# An Assessment of Heart Rate as a Tool for the Monitoring of Physiological Status in Soccer Players Following Competitive Match-play

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## Abstract

The area of recovery following soccer match play has become an increasingly popular area of focus in recent years. There is limited research around the activities and monitoring processes undertaken within elite soccer clubs. To the authors knowledge, there is only one previous research article that has attempted to understand the activities undertaken during this period within elite soccer (Nedelec *et al.,* 2013). The aim of this thesis was to understand the activities undertaken by elite soccer players during the recovery period following match play and to investigate the suitability of the various approaches to monitor physiological status during the period.

The aim of study 1 (Chapter 3) was to provide an overview of the activities undertaken by soccer players (n=53) during periods of the training week dedicated to recovery following match play. The findings of this study show that massage therapy accounted for the longest amount of time on matchday +1 (MD+1) (43min) and pitch based active recovery on matchday +2 (MD+2) (44min). Pool based active recovery was the most consistently completed method on MD+1 (64%) and pitch based active recovery on MD+2 (80%). These data may not only provide useful information on the recovery processes included in the training plans of elite soccer players but also give potential insights into the strategies that may be used to effectively monitor this recovery between games.

The aim of study 2 (Chapter 4) was to determine if heart rate variability (HRV) obtained through a purpose built smartphone application measured on the first day (MD+1) and second day (MD+2) following match play can detect changes in the physical loads undertaken by elite soccer players (n=21). No significant relationships between any of the physical loading variables assessed in this study and smartphone derived HRV MD+1 or HRV MD+2 (natural logarithm of the square root of the mean squared differences of successive R-R intervals [Ln rMSSD]) were found. This suggests that measurements of HRV through the 'ithlete' method may not be suitable for use in monitoring physiological status following soccer match play.

The aim of study 3 (Chapter 5) was to develop a reliable exercise protocol that could be used for calculation of heart rate recovery (HRR) and percentage of

maximum heart rate reached (%MAXHRr) with elite soccer players (n=15) while adhering to the specific characteristics of an exercise test that would facilitate completion with an elite soccer team. The data presented in this study suggests that the most suitable exercise protocol with regards to the reliability of the heart rate (HR) response and adherence to the physical loads used during the recovery period with elite soccer players was 6x80m straight-line runs at 5m/s with an exercise: rest ratio of 16:14s. This protocol presented coefficient of variation (CV), standard error of measurement (SEM) and physical loading data that were superior to data associated with other similarly styled protocols considered throughout this study.

The aim of study 4 (Chapter 6) was to assess the face validity of the HR response to the developed standardised exercise protocol (SEP) under controlled conditions following a high physical load simulated soccer training session (HSSTS) and a low physical load simulated soccer training session (LSSTS) (n=10). The findings of this study suggest that the HR response to the SEP was able to detect manipulated changes in physiological status as a result of a high physical load and a low physical load simulated soccer training session. The %MAXHR during the SEP was found to be significantly higher following the HSSTS (92%) in comparison to the LSSTS (90%). HRR was found to be lower following the HSSTS (17%) when compared to the LSSTS (22%).

The aim of study 5 (chapter 7) was to assess the effectiveness of using HRR and %MAXHRr measured through the SEP on the first day (MD+1), second day (MD+2), and third day (MD+3) following match play to detect changes in physical loads experienced by players (n=16) during the preceding soccer game. The findings of this study show the SEP to have limited capabilities in the detection of changes in HRR and %MAXHR on MD+1, MD+2, or MD+3. The data presented may suggest that the SEP is most suited for implementation on MD+2 or MD+3. It seems that HRR is the more sensitive of the markers investigated.

In summary, the studies undertaken as part of this thesis provided an insight into the structure of the activities employed during the recovery period following elite soccer match play and the potential opportunities to monitor physiological status during this process. Initially this involved providing an understanding of the types of activities that were completed by players during this period. This was followed by an assessment of one of the current methods of monitoring physiological status (HRV analysis in chapter 4) during this time frame. This provided the basis for a novel method to be developed. The latter studies then focussed on developing a reliable and valid method of monitoring that could be easily implemented into the schedules during the recovery period within an elite soccer club which were outlined at the outset.

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## List of Abbreviations

**%MAXHRr –** Percentage of Maximum Heart Rate Reached

**ANS** – Autonomic Nervous System

**CK** – Creatine Kinase

**CMJ** – Countermovement Jump

**CV** – Coefficient of Variation

**CWI –** Cold Water Immersion

**ECG** – Electrocardiography

**ECL –** English Championship League

**EL1** – English League 1

**EPL –** English Premier League

**ES –** Effect Size

**GPS –** Global Positioning Systems

**HSSTS –** High Physical Load Simulated Soccer Training Session

**HI** – High Intensity

**HL SEP –** Standardised Exercise Protocol following the High Physical Load Simulated Soccer Training Session

**HR** – Heart Rate

**HRR –** Heart Rate Recovery

**HRV** – Heart Rate Variability

**LSSTS –** Low Physical Load Simulated Soccer Training Session

**LL SEP –** Standardised Exercise Protocol following the Low Physical Load Simulated Soccer Training Session

**Ln rMSSD –** Natural Logarithm of the Square Root of the Mean Squared Differences of Successive R-R Intervals

**MaxHR –** Maximum Heart Rate

**MD+1** – Match Day +1

**MD+2** – Match Day +2

**MD+3** – Match Day +3

**RPE** – Rating of Perceived Exertion

**SD** – Standard Deviation

**SEM** – Standard Error of Measurement

**SEP** – Standardised Exercise Protocol

**SWC** – Smallest Worthwhile Change

**TD** – Total Distance

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# Chapter 1

## General Introduction

## 1.1 Background

Soccer is a complex sport that involves the completion of various movements and actions in an intermittent exercise pattern. From a physiological perspective this exercise pattern broadly involves the performance of high intensity actions interspersed with periods of lower intensity activity (Bangsbo, 2014). Alongside these movements performance requires various technical actions such as passing, shooting and tackling combined with tactical decisions to remain in an appropriate position throughout the game. These skills require effective contributions from systems that are partly physiological in focus. The extent to which these actions within a game disturb "homeostasis" within each player will be affected by various factors such as age, training history, and fitness levels (Nedelec *et al.,* 2012). The internal loads imposed on a player by the challenge of any given match has the potential to affect the amount of time required by each player to fully recover from the stimulus associated with match-play. This may in turn influence the time that should be left before commencing the next soccer training session, in preparation for the next game, or the timing of the subsequent match itself.

The potential for restricted recovery time between games is seen as one of the contemporary challenges associated with modern day soccer. It is common now for many elite soccer teams to play above 50 games in a single season with some of the more successful teams competing in over 60 games. These games can frequently be scheduled in response to the requirements of television companies to facilitate the demand for live games from the general public. When this fixture schedule (as little as 40 hours between the end of one game and the kick-off of the next) is also combined with the long distance travel often required to complete these fixture requirements, the evidence would suggest that it is sometimes impossible for players to fully "recover" in the short time allowed between games (Nedelec *et al.,* 2012). It would therefore seem apparent that there is an underlying need for both scientists and practitioners to be able to fully understand the impact of match-play on a players physiological status, especially during periods of high fixture congestion, and different lengths of recovery time. It has been suggested that heart rate (HR) based measures may provide a potential method of quantifying these match related changes in an individual's physiological status (Buchheit, 2014) following games.

Heart rate based measures provide detail on the physiological response to a physical stimulus during both the exercise bout itself and in the period following the cessation of exercise (Achten & Jeukendrup, 2003). From a physiological perspective, HR is associated with a change in homeostasis as the cardiovascular system plays a pivotal role in supporting the physiological functions essential to both rest and exercise. Changes in the modulation of HR are fundamentally a result of imbalances in the autonomic nervous system (ANS) or more specifically changes in sympathetic drive and parasympathetic reactivation and sympathetic withdrawal during and following exercise. These imbalances are a result of information provided by various feedback mechanisms such as chemoreceptors (changes in oxygen availability and/ or pH), mechanoreceptors (contraction of skeletal muscle), and baroreceptors (changes in blood pressure) which highlight fluctuations from homeostasis. Under normal conditions, these mechanisms allow for subtle changes in bodily outputs such as HR, vasodilation and vasoconstriction to maintain homeostasis. The relationship between the HR response and the onset of exercise has provided the basis for individuals to develop various metrics that reflect the functional status of the cardiovascular system. These metrics include exercising HR, heart rate recovery (HRR), and heart rate variability (HRV).

Exercising HR is a marker of sympathetic drive. Sympathetic drive is responsible for the increase in HR that occurs as a result of an initiation of an exercise stimulus. Le Meur *et al.* (2016) have shown the usefulness of exercising HR to assess the physiological status of triathletes. The authors found that athletes in a functionally overreached state (the first stage of overtraining which is synonymous with a short term decrease in performance) presented a lower exercising HR in response to a standardised exercise bout when compared with a control group. More research is required to fully understand the usefulness of exercising HR as a tool to assess physiological status following an exercise stimulus. This area may be particularly applicable to soccer due to the ease of implementation and the fact that HR monitoring is already used extensively within soccer. Conversely, HRV and HRR are both markers of parasympathetic activity. An increase in the activity of the parasympathetic nervous system results in a reduction in HR as observed following the cessation of exercise. Lamberts *et al.* (2009) suggested that HRR was sensitive to changes in physiological status when assessed with well-trained endurance athletes. More recent research by Le Meur *et al.* (2016) has suggested that although HRR can track changes in training status, it is unclear as to whether an increase or decrease in HRR is associated with a supressed physiological status. With this in mind, further research around HRR may be required to determine its practicality for use within elite soccer. Due to the requirement for an exercise stimulus to assess HRR, it may be possible to combine the use of exercising HR and HRR to provide an understanding of physiological status. On the other hand, HRV assesses the variability in the time between heart beats (R-R intervals) to assess changes in parasympathetic activity. Stanley *et al.* (2013) provide a comprehensive review of the current literature around the use of HRV as a tool to assess autonomic balance. The authors suggest that using HRV data alongside the quantification of training loads can allow for training schedules to be periodised individually. The data analysed by Stanley *et al.* (2013) utilised varied participant groups from inactive to highly trained athletes. However, all exercise protocols involved either continuous or interval exercise through treadmill running or ergometer cycling. More recent works have sought to validate the use of HRV for similar purposes with elite soccer players under the specific stresses of soccer specific training (Flatt & Esco, 2015). However, the usefulness of HRV as a tool to assess acute changes in physiological status following an exercise stress (such as soccer match play) in still unknown.

There is sound physiological understanding that underpins the use of HR based measures with regards to assessing physiological status in response to an exercise stimulus. However, it is not yet fully understood how transferable this is to more complex exercise stimuli such as soccer specific training. In previous research, the stimuli utilised has been more traditional endurance type exercise which tends to involve a high volume of moderate intensity exercise. It is clear that this induces a significant stress to the cardiovascular system as HR and respiratory rate must be elevated for prolonged periods to increase blood flow and oxygen supply to the working muscles. Further to this, various components of homeostasis such as hydration status, biochemical balance, and muscle glycogen stores will be affected by this type of exercise. The aforementioned factors are indicative of the recovery status of an athlete and subsequent changes in recovery status elicited by this type of stimulus may impact on the modulation of HR. Due to the nature of the demands associated with soccer, it is uncertain if the physical loads experienced by players will stress the cardiovascular system and affect the modulation of HR in a similar manner. Although it is undoubted that homeostasis will be disturbed by the demands of soccer, the intermittent pattern associated with match play allows for recovery periods following high intensity bouts. This may significantly alter the demands placed on the cardiovascular system in comparison to that of endurance type exercise. Therefore, there is a need for a more in depth analysis of all of the relevant HR based measures (exercising HR, HRR, HRV) that can be utilised within elite soccer. Furthermore, it is important to consider the practicality of assessing these HR measures with elite team sports populations, such as soccer players. The methods implemented with endurance athletes may not be suitable for use in soccer due to the time consuming nature and high physical loads associated with these methods. It may be beneficial to develop a specific protocol design for the assessment of the aforementioned HR based measures that is suitable for implementation into the predetermined training schedules and physical loading patterns experienced by elite soccer players.

## 1.2 Aims and Objectives of the Thesis

The aims of this thesis are:

1. To better understand the structure of the period following soccer match play that is dedicated to recovery and to understand the potential for monitoring of physiological status during this period.

2. To better understand if HR based measures can be used to monitor the physiological impact of soccer games in elite players.

This will involve the fulfilment of the following objectives:

1. To provide an overview of the activities undertaken by soccer players during periods of the training week dedicated to recovery following match play (Chapter 3).

2. To determine if HRV obtained through a purpose built smartphone application measured on the first day (MD+1) and second day (MD+2) following match play can detect changes in the physical loads associated with the preceding soccer match (Chapter 4).

3. To develop a reliable exercise protocol that can be used for calculation of HRR and %MAXHRr with elite soccer players while adhering to the specific characteristics of an exercise test that would facilitate completion with an elite soccer team (Chapter 5).

4. To determine the face validity of the HR response to the developed standardised exercise protocol and its ability to detect changes in physiological status under controlled conditions following a high physical load simulated soccer training session and a low physical load simulated soccer training session (Chapter 6).

5. To assess the effectiveness of using HRR and %MAXHRr measured through the SEP on the first day (MD+1), second day (MD+2), and third day (MD+3) following match play to detect changes in physical loads experienced by players during the preceding soccer game (Chapter 7).

