	Unclear

Table 4.12. Forty-eight hours post to pre between protocol changes in muscle soreness, mean different, correlations (95% Confidence Intervals) and effect statistics.

Protocols	Mean Difference (%)	95% Confidence Interval (%)	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	28.6	-0.0 to 65.3	0.050	96/2/2	Very Likely Increase
Dec5m – Dec5/15m	3.7	-19.1 to 32.8	0.755	52/19/28	Unclear
Dec5m – Dec15/5m	13.7	-1.5 to 39.9	0.198	84/10/6	Unclear
Dec15m – Dec5/15m	-15.5	-33.8 to 7.9	0.157	5/7/88	Unclear
Dec15m – Dec15/5m	-7.5	-30.9 to 23.9	0.569	22/15/64	Unclear
Dec5/15m – Dec15/5m	11.3	-13.5 to 43.2	0.372	74/13/13	Unclear

Table 4.13. Twenty-four hours post to immediately post between protocol changes in muscle soreness, mean difference, correlations (95% Confidence Intervals) and effect statistics.

Protocols	Mean Difference (%)	95% Confidence Interval (%)	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	24.6	-7.4 to 67.7	0.131	91/5/5	Unclear
Dec5m – Dec5/15m	33.4	-2.9 to 83.3	0.071	95/3/2	Likely Increase
Dec5m – Dec15/5m	-24.6	-66.5 to 69.5	0.459	21/5/75	Unclear
Dec15m – Dec5/15m	-14.8	-42.4 to 25.9	0.386	15/9/76	Unclear
Dec15m – Dec15/5m	7.2	-13.2 to 32.5	0.484	66/18/16	Unclear
Dec5/15m – Dec15/5m	25.3	-7.3 to 69.4	0.128	91/5/4	Unclear

Table 4.14. Forty-eight hours post to immediately post between protocol changes in muscle soreness, mean difference, correlations (95% Confidence Intervals) and effect statistics.

Protocols	Mean Difference (%)	95% Confidence Interval (%)	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	26.5	-2.3 to 63.7	0.070	95/3/2	Likely Increase
Dec5m – Dec5/15m	13.2	-13.0 to 47.4	0.321	78/11/11	Unclear
Dec5m – Dec15/5m	-32.9	-67.8 to 40.1	0.258	11/3/85	Unclear
Dec15m – Dec5/15m	-21.2	-37.2 to -1.1	0.041	1/2/97	Very Likely Decrease
Dec15m – Dec15/5m	-8.3	-29.6 to 19.4	0.484	18/15/68	Unclear
Dec5/15m – Dec15/5m	15.9	-6.5 to 43.6	0.159	87/8/5	Unclear

Table 4.15. Forty-eight hours post to 24 hours post changes in between protocol changes in muscle soreness, mean difference, correlations (95% Confidence Intervals) and effect statistics.

Protocols	Mean Difference (%)	95% Confidence Interval (%)	p-value	Probability Thresholds (Substantial Increase/Trivial/ Substantial Decrease) (%)	Inference
Dec5m – Dec15m	1.5	-22.4 to 32.7	0.905	45/19/36	Unclear
Dec5m – Dec5/15m	-15.1	-39.6 to 19.3	0.312	12/8/80	Unclear
Dec5m – Dec15/5m	-10.9	-49.2 to 56.2	0.659	29/8/63	Unclear
Dec15m – Dec5/15m	-7.5	-25.0 to 14.2	0.434	14/17/68	Unclear
Dec15m – Dec15/5m	-14.5	-35.5 to 13.4	0.248	9/9/83	Unclear
Dec5/15m – Dec15/5m	-7.5	-27.8 to 18.5	0.502	18/16/66	Unclear

CHAPTER 5

DISCUSSION

5.1 DISCUSSION

The aim of the current study was to investigate the ability of dRPE to detect changes in the physiological demands associated with different deceleration profiles in high-intensity running protocols. The main findings of this study were that during each of the protocols RPE_L (very likely to most likely) and RPE_B (possibly to most likely) substantially increased from the first to the last repetition. However, using an anchored-based approach, the rate of change in RPE_L and RPE_B between the protocols were trivial (likely trivial to most likely trivial) which suggests that the internal response to the protocols were similar. On the other hand, muscle soreness was elevated 48 hours post the Dec5m protocol compared to that of the Dec15m protocol which implies there was a greater level of muscle damage induced from this protocol. Comparisons in neuromuscular function demonstrate that overall, there were very few substantial differences in measures between the protocols which might suggest that this was not successfully manipulated in the protocol design. This data suggests that during these exercise conditions, dRPE was not sensitive enough to detect small differences in muscular and respiratory demands. Therefore, during certain conditions, dRPE may not provide any further information compared to that of RPE.