# Chapter 2

## Literature Review

*The aim of this chapter is to provide a comprehensive background of the areas that underpin the studies undertaken in this thesis. The chapter is split in to three sections which cover the demands of soccer, recovery in soccer, and the monitoring of recovery in soccer. The first section is of particular importance as it is vital to understand why there is a need for a recovery period following soccer match play and to understand the variables that may affect the subsequent recovery period. The second section provides an overview of the current literature that provides the rationale for the activities and interventions that are typically used in elite soccer. Finally, the third section highlights the current position of monitoring techniques used during the recovery period within elite soccer. This was important in order to gauge what would be the most appropriate method of recovery monitoring.*

## 2.1 The Demands of Soccer

### *2.1.1 The Physical Demands of Soccer Match Play*

If the performance of elite soccer players is to be enhanced, the demands of competing in the sport at the highest level must be understood. Considerable research over the last two decades has attempted to quantify the physical loads experienced by players during professional soccer matches (Bangsbo *et al.*, 1991; Bradley *et al.*, 2013a; Bradley *et al.*, 2010; Bradley *et al.*, 2009; Di Salvo *et al.*, 2010; Di Salvo *et al.*, 2013; Mohr *et al.*, 2003). In more recent years the majority of studies in this area have elected to use semi-automatic video match analysis image recognition systems (Prozone Sports Limited, Leeds, UK) to understand demands placed on soccer players. With this is mind, it seemed appropriate to only include studies that used this method to ensure there is no discrepancies in the demands of soccer were presented as a result of variance in the methods used. An overview of the studies that met these criteria can be found in table 2.1. As soccer has developed over the last few decades, there has been more emphasis placed on the physical conditioning of players which has contributed to higher intensity games during which players undertake higher physical loads than those experienced in the past (Bradley *et al.,* 2016). There is a general agreement within the literature that players cover between 9,000 and 14,000m during a game of which, between 500 and 2000m is at a high intensity (HI) (>5.5m/s) and between 250 and 900m is completed at sprinting speed (>7m/s) (KirKendall, 2011; Di Salvo *et al.,* 2013). This research area has developed in parallel with the available technology that has allowed for improvements in the quality of measurements of players' movements during match play. In particular, these advancements have improved the understanding of HI actions including high speed running, sprinting, and rapid changes of direction.

It is believed that HI activities are a vital component of performance at the elite level (Dellal *et al.*, 2011). Such HI activities are performed when players are both in and out of possession of the ball. HI actions whilst the reference players' team is out of possession of the ball include returning to the correct tactical position, applying pressure to the opposition team, and denying space on the pitch for the opposition team to play in. HI activities while the reference players' team is in possession of the ball are particularly important during counter attacking as they are crucial for creating space in advanced positions and increasing the tempo of play to penetrate the opposition defence. Ultimately, the ability of a player(s) to undertake these HI actions may have a significant effect on the outcome of a soccer game.

**Table 2.1.** An overview of recent (2006 - Present) research papers providing average data, collected through Prozone Sports Ltd® exclusively to limit methodological discrepancies, on the activity profiles of elite players.

| Authors | Participants* | Total Distance (m) | HI Distance (m) (>5.5m/s) | Sprint Distance (m) (>7.5m/s) |
|---|---|---|---|---|
| **Andrzejewski *et al.* (2014)** | PE | 11,168 | 569 | 255 |
| **Bradley *et al.* (2009)** | EPL | 10,714 | 905 | 250 |
| **Bradley *et al.* (2010)** | INT & EPL | 10,762 | 691 | 258 |
| **Bradley *et al.* (2013)** | EPL | 10,722 | 681 | 248 |
| **Dellal *et al.* (2011)** | EPL & SPD | 10,993 | 527 | 241 |
| **Dellal *et al.* (2012)** | FL1 | 11,173 | 648 | 295 |
| **Di Salvo *et al.* (2007)** | SPD & UCL | 11,393 | 950 | 343 |
| **Di Salvo *et al.* (2013)** | EPL | 10,746 | 693 | 258 |
| **Dupont *et al.* (2010)** | SPL & UCL | 11,136 | 555 | 253 |
| **Morgans *et al.* (2014)** | ECL | 10,591 | 838 | 223 |

*EPL – English Premier League Players, INT – International Players, ISA – Italian Serie A Players, SPD – Spanish Primera Division Players, FL1 – French Ligue 1 Players, UCL – UEFA Champions League Players, SPL – Scottish Premier League, ECL – English Championship League, PE – Polish Ekstraklasa.

While the above information provides a very general summary of the physical demands of soccer, the simple analysis of velocities and distances covered may not be sufficient to accurately represent the demands of the sport. It is important to consider the several hundred changes of direction, the accelerations and decelerations, the backwards and sideways running and the jockeying actions which are also an integral part of soccer specific movements. The volume of these movements may significantly increase or decrease the physiological demands experienced by players during games. Russell *et al.* (2016) reported that elite soccer players undertake 656 (±57) accelerations (>0.5m/s$^2$) and 612 (±59) decelerations (>0.5m/s$^2$) during a soccer match, of which 26 (±9) accelerations and 43 (±13) decelerations are classified as HI actions (>3.0m/s$^2$). The additional physiological demands associated with these actions are a consequence of the recruitment of a more diverse range of muscle groups and an increased requirement for eccentric and isometric muscular contractions.

Further to the above, technical actions including passing, tackling, shielding the ball, shooting, jumping and heading should also be considered in the analysis of the demands of the sport as the ability of players to repeatedly produce high quality technical actions is an essential part of performance at the elite level (Ali, 2011; Rampinini *et al.*, 2009; Russell & Kingsley, 2011; Reilly & Ball, 1984). The aforementioned technical actions are thought to significantly contribute to the physical loads associated with soccer performance (Dellal *et al.,* 2009; Hodgson *et al.*, 2014; Osgnach *et al.,* 2009). For example, Reilly and Ball (1984) found that running with the ball elicits a more profound physiological response in comparison to running without the ball. This is due to more frequent and varied stride patterns to allow control of the ball, increased muscle contraction forces and varying types of muscle contractions to propel the ball forwards, and additional use of stabilising muscles. Similarly to the different movements outlined above, this may affect the overall physiological load experienced by players.

### *2.1.2 Variations in the Physical Demands of Soccer Match Play*

There are many factors that can impact on the "generic" physical demands associated with soccer match play (Taylor *et al.,* 2008). The extent to which these factors affect the physical demands experienced by players may ultimately impact on the subsequent physiological status of players and the required recovery period. These factors, and the extent to which they can affect the physical demands of soccer match play, are explored in this section.

Factors that impact on the physical demands required of players during soccer match play may include within game factors such as individual playing position, team or individual tactical instruction, opposition formation and/or tactical setup, technical elements (team and individual possession of the ball), the circumstances of the game (score-line or the importance of the fixture), and the competition standard (technical/ tactical quality of players). There are also external factors such as environmental conditions (high or low temperatures), fixture schedules (recovery period between games), and the onset of fatigue during games that may alter the physical demands experienced by players.

Firstly, it is likely that all players will accumulate some fatigue during a soccer game regardless of these aforementioned factors that may impact on the physical demands of match play. However, the level of fatigue may be exacerbated or reduced by factors effecting physical demands. Similarly, levels of fatigue, especially in the later stages of the game, can impact on the physical demands experienced by players during soccer games (Reilly *et al.,* 2008). An example of this is studies that have reported elite soccer players to cover more distance during the first half in comparison to the second half of the game (Bangsbo *et al.,* 1991). Furthermore, it was also found that distances covered at HI and sprinting thresholds decreased in the second half in comparison to the first half. There was also a pattern of decreasing HI and sprinting distances from the first third of the second half (45-60min) to the final third of the second half (75-90min) (Mohr *et al.,* 2003). This may be a result of players being more fatigued in the second half due to the exertions of the first half.

It is apparent that the within game factors outlined above are somewhat interlinked with the largest variations in physical demands found between playing positions (Bloomfield *et al.*, 2007; Dellal *et al.,* 2012; Di Salvo *et al.*, 2007; Di Salvo*, et al.*, 2013). For example, The data presented in Table 2.2 suggests that central midfielders cover more total distance (TD) and wide midfielders cover more distance at HI and sprinting speeds in comparison to other playing positions. The variations in physical demands between positions are a result of the specific tactical roles associated with each playing position. For example, the activity profile of central midfielders is a result of their need to support defensive and offensive players whilst providing a link between defensive and attacking phases of play. However, wide midfielders' physical demands are due to their reduced defensive responsibility and focus on attacking in wide areas of the pitch where more space is available. Changes in team formations and tactical instructions are implemented by coaches in an attempt to restrict space for the opposition team or to increase the amount of space available to their players when in possession. This can result in certain players undertaking the responsibilities of multiple playing positions thereby necessitating an increase in their physical activities (e.g. wide defenders having to support attacking phases of play in the absence of a wide midfielder). These variations, as a consequence of formation or tactical set up, are generally more profound for wide defenders, wide midfielders and attackers in comparison to other positions (Bradley *et al.,* 2011; Carling, 2011). This may mean that the physiological status of individual players who play in different positions may be significantly different. In turn this may require the recovery period following each game to be individualised for players depending on their playing position and the associated demands.

**Table 2.2.** An overview of research papers providing position specific data, obtained through Prozone Sports Ltd®, including total, high intensity and sprint distances (mean ± SD) covered by elite soccer players.

| Playing Position | Source | Total Distance (m) | HI Distance (m) (>5.5m/s) | Sprint Distance (m) (>7.5m/s) |
|---|---|---|---|---|
| **Central Defenders** | Andrzejewski *et al.* (2014) | 10,335±470 | 399±89 | 185±82 |
| | Dellal *et al.* (2012) | 10,671±301 | 547±113 | 232±52 |
| | Di Salvo *et al.* (2007) | 10,627±893 | 612±114 | 215±100 |
| | Di Salvo *et al.* (2013) | 10,341±611 | 482±116 | 168±72 |
| | Dupont *et al.* (2010) | 9,924±389 | 285±95 | 123±63 |
| **Wide Defenders** | Andrzejewski *et al.* (2014) | 11,063±790 | 589±107 | 264±121 |
| | Dellal *et al.* (2012) | 11,217±405 | 683±135 | 309±70 |
| | Di Salvo *et al.* (2007) | 11,410±708 | 1,054±179 | 402±165 |
| | Di Salvo *et al.* (2013) | 11,035±663 | 712±156 | 285±113 |
| | Dupont *et al.* (2010) | 10,762±573 | 559±151 | 311±130 |
| **Central Midfielders** | Andrzejewski *et al.* (2014) | 11,760±797 | 483±100 | 167±87 |
| | Dellal *et al.* (2012) | 11,885±546 | 688±127 | 317±63 |
| | Di Salvo *et al.* (2007) | 12,027±625 | 875±184 | 248±116 |
| | Di Salvo *et al.* (2013) | 11,784±711 | 765±191 | 241±106 |
| | Dupont *et al.* (2010) | 11.935±721 | 631±240 | 293±115 |
| **Wide Midfielders** | Andrzejewski *et al.* (2014) | 11,745±690 | 697±115 | 313±122 |
| | Dellal *et al.* (2012) | 11,301±623 | 660±111 | 303±52 |
| | Di Salvo *et al.* (2007) | 11,990±776 | 1,184±174 | 446±161 |
| | Di Salvo *et al.* (2013) | 11,766±775 | 898±200 | 353±124 |
| | Dupont *et al.* (2010) | 11,742±696 | 650±162 | 298±168 |
| **Attackers** | Andrzejewski *et al.* (2014) | 10,939±648 | 677±109 | 346±129 |
| | Dellal *et al.* (2012) | 11,173±524 | 666±125 | 315±69 |
| | Di Salvo *et al.* (2007) | 11,254±894 | 1,025±161 | 404±140 |
| | Di Salvo *et al.* (2013) | 10,783±877 | 703±168 | 297±115 |
| | Dupont *et al.* (2010) | 11,317±635 | 651±200 | 240±122 |

The level of competition can also have an impact on the physical demands placed on players (Bradley *et al.,* 2013a; Rampinini *et al.,* 2009). It is believed that as competition level decreases, the physical demands (TD & HI distance) increase. Bradley *et al.* (2013a) compared distances covered by players in the top three divisions of English soccer (English Premier League [EPL], English Championship League [ECL], English League 1 [EL1]). They found that TD, HI distance and the distance covered at sprinting speed all increased as playing standard decreased (EPL – TD= 10,722m, HI Distance= 681m, Sprint= 248m; ECL – TD= 11,429m, HI Distance= 803m, Sprint= 308m; EL1 – TD= 11,607m, HI Distance= 881m, Sprint= 360m). The authors suggest that these differences in physical demands between competition levels could be a result of different styles of play (possession play with short passing vs. direct play with long passing) and variations in technical performance (number of ball contacts, number of passes) (Dellal *et al.,* 2011). Regardless of the mechanism responsible for these changes in demands between competitive levels, it is important to understand the effect this may have on the required recovery period following match play. This may be exacerbated due to the more congested fixture schedules that are an integral part of the ECL and EL1, as discussed below. Interestingly, when the effect of congested fixture periods (2/3 games per week) at the highest competitive level was assessed it was found that the physical demands are actually similar to those observed during 'normal' fixture periods (1 game per week). Carling *et al.* (2012) and Zanetti *et al.* (2018) both reported that physical demands were similar irrespective of normal or congested fixture schedules.

Environmental conditions and fixture schedules are the two most researched areas with respect to "external" factors that could impact on physical performance. With regards to environmental conditions, Mohr *et al.* (2012) found that total distance covered and HI distances were decreased in hot conditions (43°C) compared with a control condition (21°C). On the other hand, Carling (2012) found that the physical demands of soccer match play were not affected when games took place in colder temperatures (5°C vs. 21°C). The fixture schedule dictates the number of games played, the number of training days available and the required amount of recovery, therefore potentially altering the overall physical loads experience by players during a specific period. This schedule can be influenced by the fixture schedule imposed by the governing body as well as being impacted by a team's involvement in various competitions and requests by the media for fixtures to be televised live. These changes can reduce the amount of recovery time between games, thereby inhibiting the players' ability to reproduce the same physical performance in subsequent games (Morgans *et al.,* 2014a; Morgans *et al.,* 2014b; Rowsell *et al.,* 2011). Morgans *et al.* (2014b) presented physical performance data for 7 competitive games in a 29-day period with varying recovery periods between each game. Values for TD and HI distance were lower in games following short recovery periods (<72 hours) in this sample of data. This effect was exacerbated in consecutive games that were both followed short recovery periods. This data highlights the need for adequate recovery time between games in order to avoid declines in physical performance during soccer games.

In summary, the physical demands of soccer match play are made up of various movements and actions. There can be significant differences in the demands placed on each player as a result of within game factors as well as external factors. In turn this may impact on the subsequent physiological status of individual players in the days following games. This may have an effect on the amount of time required to ensure complete physiological recovery between games. This period is vitally important to ensure performance levels can be maintained throughout the duration of a soccer season.

## 2.2 Recovery in Soccer

### *2.2.1 The Need for Recovery in Soccer*

The previous section of this literature review outlined the physical loads associated with elite soccer. It is apparent that these physical demands will induce a number of physiological changes including decrements in muscle glycogen stores (Krustrup *et al.*, 2006; Reilly & Ekblom, 2005), increases in muscle soreness and muscle damage (Howatson & Milak, 2009), dehydration (Shirreffs *et al.*, 2006) and elevations in blood lactate concentrations (McLellan *et al.*, 2010; Nedelec *et al.,* 2012). Physiological recovery from soccer match play is probably therefore a multifactorial process that encompasses the return of physiological, hormonal, and biochemical components to a pre-game state. Several research studies have reported that certain parts of the recovery process following elite soccer performance, in particular the repair of muscle damage, can take from 72 to 96 hours (Andersson *et al.,* 2008; Nedelec *et al.,* 2012; Nedelec *et al.,* 2014). The recovery process outlined above is of significant importance in elite soccer, as more successful teams can play approximately 60 competitive games during a 9-10 month season. These games are played with considerable variation in the time period between games (48 to 168 hours). When recovery periods between games are short there is a potential for acute and/ or chronic fatigue to occur (Reilly & Ekblom, 2005). In order to prevent fatigue and maximise or maintain elite performance, athletes must be able to recover sufficiently during these predetermined recovery periods (Reilly & Ekblom, 2005; Reilly *et al.*, 2008; Hausswirth & Mujika, 2013; Meyer *et al.*, 2013; Nedelec *et al.*, 2013).

### *2.2.2 Recovery Processes in Soccer*

There are limited amounts of literature investigating the recovery processes that takes place following elite soccer match play (Nedelec *et al.*, 2013). However, there is an abundance of research into the physiology of recovery that take place following prolonged and high intensity exercise (Arai *et al.,* 1989; Barnet, 2006; Bailey *et al.,* 2007). The recovery processes that are most important following soccer match play are discussed in more detail below.

#### *2.2.2.1 Restoration of Muscle Glycogen Stores*

Muscle glycogen is the most important substrate for energy production during soccer performance (Bangsbo *et al.,* 2006; Nedelec *et al.,* 2012). Krustrup *et al.* (2006) found that after a soccer match 36% of muscle fibres in the vastus lateralis had almost no muscle glycogen and a further 11% were completely empty in comparison to the 73% that were full prior to the start of the match (see figure 2.1.). Due to the importance of muscle glycogen stores for elite soccer performance, it is apparent that stores must be replenished during the recovery period between games. Various groups have investigated the time scale of the replenishment of glycogen stores following a single soccer match. Gunnarsson *et* *al.* (2013) reported that at 24 & 48 hours post-game, glycogen stores were still not fully replenished to pre-game levels, whereas Krustrup *et al.* (2011) found that stores were more or less restored (9% lower than pre-game values) after 48 hours of recovery. These discrepancies may be explained by the differences in the controlled diet provided during each study. Glycogen resynthesis can only take place under certain conditions within the muscle. This occurs when glucose is available within the cell and insulin levels are sufficiently elevated to promote insulin-sensitive pathways associated with glycogen synthesis. This usually occurs following the ingestion of carbohydrates (MacLaren & Morton, 2012). Therefore, in order to promote rapid glycogen resynthesis and replenish muscle glycogen stores, correct nutritional intake that focuses around the ingestion of carbohydrates is important. The quantities, timing and type of carbohydrates consumed are crucial when attempting to maximise muscle glycogen resynthesis (MacLaren & Morton, 2012). Replenishment of glycogen stores is a vitally important part of the recovery process. As outlined above, the implementation of correct nutritional strategies following soccer match play provides the best opportunity to affect the rate of glycogen resynthesis. In general, nutritional strategies are well managed within elite soccer clubs due to previous research highlighting their benefits (Nedelec *et al.,* 2013).

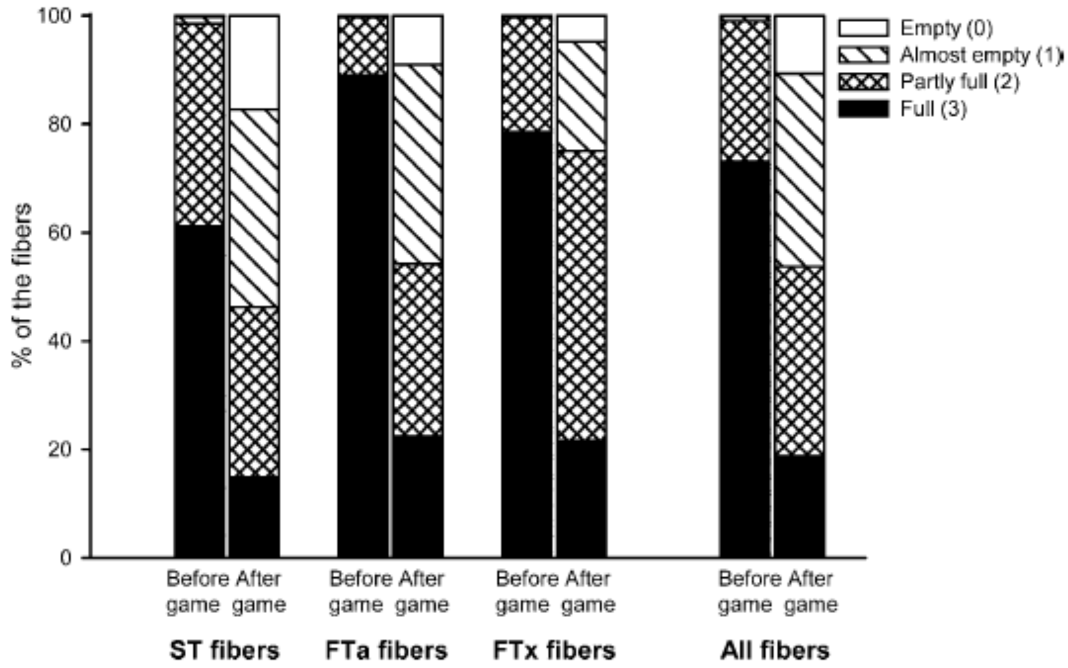


**Figure 2.1.** The findings of Krustrup *et al.* (2006) highlighting the reduction of vastus lateralis muscle fibre glycogen content as a result of soccer match performance. ST – slow twitch, FTa – fast twitch a, FTx – fast twitch x.

#### *2.2.2.2 Rehydration and Restoration of Electrolyte Balance*

During soccer match play, players can lose up to 3 litres of fluid and 133 mmol of sodium through sweating (Shirreffs *et al.,* 2006). Limited breaks in play during which fluids can be ingested, environmental conditions, and individual responses to exercise all contribute to dehydration that occurs during soccer match play (Nedelec *et al.,* 2012). Dehydration can affect physical and mental performance during the game and the subsequent recovery period (Hausswirth & Mujika, 2013). The American College of Sports Medicine suggest that rehydration strategies following exercise should be individualised depending upon sweat rate and sweat sodium content, with a general rule that 1.5 litres of fluid should be consumed for every litre of fluid lost through sweat (Sawka *et al.,* 2007). Furthermore, the sodium content of drinks must also be sufficient in order to avoid increasing urine production and to actively promote rehydration. Although these guidelines are not specific to soccer players, Shirreffs *et al.* (2006) provide recommendations that are designed for use with elite soccer players. The authors state that for moderate dehydration (the most common degree of dehydration in soccer), normal consumption of meals and beverages will facilitate rehydration within 6-12 hours (Nedelec *et al.,* 2012; Shirreffs *et al.,* 1996). Considering that there is always a minimum of 48 hours between elite competitive soccer matches, it is unlikely that the time course of rehydration is a significant issue during the recovery process between games. It has been suggested that rehydrating as soon as possible following match play may also have beneficial effects on other key components of the recovery process (Nedelec *et al.,* 2012). Various studies have found that hydration status influences the rate at which glycogen synthesis occurs (Baquet & Hue, 1990; Low *et al.,* 1996), the rate of protein synthesis (Berneis *et al.,* 1999; Keller *et al.,* 2003), and the regulation of cell function (Haussinger, 1996). In order to promote all aspects of the recovery process including replenishment of glycogen stores and repair of muscle damage, it would therefore seem important to ensure that soccer players rehydrate rapidly following match play.

#### *2.2.2.3 Repair of the Musculoskeletal System*

The physical demands of soccer match play can illicit deficits in muscular function that may be a result of muscle damage that is a consequence of HI activities such as maximal sprinting, accelerating and decelerating (Howatson & Milak, 2009; Rampinini *et al.,* 2011; Nedelec *et al.,* 2012). There are various markers such as muscle soreness, a reduction in muscle function, an increased in intracellular proteins within the bloodstream, and localised swelling around the effected muscle groups that are frequently used within elite soccer to noninvasively assess the extent of muscle damage (Howatson & van Someren, 2008; Nedelec *et al.,* 2012). As a result of these symptoms there are various ways (perception of muscle soreness questionnaires, muscle function tests, blood sampling) in which muscle damage can be quantified or monitored.

Assessing changes in biochemical markers such as creatine kinase (CK) may provide the most direct measure of muscle damage. CK is an enzyme involved in the phosphocreatine/creatine shuttle which is elevated in the blood for up to 72 hours following a soccer game (Ascensao *et al.,* 2008; Brancaccio *et al.,* 2010;

Cheung *et al.,* 2003; Fatouros *et al.,* 2010). The CK that is present is thought to 'leak' into the blood plasma following damage to the sarcolemma (McLellan *et al.,* 2010). CK exhibits peak plasma levels ~24 hours post game before returning to normal plasma levels around 72-120 hours post game following muscle repair and lymphatic drainage (Brancaccio *et al.,* 2010). The large deviation in time for CK levels to normalise is thought to be a result of a variation in training loads during the recovery period and individual adaptations to the training process (Ehlers, Ball & Liston, 2002).

The aforementioned research highlights that the restoration of the musculoskeletal system can be a prolonged process and under certain circumstances (a recovery period of <72 hours) may not be completed before the start of a subsequent soccer game. This is due to the need for various processes (i.e. reduction of inflammation, removal of waste products, repair of muscle fibres) specific to the repair of the musculoskeletal system to all take place simultaneously (Paoni *et al.,* 2002). It is important to note that delays in the repair of muscle damage during the recovery process may have an adverse impact on the time-course of other components of recovery (Nedelec *et al.,* 2012). Asp *et al.* (1998) found that 2 days after eccentric exercise, damaged muscle fibres had significantly lower glycogen stores in comparison to control muscle fibres. Overall, the previous research outlined above suggests that muscle damage repair may be a major part of the recovery process following soccer match performance. Furthermore, and probably more importantly, the suggested time-scales for restoration of the musculoskeletal system presented by these studies suggests that when recovery periods between soccer games are restricted (<72 hours), methods to accelerate muscle repair may need to be employed.

#### *2.2.2.4 Restoration of Autonomic Nervous System Balance*

The autonomic nervous system (ANS) plays a vital role in the maintenance of homeostasis within the body (Hausswirth & Mujika, 2013). As the ANS controls factors such as HR, blood flow, breathing rate and digestion, it also plays an important role in immediate and prolonged recovery following exercise (Borresen & Lambert, 2008; McArdle, Katch & Katch, 2010; Stanley *et al.,* 2013).