To date, no research has been conducted that has investigated the concept validity of dRPE within a controlled environment where protocols replicate the demands of team sports. Therefore, this study attempted to bridge the gap between the current literature which has investigated the concept validity of dRPE within a controlled laboratory environment which lacks specificity to the activity profile of team sports (Howatson and Milak, 2009) and those studies which have looked at utilizing dRPE as a means of monitoring internal load within an applied team sport setting. The latter having not investigated the concept validity first before applying dRPE to team sport training. The exercise protocols used in this study were designed to mimic high intensity runs with a short deceleration (Howatson and Milak, 2009). The aim of the exercise protocols in this study were to manipulate the muscular component of dRPE (RPE_L) independently by changing the deceleration distance. A 30 metre running distance with a five metre deceleration (Dec5m) was chosen in an attempt to elicit the greatest eccentric demand as this best reflects the sprinting and deceleration distance in team sports (Lakomy and Haydon, 2004; Howatson and Milak, 2009). To contrast this demand, a 15 metre deceleration distance was also chosen with the view that this would not require the same level of eccentric load due to having a greater distance to slow down over. The volume and intensity of the protocols were controlled for in the experimental design. The volume was controlled for by ensuring each repetition was the same distance in length and the intensity was controlled by instructing the participants to complete each repetition at 95% of the participants maximum velocity. In order to monitor the appropriateness of the protocol manipulation measures of muscle soreness, neuromuscular function, sprint performance times and dRPE were collected. Differential ratings of perceived exertion were collected immediately after each repetition so that the scores would be reflective of the most recent repetition performed rather than that of the whole protocol (Foster *et al.*, 2001; Impellizzeri *et al.*, 2004).

Overall, the external load measured using MEMS devices demonstrated that the Dec5m protocol elicited the greatest peak deceleration compared to the Dec15m protocol ($p = 0.005$). This data suggests that this external load variable was successfully manipulated between the protocols which may have increased the eccentric demand during the Dec5m protocol. The peak deceleration values reported in this study are comparable to the very high intensity (>3.5 m/s^2) decelerations which have been reported in soccer (Wehbe *et al.,* 2014), rugby union (Cunningham *et al.,* 2016), American football (Wellman *et al.,* 2015) and rugby sevens (Suarez-Arrones *et al.,* 2016). The number of very high decelerations performed within soccer have been reported to be between 16 (attackers) and 32 (midfielders) dependent on playing position (Wehbe *et al.,* 2014) which supports the reasoning for completing 20 very high intensity decelerations in this study. Whilst the deceleration distances were different between protocols in an attempt to increase the muscular load, the volume (distance covered during each repetition) of each protocol was controlled for so that it was the same between protocols. The total distance calculated by MEMS devices across the twenty repetitions was similar between protocols ($p = 0.615$) which supports the design of the exercise protocol. Although the total distance was similar between the protocols, the distance covered >7 m/s was substantially different between the protocols. The Dec15m protocol had the greatest distance covered above seven metres per second. An explanation for this might be that the there was a premature slowing down in the Dec5m protocol in an attempt to prepare for the rapid deceleration required at the end of the sprint. This would have had the potential to reduce the peak deceleration during these repetitions meaning that the eccentric load associated with stopping over 5 metres would be less. Comparisons with previous studies (Lakomy and Haydon, 2004; Howatson and Milak, 2009) are unavailable as using MEMS to measure the external load of the protocols was beyond scope of these studies. The results from this study suggest that overall, the broad aim of the experimental design was appropriate as key aspects of the external load, such as the volume (e.g. total distance) was controlled and other important aspects (e.g. the peak deceleration) was manipulated. Some differences in the indications of the intensity of the protocols, i.e, the difference in distance covered sprinting between the protocols, may indicate that other aspects of the exercise, that are important for the overall demand may not have been as well controlled as required. This may have implications for the data collected in this investigation.