Changes in parasympathetic and sympathetic activity during exercise are associated with autonomic imbalances during the recovery period (Borresen & Lambert, 2008). Stanley *et al.* (2013) suggest that for exercise involving HI activities, complete cardiac parasympathetic reactivation can take around 48 hours. As a significant portion of the physical demands of soccer match play involves the performance of HI actions, it is feasible to assume that these actions may influence autonomic balance following games. With this in mind, the time course of the recovery of normal autonomic function following soccer match play may be similar to that of HI exercise investigated in previous research (Stanley *et al.,* 2013). It is important to note that the extent of ANS imbalances incurred and the time-course of recovery following a soccer game will vary significantly between individuals as a result of variations in the physical loads experienced during match play, fitness levels, age, and training history (Hautala *et al.,* 2001).

During the recovery process, changes in autonomic function can be assessed using HRV and/or HRR (Stanley *et al.,* 2013). In the early stages of the recovery process (i.e. immediately following the cessation of exercise) parasympathetic reactivation and sympathetic withdrawal, controlled by the ANS, is responsible for an initial sharp reduction in HR. Hautala *et al.* (2001) suggest that these changes in cardiac autonomic function during the early stages of recovery (0-2 hours post exercise) occur as a result of changes in haemodynamics required to remove or recycle by-products associated with muscle contractions and the transport of nutrients and oxygen to the appropriate muscles. During the intermediate phase of recovery (2-48 hours post exercise) it is theorised that exercise-induced variations in blood plasma volume cardiac fatigue are responsible for changes in autonomic function (Douglas *et al.,* 1987; Rezk *et al.,* 2006; Stanley *et al.,* 2013; Whyte *et al.,* 2000). The changes in blood plasma volume may be a result of dehydration that occurs as a result of soccer match play. The rate at which players rehydrate following match play may therefore impact on the recovery of the autonomic nervous system (see section 2.2.2.2.).

It appears that assessments of ANS function through HR based measures is an interesting area with regards to the monitoring of physiological status in the period following soccer match play. The ANS and HR based measures of recovery will be discussed in more detail in the following section of this literature review.

In summary, many of the other factors discussed above may be categorised as specific markers of recovery. An example of monitoring within these factors is CMJ monitoring which gives an isolated insight into the regain of neuromuscular function during the recovery period. Stanley *et al.* (2013) suggest that monitoring of autonomic function through HRV or HRR may provide a more global marker of recovery following exercise. This refers to the ability of these monitoring tools to provide insight into various factors that may have an impact on the progress of recovery (rehydration, neuromuscular function, biochemical balance, ANS balance). In turn, this may provide a more rounded understanding of an athlete's physiological status. However, this does not propose that these measures can be used to monitor other aspects of recovery such as replenishment of muscle glycogen stores or repair of muscle damage (Buchheit *et al.,* 2011; Chen *et al.,* 2011).

### *2.2.3 Strategies for the Acceleration of the Recovery Process*

As many components of the recovery process can take more than 72 hours to complete, it is apparent that during condensed recovery periods (<48 hours) there is a requirement to implement protocols that may support the recovery process as much as possible. Various strategies have been implemented within soccer and other team sports in an attempt to return athletes to their optimal physiological condition before the start of subsequent games (Nedelec *et al.,* 2013). These strategies include nutritional interventions, cold or contrast water immersion, active recovery (sub-maximal exercise), massage, stretching, compression garments and electrical stimulation (Nedelec *et al.,* 2013; Venter *et al.,* 2010; Venter, 2014). Nedelec *et al.* (2013) shown that various recovery strategies are common within elite soccer. The use of nutritional strategies was most common (97%) while only 13% of practitioners reported the use of electrical stimulation.

The variation in utilisation of these strategies may be linked to the variance in efficacy between different strategies. Nutritional interventions have been reported to be the most effective strategies through a considerable number of research articles (Burke, Loucks & Broad, 2006). There is conflicting evidence highlighting both positives and negatives associated with cold-water immersion (Vaile *et al.,* 2008; Ihsan *et al.,* 2014; Yamane, Ohnishi & Matsumoto, 2015). The other strategies outlined above have limited associated research that is also inconclusive with regards to the efficacy of these strategies. With this in mind, many soccer teams choose to focus on utilising strategies that are practical for use in their specific environment or tie in with the personal preferences of their specific group of players (see table 2.3.) (Nedelec *et al.,* 2013; Venter 2014).

**Table 2.3.** Recovery strategy preferences of French professional soccer teams displayed as percentage utilisation for the 7 most used strategies (Nedelec*, et al.*, 2013).

| Recovery Strategy | Percentage Utilisation |
|---|---|
| Nutrition and Rehydration | 97% |
| Cold Water/ Contrast Water Immersion | 88% |
| Active Recovery | 81% |
| Massage | 78% |
| Stretching | 50% |
| Compression Garments | 22% |
| Electrical Stimulation | 13% |

### *2.2.4 The Need for Monitoring of Recovery in Soccer*

The external physical demands experienced by players during each competitive soccer game will differ significantly and will therefore probably vary the extent of fatigue that players must recover from after each game (Nedelec *et al.,* 2014). This may be exacerbated by various factors such as age, body composition, training history and injury records. The combination of these factors and the aforementioned external loads will determine the individual internal response to soccer games experienced by each player. In turn, this internal response may affect the duration of the recovery process required by each individual (Nedelec *et al.*, 2012). This makes it apparent that there is a need to monitor the progress of the recovery process following soccer match play. This may allow practitioners to adjust the subsequent training schedules to ensure players' physical wellbeing.

The aim of monitoring the recovery process would be to assess the time-course of various components of recovery including muscle damage, the restoration of muscular function, the replenishment of muscle glycogen stores and the rebalance of the ANS through indirect measurements. An example of this would be the assessment of changes in heart rate response relating to changes in autonomic balance. Changes in autonomic balance are thought to be an indicator of physiological status and may therefore suggest if the recovery process has completed. The data collected on the recovery status of each individual player may then potentially be used to determine if a player is ready to resume training in preparation for the next fixture. Failure to monitor the recovery process may result in players returning to training too quickly following a game. This may increase the likelihood of injuries, illness, overtraining and subsequent decrements in future performances.

There have been numerous strategies to monitor recovery following soccer match play. The various available methods include countermovement jumps (CMJ) (Cortis *et al.,* 2013), sprint tests/ repeated sprint tests (Andersson *et al.,* 2008), saliva sampling (cortisol/ Immunoglobulin A) (Morgans *et al.*, 2014a; Morgans *et al.*, 2014b), blood sampling (creatine kinase, testosterone-cortisol ratio, c-reactive protein) (Smart *et al.,* 2008; McLellan *et al.,* 2010; Sietsema *et al.,* 2010) and HR monitoring (HRV/ HRR) (Bricout *et al.,* 2010; Bonaiuto *et al.,* 2012). Each of these approaches is associated with specific issues that include high physical loads, risk of injury, and impracticalities that focus around time restrictions and training/ game schedules. This frequently makes them unsuitable for continuous use over the duration of a soccer season. Research also suggests that such monitoring tools do not incorporate all of the components associated with physiological recovery important for elite soccer performance. Each of the methods outlined above focus on monitoring one particular component of the recovery process, with many studies opting to utilise multiple monitoring tools in combination in order to provide a more comprehensive assessment of an individual's recovery status. However, using multiple monitoring tools may be time consuming both when collecting data from players and analysing data afterwards making these approaches impractical for use in the elite soccer environment.

With the above in mind, there is a requirement for an effective, reliable and practical recovery-monitoring tool to be adapted or developed for use with elite soccer players. The recovery-monitoring tool must be able to provide an overall assessment of physiological recovery i.e. is sensitive to changes in factors such as muscle glycogen stores, muscular function and autonomic function. Further to this, the monitoring tool must adhere to strict criteria to be suited for use with elite soccer players. As many previously used monitoring tools carry high physical loads that make them impractical for use during recovery periods, it is important that a new monitoring tool would illicit low physical loads. Finally, the procedure around the monitoring tool must be short in duration and preferably be able to be integrated into pitch-based training sessions.

## 2.3 Monitoring of Recovery

### *2.3.1 Current Practice of Monitoring Recovery in Soccer*

There are many different methods that have been highlighted in previous research which attempt to monitor the recovery process following strenuous exercise and in some cases following soccer match play (Andersson *et al.,* 2008; Bonaiuto *et al.,* 2012; Cortis *et al.,* 2013; Morgans *et al.*, 2014a). These methods, that are explored further in the sections below, include CMJ tests, sprint tests, assessment of biochemical markers in the blood, and the assessment of HR data. Each of these methods have been designed to assess components of the recovery process that occur following soccer match play. However, most of these methods are associated with issues that make them impractical for continued use throughout an entire soccer season. As mentioned above, it may be beneficial to develop a tool that is able to assess ‘global’ physiological recovery which is able to assess multiple factors associated with the progress of recovery simultaneously. With this is mind, it is suggested that an appropriate tool for the monitoring of the recovery process following soccer match play would be able to give an assessment of ‘global’ physiological recovery, be non-invasive, carry low physical demands, and be able to be used repeatedly over the course of a soccer season.

*2.3.2 Countermovement Jump Monitoring in Soccer*

In previous research, CMJ tests have been used to assess neuromuscular fatigue and muscle function following soccer match performance (Andersson *et al.,* 2008; Cortis *et al.,* 2013; Silva *et al.,* 2013). Silva *et al.* (2013) and Andersson *et al.* (2008) both reported that CMJ performance was impaired 24 hours after the completion of an elite soccer match. However, Silva *et al.* (2013) found that CMJ performance had returned to normal levels at 48 and 72 hours post-game, whereas Andersson *et al.* (2008) stated that CMJ height was significantly lower than pre-game performance for up to 69 hours following a soccer game. Although the current literature base suggests that CMJ tests can be used to monitor recovery of neuromuscular function, it should be noted that the majority of research studies using CMJ tests have also simultaneously employed another monitoring tool (Andersson *et al.,* 2008; Cortis *et al.,* 2013; Silva *et al.,* 2013). This may be to assess another component of recovery and potentially further substantiate any suggestions around the progress of the recovery process. This may suggest that CMJ monitoring in isolation may not be an appropriate method to assess recovery due to its inability to cover all components of the recovery process. Further to this, the uncertainty in the literature around CMJ monitoring, the equipment required for accurate and reliable measurement of CMJ performance is expensive and may make their use unjustifiable for some soccer teams.

*2.3.3 Sprint Test Monitoring in Soccer*

CMJ, sprint and repeated sprint tests have been used in conjunction with each other as monitoring tools to assess recovery of muscle function following a soccer game. Previous research is inconclusive as to whether sprint tests are sensitive or not to changes occurring during the recovery process following a soccer game. Silva *et al.* (2013) (utilising 5m and 30m tests) and Andersson *et al.* (2008) (using 10m and 20m tests) found no difference in sprint performance at 24, 48 and 72 hours post game when compared to pre-game values. Conversely, Ascensao *et al.* (2008) concluded that 20m-sprint performance was significantly decreased at 24, 48 and 72 hours post-game (vs. pre-game). Regardless of their efficacy, there are significant implications associated with sprint tests making them impractical for use with elite soccer players. There is an increased risk of soft tissue injuries, particularly hamstring injuries, occurring when maximal exercise is performed in a fatigued state (Small *et al.,* 2009). This suggests that any strenuous exercise that could be deemed 'maximal' should be avoided during the recovery period in order to reduce the risk of injury and maintain low physical loads to aid physiological recovery (Nedelec *et al.,* 2012).

*2.3.4 Monitoring of Biochemical Markers in Soccer*

There are significant amounts of research focusing around the investigation of using biochemical markers to monitor the recovery process following soccer match play (Ascensao *et al.,* 2008; Brancaccio *et al.*, 2010; Fatouros *et al.,* 2010; Scott *et al.,* 2016). Previous studies have generally focused on the use of blood samples to assess CK as a biochemical marker of muscle damage during the recovery process although other markers such as lactate dehydrogenase, c-reactive protein, and myoglobin may be used. In general, blood sampling presents some challenges with regards to its use within elite soccer. Firstly, the nature of blood sampling is invasive and may be problematic when trying to obtain multiple samples during the 72 hour period following match play. Furthermore, the costs associated with blood sampling may make this test inaccessible to the majority of soccer teams.

Previous literature shows that CK analysis may be able to provide an insight into the recovery process from the perspective of muscle damage. Ascensao *et al.* (2008) reported that CK levels were significantly elevated in comparison to pre-game values at 24, 48 and 72 hours following a competitive soccer match. These findings are supported by Fatouros *et al.* (2010) who also found CK to be significantly elevated at 24, 48 and 72 hours post-game compared to pre-game levels. Despite both studies providing varying CK levels over the 3-day period due to individual differences and variations in the physical demands of the soccer game, a similar pattern was presented in the data (24 hours = elevated, 48 hours = peak value, 72 hours = still elevated but starting to return towards pre-game levels). Silva *et al.* (2013) presented slightly different results where CK was elevated at 24 and 48 hours but returned to normal at 72 hours post game.

It should be noted that all of the studies discussed above used venous blood samples to acquire the amount of blood required to determine CK levels, which as outlined above may be impractical for continuous/ prolonged use with elite soccer players. Although capillary blood samples can also be used to ascertain CK levels (Scott *et al.,* 2016) there are questions as to whether blood samples taken from different areas will provide the same results (Larsson-Cohn, 1976; Foxdal *et al.,* 1990). Scott *et al.* (2016) also concluded that CK may be of limited use when attempting to influence decision making around the process of players returning to training following the recovery period after soccer match play. With the limitations associated with blood sampling outlined above, it is unlikely that these methods could be used to enlighten the progress of the recovery process within elite soccer.

### *2.3.5 Heart Rate Monitoring in Soccer*

In general, HR monitoring is common within elite soccer and can be used to monitor training load, physiological adaptations to training, and the recovery process following match play. Assessment of maximum exercising HR, HRV and HRR have all been utilised in recovery monitoring (Buchheit *et al.,* 2007; Buchheit, 2014; Le Meur *et al.,* 2013). Changes in cardiac activity during the recovery period are a result of imbalances in the ANS, which is subsequently a result of various changes from homeostatic conditions (Douglas *et al.,* 1987; Hautala *et al.,* 2001; Rezk *et al.,* 2006). In turn, these imbalances in the ANS will impact on the modulation of HR which may become apparent when analysing HR data obtained during rest, exercise, or recovery. Stanley *et al.* (2013) suggest that monitoring through HR based measures can provide a global marker of recovery that incorporates all components of the process. In theory, this is a result of the impact changes in homeostasis has on the ANS (Stanley *et al.,* 2013).

The collection of HR data at various time points during an athlete's day can allow for several parameters to be calculated which can be used to analyse training loads, adaptations to training, fitness, fatigue and recovery (Alexandre *et al.,* 2012). There are numerous methods used to analyse raw HR data including exercising HR, average HR, HR exertion (the accumulation of a weighted value given to the time spent in each heart rate zone), time in the 'red zone' (above 85% of maximum heart rate), HRV, and HRR. When attempting to assess the recovery process, HRV, HRR and exercising HR seem to be the most effective parameters utilised in previous research (Buchheit, 2014; Le Meur *et al.,* 2013). These parameters seem to give the best representation of the fluctuations in the ANS that effect HR modulation as a result of physiological issues such as muscle damage, dehydration, and glycogen depletion that are present during the recovery period. The efficacy of these methods has been presented in previous research in this area which utilised athletes from endurance type disciplines (Lamberts *et al.,* 2009; Le Meur *et al.,* 2016; Stanley *et al.,* 2013). Within these studies, it is clear that the type of exercise stimulus employed induces a significant shift away from homeostasis. In turn, this allows for the change in physiological status to be tracked following exercise. Information regarding HRV, HRR, and exercising HR is explored in further detail in the sections below. These sections include information around the background to these methods and an assessment of any relevant literature investigating the use of these methods within soccer.

#### 2.3.5.1 *Heart Rate Variability (HRV)*

Heart rate-based measures used to assess recovery seem to focus around the monitoring of changes to the ANS. ANS activity can be assessed quickly and non-invasively through the use of HRV. There are various methods that can be used to assess HRV including time-domain and frequency-domain methods. Stanley *et al.* (2013) suggest that the natural logarithm of the square root of the mean sum of the squared differences between R–R intervals (Ln rMSSD) is the most reliable and applicable measure for daily measure under normal conditions. This method assesses the variation in the time between the peak of the R wave that occurs in each heartbeat and is believed to be a reflection of the modulation of HR. Frequency-domain methods appear to show worse reliability in comparison to time-domain methods. This is thought to be a result of the greater influence that respiration has on frequency-domain methods in comparison to time-domain methods. Although HRV has been utilised in clinical and sporting settings for many years, it has only been more recent advancements in technology that have allowed for simple daily measurements to be obtained within elite soccer environments. These measurements are generally obtained through the use of chest belt HR monitors or specially designed sensors. In general, research articles that have reported the use of HRV (obtained through the methods outlined above) in elite soccer have assessed its relationship with daily or weekly changes in training load (Flatt & Esco, 2015; Flatt *et al.,* 2016; Thorpe *et al.,* 2017). The methods of analysing the data collected through HRV may be of great importance. The investigations by Flatt and Esco (2015) and Flatt *et al.* (2016) found good relationships between changes in training load and the 5-day and 7-day average for HRV respectively. The authors of these studies also suggested that alterations to future training loads could be made using the presented changes in HRV data. On the other hand, Thorpe *et al.* (2017) found no correlation between daily measures of HRV and daily fluctuation in training load. Although these findings would seem to suggest that only 5-day or weekly averages should be used to assess HRV data, it is important to consider the desired outcomes of the analysis before selecting the method to be used in any future research. The calculation of weekly averages may be important for the assessment of general training status and adaptations to training but further research is required to understand if daily measurements of HRV may be of importance when attempting to assess changes in physiological status on an acute basis following soccer match play.

#### 2.3.5.2 *Exercising Heart Rate*

Exercising HR is a proxy measure of sympathetic drive which is representative of the increase in HR that occurs at the onset of exercise. Exercising HR is usually assessed as a response to a standardised exercise bout. The use of a standardised exercise bout allows for exercising HR to be compared with previous values longitudinally in response to the same exercise bout. For the purposes of repeatability it has been suggested that a HR response in the region of 85-95% is beneficial (Lamberts & Lambert, 2009; Lamberts *et al.,* 2011). Previous research has found that an exercise stimulus that attains a HR response in this range is better for the reliability of measuring exercising HR.

In previous research, exercising HR has been predominantly used to monitor the balance between adaptation and overreaching or overtraining rather than assessing the physiological status of athletes during the recovery process following exercise (Le Meur *et al.,* 2016). Although the primary aim of these previous research studies may not have been to assess the recovery process, allowing for adequate recovery following exercise is related to the onset of overtraining (Lambert & Borressen, 2006). With this in mind, it is feasible to assume that exercising HR may be linked to physiological status during the recovery period. Thorpe *et al.* (2017) appears to have presented the only specific findings around exercising HR with elite soccer players to the authors knowledge. They found there to be a strong relationship between fluctuations in HI distance covered by players and the exercising HR reached during a 5 minute sub-maximal test completed at 130W (85rpm) on a cycle ergometer. However, it is questionable as to whether this exercise protocol elicits a high enough HR response to meet the criteria for repeatable measurements as outlined above. Actual HR data was not reported by Thorpe *et al.* (2017) which makes it difficult to ascertain if the findings of this study are reliable. Further research is required to understand the effectiveness of using exercising HR to monitor physiological status during the recovery process.

#### 2.3.5.3 *Heart Rate Recovery (HRR)*

Monitoring of HRR involves examining the relationship between sympathetic and parasympathetic activity during and following an exercise bout to evaluate variations from 'normal' values. As mentioned in the above paragraph concerning exercising HR, it would seem that an exercise protocol that can repeatedly elicit an appropriate HR response would be required for reliable measurement of HRR. The criteria for the exercise bout used in the calculation of HRR may be similar to that outlined in previous research which aimed to ensure accuracy and reliability of the HRR data collected (Lamberts *et al.,* 2011). Following the exercising component, HRR assesses the return of HR back to resting values. This is a result of sympathetic withdrawal and parasympathetic reactivation (Buchheit *et al.,* 2007). Previous research suggests that HRR has been predominantly used with endurance-based athletes (Lamberts *et al.,* 2009; Maeder *et al.,* 2009; Lamberts *et al.,* 2010) and only more recently has been adapted for use in team sports such as soccer (Bonaiuto *et al.,* 2012; Buchheit *et al.,* 2012; Buchheit, 2014; Taskin *et al.,* 2014). The previous research utilising endurance based exercise shows there to be validity in the use of HRR as a tool to assess physiological status. Lamberts *et al.* (2009) found there to be a strong relationship between 40km time trial performance and subsequent HRR. The authors also suggest that HRR has the ability to track changes in training status and to aid future training prescription. The following part of this section will assess the previous use of HRR with soccer players and the challenges presented for continuous use with these cohorts.

The area of using HRR to monitor physiological status in elite soccer is become increasingly popular (Rave *et al.,* 2018). When attempting to implement a measurement of HRR into the predetermined training schedules in place within a soccer club there are various factors to consider. Firstly, it is important to ensure that the exercise protocol used is appropriate for the physical loading patterns currently in place. As this will be during the recovery period following games it is also important to avoid the use of high intensity or maximal exercise which may exacerbate fatigue or risk injury. Simultaneously the exercise must be able to elicit the desired HR response for the purpose of calculating HRR.

With the above in mind, various studies have utilised different exercise protocols to elicit an exercising HR for calculation of HRR with different groups of soccer players. In review, there are specific issues associated with each of these protocols that may render them unsuitable for continued use with elite soccer players. The most suitable previously used method appears to be the *5'-5' test* employed by Buchheit *et al.* (2012). This involves five minutes of submaximal exercise at a constant speed of 9km/h followed by five minutes of seated rest. Unlike many of the other protocols in this section, this protocol was purposely designed for use with elite soccer players. The associated physical demands are therefore suitable for use with elite soccer players. However, due to the low intensity and continuous nature of the exercise used, it is apparent that a sufficient exercising HR (85-95%) for valid and reliable calculation of HRR is not reached. The actual HR reached during the *5'-5' test* was ~73% of maximum. It may be more beneficial for the exercise used in such protocols to utilise higher intensity intervals. This may allow for the manipulation of work: rest ratios to elicit a higher HR response. Despite the structural issues that may affect the use of this method on a longitudinal basis, Buchheit *et al.* (2012) found there to be moderate relationships between HRR and markers of soccer related performance. Similar issues are apparent with the exercise protocol employed by Thorpe *et al.* (2017). This study involved players undertaking a bout of cycling at submaximal intensity (130W, 85rpm) for a 5 minute period. Although this protocol is unlikely to cause any issues as a result of implementation during the recovery period, the HR response (actual values were not stated in this study) elicited is unlikely to reach the levels required for accurate calculation of HRR. Perhaps unsurprisingly the findings of this study show there to be no relationship between HRR and daily changes in training loads.

Other methods have attempted to modify previously established methods of monitoring within soccer. Fox *et al.* (2017) assessed the use of the submaximal version of the Yo-Yo Intermittent Recovery Test Level 1. The duration of this test was 6 minutes and involved incremented speed levels of shuttle running separated by standardised recovery periods. No relationships were found between HRR following this test completed on the second day after soccer match play and the physical demands of the preceding match. No specific data was reported relating to the HR response experienced by participants during this actual study. However, previous research around the use of the sub-maximal Yo-Yo test has found the maximum HR reached to be approximately 75-80% (Owen *et al.,* 2017). Although this may provide a more suitable HR response when compared with the methods used by Buchheit *et al.* (2012) and Thrope *et al.* (2017), in comparison to the suggestions made by Lamberts *et al.* (2011) this response may still be too low for reliable measurement of HRR.

In conclusion, the overview of previous research presented above shows that HRR could be a useful tool during the recovery process within elite soccer. The theory behind HRR suggests that its ability to assess autonomic balance may be beneficial to understanding players physiological status during this period of recovery. However, it would appear that a lack of consensus around the methods that should be used to calculate HRR is affecting the productiveness of the data available to practitioners. This lack of consensus seems to be a result of an inability to balance the requirement for a HR response between 85-93% and the need for appropriate exercise to be used to elicit this response (i.e. no maximal sprinting etc.). Future research may aim to eradicate some of the issues outlined above through the development of a standardised protocol for the measurement of HR based measures with elite soccer players.

*Following the above review of the current literature it seemed important to further investigate the use of HR measures within elite soccer. Initially, this involved assessing the current use of HRV as a measure of physiological status in the period immediately following soccer match play (<48 hours). The literature provides a good overview of the methods that can be used to accurately measure HRV. However, these methods carry practical issues that has brought about the development of more time effective methods of measuring HRV within field settings. It seemed important to assess these methods to understand their usefulness in elite soccer. The next stage was to investigate the use of HRR and %MAXHRr with soccer players. The literature shows that these markers may be important tools for the assessment of physiological status. However, there is a lack of consensus around the methods with which these makers should be obtained. This thesis aimed to provide a better understanding of the methods that could be potentially used to collect HRR and %MAXHRr data for the assessment of physiological status following soccer match play.*

# Chapter 3

## An Assessment of the Recovery Activities Completed Following Competitive Match-Play in 1st Team, U21 and U18 Elite Soccer Players

## 3.1 Introduction

The physical loads associated with elite soccer performance are well documented (Di Salvo *et al.,* 2013). The frequent requirement for teams to play 2 or 3 games per week due to the fixture demands across various competitions results in the recovery periods between games being short. In an attempt to ensure that physical, technical and tactical performance is not adversely affected by this number of games, it is imperative that opportunities for recovery following competitive fixtures are maximised (Lambert & Borresen, 2006; Mohr *et al.,* 2015).

The available literature that has focussed on recovery in soccer has primarily focussed on the efficacy of different strategies (e.g. cold-water immersion, active recovery, sleep hygiene, stretching, compression garments and massage) that can be used to reduce the duration of the recovery process (Dawson *et al.,* 2005; Weerapong, Hume & Kolt, 2005; Duffield, Cannon & King, 2010; Ascensao *et al.,* 2011; Nedelec *et al.,* 2013; Fullagar *et al.,* 2016). Currently, there is limited research around the quantification of these recovery strategies and how they are implemented and utilised by elite soccer teams (Nedelec *et al.,* 2013; Venter *et al.,* 2010). This may be due to the fact that the specific strategies utilised by teams are considered to provide them with a competitive advantage and are therefore not open to wider dissemination or scientific study. Nevertheless, it is important to attempt to quantify the activities that soccer players are undertaking during the recovery period in a systematic way in order to ascertain what approaches are actually used in the "real world" as well as the temporal distribution of these interventions and their effectiveness. A better understanding of the activities undertaken by players following match play may allow practitioners to fully evaluate, and to subsequently improve the practice during the important time period that follows games.