Alongside controlling the volume of each protocol in the experimental design, the intensity was controlled for by instructing the participants to complete each repetition of the protocol at 95% of their max velocity. The importance of maintaining near maximal efforts on each repetition was highlighted by Howatson and Milak (2009) as when participants run at faster speeds a much larger breaking force is required to be able to stop in the deceleration zone. As a result of this, the eccentric muscular demand is greater which is important when trying to manipulate the muscular demands associated with a task. During the familiarization protocol, on average, the participants completed each rep within 94.9 ± 2.3% which suggests that the intensity of each repetition was controlled for. However, the familiarization protocol only involved ten repetitions of a 20 metre acceleration with a ten metre deceleration. During the main exercise protocols the results indicate that changes in 30 metre sprint performance from the first to the last repetition were *likely* increased for the Dec5m ($p = 0.025$), Dec15m ($p = 0.008$) and Dec15/5m ($p = 0.015$) protocols and *possibly* increased for the Dec5/15m ($p = 0.143$) protocol. The increase in performance times across the protocols may suggest that the breaking force required to stop was reduced and subsequently so was the eccentric muscular demands. This has the potential to have adjusted the peripheral (RPE_L) signals as there was a reduction in the force at which the contracting muscle is lengthened (Proske and Morgan, 2001). However, the average maximum velocity was consistent across all the protocols and there were no substantial differences between protocols from the first to the last repetition. This data also supports the fact that the additional distance covered at sprinting speeds during the Dec15m protocol compared to the Dec5m protocol occurred after the 30 metre acceleration. Therefore, it can be concluded that the intensity of these accelerations were controlled for as there were no differences between protocols in maximum velocities.

In the current study the Dec5m protocol showed elevated muscle soreness in comparison to the Dec15m protocol when comparing the subjective scores forty-eight hours post to pre protocol (very likely increase) and 48 hours post to immediately post protocol (likely increase). However, there was no difference between these two protocols when comparing 24 hour measures. This suggests that whilst muscle soreness was starting to reduce in the Dec15m protocol the Dec5m protocol soreness stayed elevated after 48 hours. These finding are in agreement with Thompson *et al.*, (1999) and Howatson and Milak (2009) whom both reported elevated muscle soreness 48 hours post protocol after the Loughborough Intermittent Shuttle Test (LIST) and a repeated sprint protocol with a short deceleration respectively. These results suggest that the design of the protocols successfully manipulated the eccentric demands as seen by the increase in muscle soreness in the Dec5m protocol.

Changes in neuromuscular function measured using a horizontal jump pre, at the mid-point and post protocol were unclear between all protocols apart from there was a possible increase in neuromuscular function between the Dec5m and Dec5/15m protocol and a possible decrease between the Dec5/15m and Dec15/5m protocols. These results suggest that overall, there was no substantial difference in neuromuscular fatigue between the protocols. Previously, the use of a horizontal jump to assess fatigue after soccer match play has been questioned based on its sensitivity to detect markers of fatigue compared to other jump tests such as a countermovement jump (Thomas *et al.*, 2017). It is unknown as to whether similar results would have been shown if a countermovement jump was utilized instead based off the recommendations of Thomas *et al.*, (2017). However, the rationale to use a horizontal jump was due to the fact that accelerating and decelerating require strength in the horizontal axis and, as such, you would expect that these muscles may show signs of fatigue after performing these actions in this axis (Castillo *et al.*, 2017). The aim of this study was to investigate between protocol changes in horizontal jump to assess whether the Dec5m protocol was more peripherally demanding than the others and in this case there were no differences suggesting that there was no difference in neuromuscular fatigue between protocols. This would suggest that the design of the exercise protocols in this study were not suitable to have manipulated neuromuscular function between the protocols. However, it might be possible that the choice of neuromuscular fatigue measure was not appropriate for this study.

Although the above results suggest that the exercise protocols overall were successfully manipulated in order to increase the muscular load associated with the task this was not reflected in the RPE_L scores between protocols. Overall, there was no difference in peripheral (RPE_L) or central (RPE_B) ratings of perceived exertion between the protocols using an anchored based approach. However, during all the protocols RPE_L and RPE_B increased as the protocols progressed suggesting that dRPE is sensitive enough to detect increases in these demands across exercise periods albeit there was no difference between protocols. These preliminary results suggest that dRPE might not be a sensitive enough measure to detect small differences in the muscular and respiratory demands of exercise and so may have limited utility to monitor the subjective response to exercise under some conditions.