The aim of this study was to provide an overview of the activities undertaken by soccer players during periods of the training week dedicated to recovery following match play. Three different squads (1st team, U21, U18) at the same professional soccer club were used in an attempt to broaden the insight about recovery protocols to different levels of play. This is important given that different squads may employ different approaches to recovery due to external factors such as the resources available to them and the fixture schedule they must complete.

## 3.2 Methods

### *3.2.1 General Study Design*

This study was an observational study designed to give an overview of the activities undertaken by groups of elite soccer players during the recovery period following a soccer match. All activities that took place on designated recovery days (specifically one day [MD+1] and two days after match play [MD+2]) during a 4-month period (February – May 2015) for 3 squads of players were observed. Where possible these observations were supported by the collection of objective data in an attempt to provide some quantification around the nature of the activities completed by the players in each area of the recovery process. Only activities completed under instruction while players were at the training ground were recorded for analysis. No information around sleep or the nutritional intake of individuals was collected. Data was collected through global positioning system (GPS) and HR monitors during pitch based recovery sessions to provide an estimation of the physical loads associated with on-field recovery sessions. No data relating to the demands associated with recovery activity was collected during any of the other categories of recovery activity. On 3 designated recovery days during the data collection period one group within the sample ($1^{st}$ team) completed the recovery activities away from the club's training ground. This influenced the activities that the participants could complete. More specifically this meant that cold water immersion (CWI) was not available to players on these days. These omissions will slightly impact the representativeness of the data in these areas.

### *3.2.2 Participants*

Twenty-two professional soccer players (Mean ± SD: age 25±5 years, height 1.80±0.07m, body mass: 80.1±8.4kg) and thirty-one elite development soccer players (Mean ± SD: age 19±1 years, height 1.78±0.06m, body mass: 75.6±9.2kg) from an English Premier League soccer team took part in the study. Participants were separated into 3 groups (1st team [n=22], under 21s [n=19] and under 18s [n=12]) depending on the squad that they played games for during the testing period. Only data from players who completed more than 45 minutes of the preceding game during the observation period were included in the data collection for the study. This selection criterion was based on a practical rationale (players who played less than 45 min were not allocated to recovery sessions following games) operated by the club in question. This approach may however also have some support from the scientific evidence base (e.g. help ensure a similar and appropriate physiological demand across all the participants). All participants were informed of the procedures involved in the study and provided written informed consent. This study was conducted according to the requirements of the Declaration of Helsinki and was approved by the University Ethics Committee of Liverpool John Moores University.

### *3.2.3 Data Collection*

A 2-day evaluation period following each competitive fixture was selected for use throughout the study for the evaluation of the recovery period. This time frame was used as it was assumed to span the key time points from a physiological perspective that are associated with the recovery process following soccer match-play (Nedelec *et al.,* 2012; Stanley *et al.,* 2013). This time period was also of practical relevance as it coincided with the time period before normal structured soccer training was resumed by all players at the club in question. The collection of data across a 4-month testing period was used in an attempt to provide a comprehensive and representative assessment of the recovery processes used. The testing period included 18 games for the 1st team squad, 12 games for the U21s squad, and 13 games for the U18s squad. This approach also helped to ensure that data was collected during different playing schedules that regularly occur within elite soccer (one game per week, two games per week, three games per week, congested fixture schedules, breaks for international games).

To record the observational information, a standardised data recording sheet was developed. This sheet was used for the collection of information concerning the activities completed on identified recovery days following competitive match-play during the testing period. The development of these data collection sheets was based on information from previous research studies associated with the assessment of the recovery period following soccer match play (Nedelec *et al.* 2013). In addition, observations of the current practice within the elite soccer club in question during the recovery period were also used to ensure that any data collection sheet had the potential to record all aspects of recovery that were identified as important.

Several data collection sheets were initially designed and trialled before the development of the one that was selected for use throughout the study. The pilot work completed with each sheet was aimed at assessing the suitability of each of the data collection sheets for use in the investigation. This primarily involved evaluating the ability of the sheet to collect information on both (a) the general aspects of the recovery process that were being undertaken and (b) sufficient detail of the protocols that were being used with each of these strategies. The final version of the data collection sheet that was used during this study is presented in Figure 3.1.

Activities were separated into 7 categories. These included pitch based recovery, gym based activity, pool based recovery, massage, CWI, stretching and foam rolling and cycle based recovery. Specific definitions associated with each of these categories are outlined in table 3.1. These categories were selected to align with the categories used in previous research (Nedelec *et al.,* 2013). However, the 'active recovery' category that was described in previous research was split into a number of discrete components (pitch based, gym based, pool based, bike based). This was done in order to provide insight into the use of each mode of exercise during the recovery period as the type of exercise completed may be important to the recovery process. Pool based activity followed a standard protocol for all sessions completed by all squads. This consisted of swimming (6x20m), jogging, backwards jogging, side steps, high knee drives, hip mobility (all 2x20m), squat, lunge, lateral lunge (all x4). Similarly, stretching and foam rolling sessions also followed a standard protocol for all squads including 30s holds of each stretch for the following muscle groups: calves, quadriceps, hamstrings, gluteus, hip flexors, groins, abductors, and 30 seconds of foam rolling for each of the following muscle groups/ areas: calves, quadriceps, hamstrings, glutes, hip flexors, groins, abductors, lower back.

Observations and recording of recovery activities was completed by a small group of researchers (n=3). These individuals were responsible for the support of the practitioners who were responsible for the delivery of the corresponding recovery session for the players in question. These individuals were also in attendance at the preceding competitive fixture. The researcher was required to observe players' activities and record the detail of the recovery sessions in real time. The data collection sheet was completed electronically immediately following each recovery session by the same researcher. The completed data collection sheets were then sent to the lead researcher for storage and analysis. Prior to the start of the data collection period all researchers were trained in how to complete the data collection sheet. This training included how to identify and provide information around the categorisation of activities as well as the specific details that required recording for each activity when completing the data collection sheet. Following the training period, a trial period was conducted to ensure that all researchers were adhering to the approach required for data collection. This involved the researcher who was responsible for each squad and the lead researcher completing the data collection sheet independently and simultaneously for the same recovery period. The data sheets were then compared immediately following the completion of the sessions to ascertain if a consistent approach to data collection was being applied across all squads.

Following the completion of all data collection sheets, all data was collated and processed for statistical analysis. Data from all squads was then split depending on the day it was collected (MD+1 or MD+2) and the category of activity which it belonged to. This allowed for the calculation of average and standard deviations for each group of data. Information that was not suitable for statistical analysis was assessed with regards to the frequency of each variable during the testing period (e.g. the number of lower body gym sessions undertaken, the number of upper body gym sessions undertaken, the number of core gym sessions undertaken).

**Table 3.1.** Definitions associated with the specific categories of activities included in the investigation. This table also highlights the specific data that was recorded for the activities in each category are also included.

| Category | Definition |
|---|---|
| Pitch-Based recovery | All exercise completed on a soccer pitch including soccer specific training sessions, jogging & mobility work. |
| Gym-Based Activity | All session completed in the gym as part of the players predetermined strength and conditioning programme that were completed on match day +1 and match day +2. |
| Pool-Based recovery | All exercise completed in the pool including swimming, jogging, stretching & mobility work. |
| Massage | All soft tissue massage therapies provided by medical staff aimed at aiding recovery from match play not including physiotherapy for any injuries. |
| CWI | Immersion in cold water for any period of time. *An ice bath set at 10°C was available to all players for all recovery days.* |
| Foam Rolling & Stretching | All sessions spent foam rolling and/or stretching only whilst in the gym area. |
| Cycle -Based recovery | All sessions completed on a cycle-ergometer. *All cycle -based sessions were completed on a cycle ergometer (Keiser M3, USA) cycling at a power output of 90-95 watts and a cadence of 80-85 rpm.* |

*3.2.4 Statistical Analysis*

All data were presented as mean ± standard deviation (SD). Paired sample t-tests were used to assess differences between MD+1 and MD+2 for the data for all squads combined, with a significance level set at $p<0.05$. No comparisons between squads were conducted as the aim of this study was to broaden the insight of this investigation through the use of multiple squads rather than to assess the differences between squads. All data was checked and found to be normally distributed. All statistical analyses were completed using SPSS 21.0 (IBM, Chicago, IL, USA). Consistency of use (%) was also calculated for each category of recovery activity on both recovery days to show how regularly activities were completed during the testing period. It was assumed that there was potential for each activity to be completed once on each recorded recovery day that was not a designated day off. The calculation used for this was:

Consistency (%) = (Total number of occasions the activity was utilised) ÷ (Total number of potential occasions the activity could have been utilised) x 100

| Player Initials | Position | Minutes Played | Date of Game | | | Pitch Based Exercise | | Gym Based Exercise | | Pool Based Exercise | | Massage | | CWI | | Stretching/ Foam Rolling | | Bike | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1st Day Recovery | Duration | Squad/ Recovery/ Rehab | Duration | Uppers/Core / Lowers | Duration | Exercises | Duration | Body Area | Duration | Temp (°C) | Duration | Muscle Groups | Duration | RPM/ Gear |
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| Player Initials | Position | Minutes Played | Date of Game | | | Pitch Based Exercise | | Gym Based Exercise | | Pool Based Exercise | | Massage | | CWI | | Stretching/ Foam Rolling | | Bike | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2nd Day Recovery | Duration | Squad/ Recovery/ Rehab | Duration | Uppers/Core / Lowers | Duration | Exercises | Duration | Body Area | Duration | Temp (°C) | Duration | Muscle Groups | Duration | RPM/ Gear |
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**Figure 3.1.** Data collection sheet used to record the specific information on all recovery activities completed by all players during the data collection period.

## 3.3 Results

Overall, 43 games took place during the testing period. This resulted in a total of 86 identified recovery days for the sample. Of the recovery days recorded, 11 were MD+1, 30 where MD+2, and 45 were days where players were not required to report to the training complex (Day Off). The breakdown of how many games and recovery days that were used for data collection for each squad can be found in table 3.2. A relatively even split between groups can be observed which suggests that there is a good representation of the different groups identified in the study in the data.  The days when players were not required to report for formal sessions following match play (Day Off) may have implications that are important for recovery as days off may provide the opportunity for players to sleep longer and therein facilitate the recovery process (Nedelec *et al.,* 2015).

**Table 3.2.** Total number of competitive games and associated designated recovery days associated with each squad that were completed during the data collection period.

| Squad | Games | Matchday+1 | Matchday+2 | Day Off |
|---|---|---|---|---|
| **1st Team** | 18 | 4 | 12 | 20 |
| **U21** | 12 | 2 | 8 | 14 |
| **U18** | 13 | 5 | 10 | 11 |

Table 3.3 presents data from all 3 squads showing the average (±SD) time spent completing each of the 7 defined recovery activities on MD+1 and MD+2. This data highlights a focus on active recovery. These active strategies accounted for on average 58% of time spent undertaking recovery activities. This is an interesting finding as previous research seems inconclusive as to the potential benefits of active recovery (Andersson *et al.,* 2010; Belcastro and Bonen, 1975; Choi *et al.,* 1994). On average 26% of the overall time was spent undertaking passive recovery modalities, such as massage therapy over MD+1 and MD+2. This data would also seem to contrast with the evidence base as few studies have found any physiological benefits to be associated with massage therapy during the recovery period (Zainuddin *et al.,* 2005; Wiltshire *et al.,* 2010). Although data was collected regarding the use of CWI during the recovery period, it was found that this

modality was one of the least consistently completed on both MD+1 (27%) and MD+2 (27%). Furthermore, the amount of time spent in CWI was short in comparison to other activities. This may be due to the suggested amount of time (~10 minutes) needed to bring about the potential benefits of cold water immersions (Ascensao *et al.*, 2011).

Comparisons between MD+1 and MD+2 showed that pitch-based sessions was the only category that was significantly different in duration between days ($p<0.05$). This is somewhat expected considering the volume of exercise that players performed was controlled and increased over time following match play as a function of the coaching philosophy employed at the club. While pitch-based recovery took precedence on MD+2, players appeared to spend the most amount of time on MD+1 receiving massage treatments (see table 3.3).

**Table 3.3.** Average (±SD) amount of time (min) spent by players from all squads completing each of the 7 activities on MD+1 and MD+2.

| Day | Pitch Based | Gym Based | Pool Based | Bike | Massage | CWI | Stretching/ Foam Rolling |
|---|---|---|---|---|---|---|---|
| **MD+1** | 19±0 | 25±7 | 16±2 | 19±4 | 43±19 | 7±2 | 15±4 |
| **MD+2** | 44±15 | 26±12 | 14±3 | 16±5 | 39±18 | 10±1 | 15±5 |

Data assessing how consistently each activity was undertaken by players from all squads during the recovery process following all games during the testing period is presented in table 3.4. This data highlights that pool based recovery (64%) was the most consistently completed activity on MD+1. Pitch based recovery was the most consistently completed activity on MD+2 (80%). Average (± SD) GPS and HR data collected during all pitch based recovery sessions can be found in table 3.5. This information shows that physical loads experienced by players during pitch based session on MD+2 are higher than those experienced on MD+1.

**Table 3.4.** Average consistency (%) of completion for all players from all squads for each of the 7 activities on MD+1 and MD+2.

| Day | Pitch Based | Gym Based | Pool Based | Bike | Massage | CWI | Stretching/ Foam Rolling |
|---|---|---|---|---|---|---|---|
| **MD+1** | 2/11 (18%) | 4/11 (36%) | 7/11 (64%) | 6/11 (55%) | 5/11 (45%) | 3/11 (27%) | 5/11 (45%) |
| **MD+2** | 24/30 (80%) | 20/30 (67%) | 8/30 (27%) | 17/30 (57%) | 7/30 (23%) | 8/30 (27%) | 16/30 (53%) |

**Table 3.5.** GPS and HR data (Average ± SD) for all 1st team, U21 and U18 pitch-based sessions completed on different recovery days during the testing period.

| Squad | Session Type | Duration (min) | Total Distance (m) | Meters per Minute | High Intensity Distance (>5.5m/s) (m) | Max Speed (m/s) |
|---|---|---|---|---|---|---|
| **1st team** | MD+1 | 19±1 | 1412±102 | 73.0±5.0 | 0±0 | 3.7±0.6 |
| | MD+2 | 32±1 | 2354±66 | 72.9±2.5 | 2±3 | 4.8±0.5 |
| | MD+2 & MD-1 | 61±3 | 2225±316 | 36.8±6.3 | 10±10 | 6.0±0.8 |
| **U21** | MD+2 | 46±14 | 2265±807 | 48.0±4.8 | 17±29 | 5.4±1.1 |
| | MD+2 & MD-1 | 37±1 | 982±378 | 26.5±10.9 | 12±8 | 6.5±1.4 |
| | MD+2 & MD-2 | 80±0 | 5371±407 | 67.1±6.8 | 241±38 | 7.9±1.5 |
| **U18** | MD+2 | 32±1 | 2073±477 | 65.4±12.3 | 31±42 | 5.4±0.1 |
| | MD+2 & MD-1 | 41±6 | 3620±597 | 88.8±12.0 | 52±24 | 6.5±1.8 |
| | MD+2 & MD-2 | 51±17 | 2849±1270 | 54.7±6.8 | 72±69 | 6.3±1.2 |

## 3.4 Discussion

The aim of this study was to provide an overview of the activities undertaken by elite soccer players during a period of recovery following match play. In an analysis of any recovery strategy it would seem important to consider the amount of time spent undertaking the specific recovery activities as well as the consistency with which the activity was completed over the data collection period. Such information may provide a basis for assumptions to be made regarding the efficacy of the protocols used. The data collected showed that the largest amount of time was spent undertaking pitch based recovery activities on MD+2 (~44 min). This was closely followed by massage therapy on MD+1 (~43 min) and MD+2 (~39 min). When comparisons of the consistency of use of strategies was made, pitch based recovery on MD+2 (80%) was found to be the most consistent form of recovery strategy with massage therapy only being completed for 45% and 23% of the time on MD+1 and MD+2 respectively. Gym based sessions on MD+2 (67%) and pool based sessions on MD+1 (64%) also showed good levels of consistency but were still inferior to pitch based sessions on MD+2. CWI was found to account for the least amount of recovery time of any of the activities recorded during this study (MD+1 – 7min, MD+2 – 10min) and were also one of the least consistently completed interventions (MD+1 – 27%, MD+2 – 27%). This may be due to the discomfort experienced during cold water immersion (Galvan *et al.,* 2006). Stretching/ foam rolling was also completed for only short periods (MD+1 – 15min, MD+2 – 15min) and was inconsistently undertaken (MD+1 – 45%, MD+2 – 53%). Overall, it appears that active recovery (especially through pitch based exercise) plays a dominant role during the recovery period. It appears that the focus on the use of active recovery methods as opposed to passive methods may be due to the culture within the club investigated in this study. The rationale for implementing active recovery methods may be to keep in line with the clubs practical strategy. At the club in question this involved players undertaking as many activities as possible involving soccer specific exercise on the soccer pitches rather than in the gym or the swimming pool. It should be noted that the findings of this study may not fully represent the exact amount of time allocated to each category as activities such as stretching were also completed as part of sessions attributed to other categories such as pitch based and pool based active recovery due to the nature of these activities.

There are a limited number of studies in the literature that have attempted to quantify the recovery activities in a similar way to the methods utilised in the current study. The main difference in the approach undertaken here when compared to previous research is the level of detail that has been collected around the specific activities undertaken during the recovery period, for example, the GPS data collected during pitch based sessions (Nedelec *et al.,* 2013; Venter *et al.,* 2010). This detail is vitally important when attempting to understand the processes that occur during recovery in an elite playing population as it allows more informed decisions to be made around prescription of training loads during the recovery period. The findings of the current study appear to broadly agree with those of Nedelec *et al.* (2013). These authors presented data on the popularity of recovery modalities within elite French soccer teams. They found active recovery (81%) and massage therapy (78%) to be the most popular methods along with hydrotherapy (88%). It should be noted that in the study in question, active recovery included pitch based, cycle based and pool based recovery sessions (in the current study these are investigated as separate entities). Although the current study only investigated the use of recovery modalities at one soccer club, similar findings were observed with regards to the use of pitch based recovery sessions (80%), cycle based recovery (57%) and pool based recovery sessions (23%) being completed on fewer occasions. This would suggest that active recovery protocols are common in elite soccer despite the lack of a comprehensive evidence base that highlights the effectiveness of these approaches. Previous research has suggested that active recovery accelerates the recovery process through enhanced blood lactate removal, quicker restoration of muscle glycogen stores, and faster reduction in the inflammation response around damaged muscle fibres (Andersson *et al.,* 2008; Andersson *et al.,* 2010). Although these potential benefits may justify the inclusion of active recovery within the recovery process for some practitioners, other reasons for utilising these methods may be due to the philosophy in place at the soccer club in question. This may be in line with the preferences of the technical coaches or manager at the club which may involve utilising soccer related activities as frequently as possible in all activities completed by players. The use of active recovery, integrated through the use of football specific movements, may also be a method of gaining good adherence from all players to the recovery process due to the more enjoyable nature and the familiarity of the activities involved.

Our data would suggest that the use of active recovery on MD+1 is more frequently completed through the use of pool (64% completion) and cycle (55% completion) based sessions. As outlined above, these pool-based and cycle-based sessions always followed a set protocol. However, on a small number of occasions the content of sessions may have varied from the standardised protocols outlined above. An example of this is that one player completed one bike based recovery session at a lower power output (~80W) than stated in the methods section of this chapter. Pitch-based recovery sessions were observed to be more prevalent on MD+2 (80% completion). This pattern seems to primarily be a consequence of the specific practical strategy used at the club to integrate neuromuscular system activity within the recovery process. There may also be a theoretical explanation to this pattern. During the earlier stages of the recovery process (MD+1) there are various potential benefits associated with active recovery. Pool based recovery may contribute to the recovery process through its potential to reduce post-exercise physiological markers such as inflammation. This is a result of the hydrostatic properties of water immersion which creates an increased pressure gradient from the extremities towards the central cavity. This promotes a reduction in the levels of circulating C-Reactive protein which may have the potential to accelerate the recovery process by stimulating a desirable environment around the damaged muscles (Wilcock *et al.,* 2006; Lum *et al.,* 2010). Other active recovery strategies used here, such as cycle based active recovery, may also be of benefit by improving other physiological processes such as glycogen resynthesis following exercise (Barnett, 2006). Previous research may however suggest that this may not be the case (Fairchild *et al.,* 2003). Despite the physiological benefits of cycle based active recovery being inconclusive it is still utilised as a recovery modality in soccer. The reasoning for this is probably threefold (i) the convenience of its implementation within the recovery period (ii) the concept of players actively engaging in the recovery period rather than undertaking passive tasks (iii) the assumption that the potential reward of accelerating the recovery process will outweigh any potential risks associated with low intensity, non-weightbearing exercise.

The utilisation of pitch-based sessions are more common on MD+2 in elite soccer (MD+1 – 18% vs. MD+2 – 80%). From a practical perspective this may provide a gradual reintroduction to the physical loads players will experience in soccer specific training sessions following the recovery period. However, there may be more complex issues involved in the decision making process that results in players undertaking pitch based recovery sessions during the recovery period. Pitch based recovery may allow for low intensity technical practice to be undertaken which may appeal to the soccer coaches. This compromise between the strategies that may be prioritised by technical coaches and sports scientists may be vitally important to support cohesion between the key practical stakeholders and drive general decision making at the club around overall training philosophy. The physiological benefits of pitch based active recovery may be similar to those associated with other modalities of active recovery (increased blood flow, reduction of inflammation, removal of waste products) (Andersson *et al.,* 2010; Reilly & Ekblom, 2005). It is important however to take into consideration the volume and intensity of physical loads carried by active recovery, in particularly pitch-based sessions. While there are numerous potential benefits to low intensity exercise during the recovery period higher intensity exercise may have the potential to inhibit recovery and exacerbate fatigue levels (Belcastro & Bonen, 1975). With this in mind, the physical loads associated with pitch-based recovery sessions are generally controlled in order to avoid high volume or high intensity activities such as sprinting or rapid changes of direction which may exacerbate fatigue levels or aggravate muscle damage.

It is clear that the recovery process following soccer match play is extremely complex, lasting up to approximately 72 hours post-match (Brownstein *et al.,* 2017). With this in mind, the use of multiple recovery modalities may be required to combat the various components of physiological recovery (Kinugasa & Kilding, 2009). As the efficacy of many recovery modalities are inconclusive when investigated in isolation (Nedelec *et al.,* 2013), the use of multiple methods simultaneously may be required to positively affect the recovery process. There is a lack of previous research assessing the benefits of utilising multiple recovery methods (Barnett, 2006). Working under the assumption that there are physiological benefits to a multimodal approach, it is important to consider the timings of utilising each modality in order to maximise effectiveness. It is also important to consider the effect of combining recovery methods and if this may have a positive effect on the overall recovery process.

In conclusion, the findings of this study show that the approach to the recovery period within an elite soccer club involved the use of a variety of recovery methods that attempted to improve the recovery process. Massage therapy accounted for the longest amount of time on MD+1 (43min) with pitch based active recovery dominating on MD+2 (44min). Pool based active recovery was the most consistently completed method on MD+1 (64%) with pitch based active recovery the most common on MD+2 (80%). The reasoning behind the implementation of these methods is a combination of underpinning physiology and practical reasons. Future research may aim to fully understand the physiological responses of elite soccer players to the recovery modalities discussed above. This may provide a sounder rationale for the use of particular recovery strategies following soccer match play. The data presented in this study may not only provide useful information about the recovery processes included in the training plans of elite soccer players but also give potential insights into the strategies that may be used to effectively monitor the recovery process between games.

# Chapter 4

## The Effectiveness of a Smartphone-Derived Heart Rate Variability Measure to Assess Changes in Physiological Status Following Soccer Match Play in an Elite Playing Population

## 4.1 Introduction

To maintain high physical, technical and tactical performance levels over the duration of an entire soccer season a subsequent recovery period after a soccer match is required (Nedelec *et al.,* 2012). In addition to the implementation of methods that aim to facilitate the recovery process, the use of approaches that may support the monitoring of recovery following match play are essential. The successful application of such approaches may play an important role in ensuring that each individual can perform effectively in subsequent matches or training (Meyer *et al.,* 2013; Twist & Highton, 2013).

Chapter 3 outlined the activities undertaken by elite soccer players during an identified recovery period (match day +1 [MD+1] and match day +2 [MD+2]). From a practical perspective, this data provides some insight into the potential opportunities that may be available to practitioners to monitor physiological status following match play. The available scientific literature would suggest that a variety of methods have been used in an attempt to monitor physiological recovery following soccer match play. These include the analysis of neuromuscular parameters such as CMJ performance and the measurement of blood metabolites concentrations (Cormack *et al.,* 2008; Scott *et al.,* 2016). An important assumption in any assessment of physiological status following match-play is that there is a relationship between the physical loads experienced by players during games and the associated disruptions to homeostasis (through factors such as muscle damage, glycogen depletion, neuromuscular fatigue and dehydration) that occur over the 90 minutes. There is however no current scientifically validated and practical way of directly assessing detailed physiological changes in homeostasis within a practical environment such as a soccer club. In order to address this limitation, applied approaches generally attempt to utilise a “proxy” or surrogate measure of the displacement from homeostasis following soccer match play to give an indication of the physiological status of individual players. If the effectiveness of these approaches is to be evaluated it is important to test their potential usefulness following a stimulus that has the potential to disrupt homeostasis. It is assumed that the most physiologically challenging stimulus experienced by players during their preparation/competition routines is competitive match-play. This logic is based on these activities resulting in the greatest volume and intensity of activity experienced by players. This would suggest that the period following match play (≤ 48 hours) may offer the best opportunity to indirectly evaluate the usefulness of any potential tool that may provide information on an individual's recovery from a physiological challenge.