Ratings of perceived exertion are a subjective representation of the internal load response to training and competition and due to this it is highly individual. In this study there was a large variance observed with the dRPE scores and whilst overall there was no difference between protocols individual differences were observed. This suggests that it may be possible on an individual level dRPE is sensitive enough to detect changes. For example, during the Dec5m protocol the RPE_L mean score on the 20th repetition was 60 AU. However, the variation in RPE_L scores between the participants was a standard deviation of 29 AU. Hopkins (2000) suggests that when such individual variations are observed the researcher should look to identify the participants characteristics in an attempt to understand what has caused these differences between participants. However, as previously discussed in the literature review identifying these characteristics which have an effect on the internal load of participants is difficult as it can be a magnitude of different factors such as age, genetic background and the individuals starting fitness level (Bouchard and Rankinen, 2001; Impellizzeri *et al.*, 2005; Gil-Rey *et al.*, 2015a). Also, not only can these characteristics differ between individuals but the internal load response to the same exercise stimulus can vary markedly between the same individual on different days due to the individuals state of fatigue, illness or psychological wellbeing (Bourdon *et al.*, 2017; Impellizzeri *et al.*, 2019). The results from this study highlights the importance of treating each player as an individual as the internal demand's players experience whilst completing the same external load can be quite different between each other. Therefore, this is a limitation of this current study as analysis was not conducted on an individual level.

Another limitation of this current study which may have caused confounding results is the level of familiarization the participants completed to get accustomed to the dRPE scale. It was presumed that the participants were familiarized with the dRPE scale as they had previously completed an incremental test and the participants trained and competed regularly. Therefore, it was assumed that the participants had been exposed to a range of training intensities so that they would have a large perceptual reference filter for RPE_L and RPE_B as suggested by Impellizzeri *et al.*, (2004) and Pageaux (2016). However, whilst the participants were accustomed to providing an RPE after training and matches the participants had only previously provided separate peripheral and central ratings during the familiarization protocol which was not a maximal test. Thus it cannot be certain that the participants had ever completed an activity where they found the muscular demand 'maximal' which may have meant their RPE_L scores were under or over estimated as the participants had no point of reference to provide their current RPE_L scores against (Impellizzeri *et al.*, 2004; Pageaux, 2016). Similarly, no dRPE study to date has detailed the process by which the participants were familiarised with providing RPE_L and RPE_B ratings. Therefore, this limitation needs to be addressed before any further dRPE studies are conducted.

Further research should include the design of an exercise protocol which exposes participants to 'maximal' feelings of leg muscle exertion and feelings of breathlessness so that participants are suitably familiarised before the concept validity of dRPE can be confirmed. Once this has been conducted, further studies should implement this familiarisation protocol and then investigate the sensitivity of dRPE during different exercise protocols which replicate the demands of team sports on an individual level. If the participants have been suitably familiarised more robust conclusions of the concept validity of dRPE can be confirmed.

5.2 CONCLUSIONS

In conclusion, the current study successfully designed exercise protocols which manipulated the muscular load associated with the task as indicated by the objective measures. However, this was not reflected in the subjective internal response of the participants when providing RPE_L and RPE_B ratings. Therefore, the data from this study suggests that dRPE is not sensitive enough to detect changes between the protocols used in this study with this particular cohort of participants. Thus, not providing any additional information compared to that of a global RPE when comparing group means. However, the variance observed in individual’s internal response to these exercise protocols suggest that in some conditions dRPE may provide some additional information which may otherwise be masked when collecting a global RPE. Nonetheless, this study only investigated the sensitivity of dRPE during a specific deceleration-based protocol with a specific cohort of recreational team sport players. Therefore, no conclusions can be drawn to the overall sensitivity of dRPE when utilized within a wider population under different exercise or sport scenarios. The major limitation of this study around the familiarization process means that more robust conclusions cannot currently be drawn. Therefore, given the suggested advantages of using dRPE as a means of monitoring internal load further studies investigating the concept validity of dRPE are warranted but only if the participants have gone through a thorough familiarization process beforehand which would address the limitation of this current study.

CHAPTER 6

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