Heart rate-based measures may provide a useful approach under these circumstances due to their practical simplicity of use and their theoretical ability to provide an overall assessment of the progress of global physiological recovery following a soccer match (Stanley *et al.,* 2013). Any subsequent changes in HR related measures, particularly variables such as HRV, may therefore provide a surrogate representation of 'overall' recovery. Assessing changes in HRV appears to track the return to homeostasis following exercise (Hautala *et al.,* 2001). Traditionally HRV is assessed under very controlled conditions using specialist equipment such as 12 lead electrocardiograph (ECG). However, this is not practical for frequent use in elite sports environments, especially in team sports where multiple athletes are often required to be tested during a short time period. Recent advancements in technology have allowed measurements to be completed using smartphone-based applications in a test lasting between 60-300 seconds using the Ln rMSSD method to calculate HRV in line with previous recommendations (Stanley *et al.,* 2013). Smartphone derived HRV has also been reported to be a valid measure of HRV when compared with the use of the ECG method (Flatt & Esco, 2013). This type of approach has the potential to be applied in real world practical team sports environments.

The aim of this study was to determine if HRV obtained through a purpose built smartphone application measured on the first day (MD+1) and second day (MD+2) following match play was related to the physical loads associated with the preceding soccer match. The findings of this study are of particular interest due to the requirement for a simple tool to efficiently monitor the physiological status of a group of soccer players in the recovery period following soccer match play.

## 4.2 Methods

*4.2.1 General Study Design*

Activity data from each player was collected during all competitive matches included in this study. Following each match, players were required to complete the HRV measurement on MD+1 and MD+2 where possible. These sampling time points were selected as previous research has suggested that autonomic balance may be disturbed for up to 48 hours following HI exercise (Stanley *et al.,* 2013). The HRV measurement was not completed on designated days off when players were not required to attend the training facility due to the lack of an ability to apply consistent procedures during the completion of the measurement. The predetermined team schedule and subsequent players' attendance to the training facility following matches also influenced the data collection. As such three different categories of data collection seemed important: matches followed by the collection of HRV on MD+1 and MD+2 (n=7), matches followed by collection of HRV on MD+1 only (n=18), and matches followed by collection of HRV on MD+2 only (n=14). All of these data points were included in this study. This was due to the relevance of these time periods for the rebalance of the ANS following match play. As outlined in the aims, this study looked to determine if HRV on MD+1 or MD+2 was related to the physical loads experienced in the preceding match.

*4.2.2 Participants*

Twenty-one professional soccer players (Age: 25±4 years, Weight: 80.0±8.5kg, Height: 1.79±0.06m) from an English Premier League soccer club took part in the study. All participants provided written informed consent prior to the start of the study. Participants included in this study completed at least one competitive match during the 2014-2015 season (players who were substituted on or off during games were excluded from the investigation) and completed a measurement of HRV on either the match day +1 (HRV MD+1) or match day +2 (HRV MD+2) following that game. This study was approved by the Ethics Committee of Liverpool John Moores University and conformed to the declaration of Helsinki.

### *4.2.3 Procedures for the Data Collection of Activity Profiles During Matches*

Computerised semi-automatic video match analysis image recognition systems (Prozone Sports Limited, Leeds, UK) were used to collect physical performance variables for each player during all competitive matches included in this study (Bradley *et al.,* 2009). This system and process has been validated to provide reliable and accurate data (Di Salvo *et al.,* 2006; Di Salvo *et al.*, 2009). The variables that were selected for analysis were match duration, total distance, distance per minute (total distance divided by match duration), HI distance (distance covered above 5.5 m/s), and HI distance per minute (HI distance divided by match duration). These variables were selected in order to give an all-round representation of the volume and intensity of the match demands experienced by players during each game. Previous studies have quantified the physical loads associated with soccer performance using the same methodology as this study (Bradley *et al.,* 2009; Bradley *et al.,* 2010).

The physical loads associated with training sessions were not included in this study despite their potential to impact on the physiological status of players. The reasons for this are twofold: firstly it is clear that the physical loads associated with match play account for the most significant (hardest) stimulus experienced by players when compared with the physical loads experienced during training sessions. This would suggest that match play is most likely to disturb the balance of the ANS. Secondly, the methods utilised to obtain physical loading data during training sessions (Global Positioning Systems) differed from those used during games (Image Recognition Systems) which would have made combining physical loads problematic.

### *4.2.4 Procedures for Data Collection of Heart Rate Variability*

Heart rate variability was measured using a specially designed finger sensor (ithlete, HRV Fit Limited, UK) connected to a smart-phone (Apple, California, USA) using a purpose built team application (ithlete, HRV Fit Limited, UK). The ithlete system used in this study represents a relatively new technology but has been used in various research projects (Flatt & Esco, 2013; Flatt & Esco, 2015; Flatt & Esco, 2016; Flatt *et al.,* 2016) with some studies assessing the validity of ithelte when compared with the use of ECG (Heathers, 2013). This approach is commonly used by teams and individual athletes in a number of different professional sporting environments including soccer, ice hockey, Australian rules football, powerlifting, cycling, and marathon running (HRV Fit Ltd., www.myithlete.com).

Players completed the measurement immediately upon arrival at the training ground on each testing day. All measurements were completed under the same conditions with players in a seated position, in a quiet room, with the measurement starting after 1 min of seated rest. The measurement was completed before players had consumed any food or drink on that particular day. Players were required to fit the finger sensor on to the index finger of their dominant hand. Once the application had detected a stable heart rate (continuous beat to beat recording of heart rate for 5 s) the player was able to initiate the measurement. This involved collection of 55 seconds of heart rate data. During the measurement breathing rate was also controlled using a visual aid displayed through the application. R-R intervals (the time between an exact time point in each heart beat) were measured by the application and automatically processed into the Ln rMSSD. From these values an arbitrary value (ranging from ~60-100) was generated (Ln rMSSD times by 20) and presented in the application on completion of the measurement. Values at the lower end of the scale (~60) correlate to a suppressed physiological status and vice versa. A value ≥85 was deemed to show good physiological status within the group of players assessed in this study. The extent to which this changed during the recovery period was dependant on various individual characteristics such as fitness levels, playing position, and training history. The HRV data was exported to an electronic database following collection for collation and longitudinal analysis.

*4.2.5 Statistical Analysis*

Data were analysed using linear mixed models, with HRV MD+1 or HRV MD+2 as the dependent variables. Physical loading variables (match duration, total distance, distance per minute, high intensity distance, high intensity distance per minute) were used as the independent variables. A random intercept was set for each individual player. Standardised effects were calculated to determine an effect size (by multiplying the coefficients by two times the between-subject standard deviation of the independent variable and dividing this by one times the between-subject standard deviation of the dependent variable). The effect size (ES) was evaluated according to the following thresholds: <0.2 = trivial effect, 0.2-0.6 = small effect, 0.6-1.2 = moderate effect, 1.2-2.0 = large effect, and >2.0 = very large effect. Statistical significance was set at $p<0.05$. The above analyses were completed using R, v3.0.3 (The R Foundation). Smallest worthwhile change (SWC) for HRV was calculated as 0.2 times the between subjects standard deviation (Hopkins, 2004). SWC for HRV was calculated utilising the data collected in the current study, previous unpublished work by our group and suggestions made by Buchheit (2014).

## **4.3 Results**

Average (±SD), maximum and minimum values for all match activity variables assessed in this study can be found in table 4.1. This data would seem to be typical for elite level soccer players during competitive games (Bangsbo, 2014). This data also seems to highlight the large variations in team and individual activity profiles between games that are known to exist. This is due to within game factors such as tactical strategies, score line, and the technical quality of the opposition (Abbott *et al.,* 2018; Almeida *et al.,* 2014; Bradley *et al.,* 2011). These variations in physical loads are an important part of this study as these variations may impact on the subsequent recovery periods required by each individual player which may be represented in changes in HRV.

**Table 4.1.** Average, standard deviation, maximum and minimum data for physical load variables recorded during games throughout this study. Data is presented for all players and for each playing position.

| Playing Position | | Total Distance (m) | Distance per Minute (m/min) | High Intensity Distance (m) (>5.5m/s) | High Intensity Distance per Minute (m/min) |
|---|---|---|---|---|---|
| **All Players** | Average | 10730 | 112.2 | 930 | 9.7 |
| | SD | 924 | 9.9 | 310 | 3.3 |
| | Max | 12727 | 136.6 | 1641 | 17.4 |
| | Min | 8738 | 90.0 | 371 | 3.9 |
| **Central Defenders** | Average | 9656 | 100.8 | 554 | 5.8 |
| | SD | 446 | 5.2 | 141 | 1.4 |
| | Max | 10585 | 111.9 | 1000 | 10.0 |
| | Min | 8738 | 90.0 | 371 | 3.9 |
| **Wide Defenders** | Average | 10876 | 113.7 | 1053 | 11.0 |
| | SD | 506 | 6.1 | 264 | 2.8 |
| | Max | 11632 | 123.5 | 1519 | 15.9 |
| | Min | 9728 | 100.5 | 687 | 7.1 |
| **Central Midfielders** | Average | 11255 | 117.7 | 1005 | 10.5 |
| | SD | 821 | 8.8 | 265 | 2.8 |
| | Max | 12727 | 136.6 | 1641 | 17.4 |
| | Min | 9104 | 95.8 | 545 | 5.7 |
| **Wide Midfielders** | Average | 10785 | 113.5 | 1192 | 12.5 |
| | SD | 880 | 9.1 | 213 | 2.2 |
| | Max | 12490 | 130.6 | 1573 | 16.6 |
| | Min | 9296 | 102.0 | 855 | 9.0 |
| **Forwards** | Average | 10911 | 113.7 | 987 | 10.3 |
| | SD | 539 | 5.6 | 172 | 1.8 |
| | Max | 12091 | 124.9 | 1355 | 14.0 |
| | Min | 9706 | 102.4 | 689 | 7.2 |

Average (±SD), maximum and minimum values for HRV measurements on MD+1 and MD+2 can be found in table 4.2. There seems to be large inter-individual differences in HRV. These differences are more pronounced on MD+1 (range = 41.8) than on MD+2 (range = 31.1). These values are similar to the findings of previous research investigating HRV in soccer players (Flatt *et al.,* 2016).

**Table 4.2.** Average (±SD) data for HRV measurements recorded on MD+1 and MD+2 during this study. The data provided is an arbitrary value produced by the ithlete software.

| Recovery Day | Average | Standard Deviation | Maximum | Minimum | SWC |
|---|---|---|---|---|---|
| **MD+1** | 89.8 | 7.5 | 113.3 | 71.5 | 1.75 |
| **MD+2** | 92.1 | 6.6 | 106.0 | 74.9 | |

In total, 189 unique data points were fitted to 10 different linear mixed models. Five of these models involved data (n=93) from HRV measurements taken on MD+1 (HRV MD+1). There were no significant effects found between HRV MD+1 and any of the physical load variables investigated in this study ($p<0.05$). All effect sizes were deemed as trivial (<0.2) with the exception of the effect size of match duration (0.23). All raw coefficients, effect sizes and *p* values for each model involving HRV MD+1 can be found in table 4.3. The raw coefficients show that the variable with the greatest impact on HRV on MD+1 is high intensity distance per minute. An increase of 1m of high intensity distance per minute would result in a decrease of 0.2 in HRV MD+1.

**Table 4.3.** Raw coefficients, effect sizes and *p* values for all linear mixed models ran between HRV MD+1 and physical loading variables.

| Independent Variable | Raw Coefficient | Effect Size | *p* Value |
|---|---|---|---|
| **Duration** | -0.03130 | 0.23 | 0.39 |
| **Total Distance** | 0.00074 | 0.11 | 0.49 |
| **Distance per Minute** | 0.07405 | 0.12 | 0.45 |
| **High Intensity (HI) Distance** | -0.00232 | 0.14 | 0.41 |
| **HI Distance per Minute** | -0.21715 | 0.14 | 0.42 |

The other 5 models investigated HRV measurements (n=96) taken on MD+2 (HRV MD+2). Similarly to HRV MD+1, there were no significant effects found between HRV MD+2 and any of the physical loading variables investigated in this study

($p<0.05$). Again, all effect sizes were deemed as trivial (<0.2) with the exception of match duration (0.40). All raw coefficients, effect sizes and *p* values for each model involving HRV MD+2 can be found in table 4.4. The raw coefficients show that the variable with the greatest impact on HRV MD+2 is match duration. An increase in the game duration by 1 min would result in an increase of 0.5 in HRV. The next highest raw coefficient was distance per minute which suggests that an increase of 1m per min would result in a 0.1 drop in HRV MD+2.

**Table 4.4.** Raw coefficients, effect sizes and *p* values for all linear mixed models ran between HRV MD+2 and physical loading variables.

| Independent Variable | Raw Coefficient | Effect Size | *p* Value |
|---|---|---|---|
| **Duration** | 0.51100 | **0.40** | 0.36 |
| **Total Distance** | -0.00088 | 0.14 | 0.47 |
| **Distance per Minute** | -0.10286 | 0.18 | 0.34 |
| **High Intensity (HI) Distance** | -0.00018 | 0.01 | 0.97 |
| **HI Distance per Minute** | -0.04507 | 0.03 | 0.88 |

## 4.4 Discussion

The aim of this study was to assess the relationship between smartphone derived HRV collected on MD+1 and MD+2 and the activity completed during the preceding soccer match. An understanding of this relationship has the potential to inform the usefulness of this approach to support the recovery strategies used with elite players. No relationships were found between any of the indicators of match activity investigated in this study and HRV indices measured on either MD+1 or MD+2. This suggests that smartphone derived HRV assessed on either MD+1 or MD+2 is insensitive to changes in the amount of physical activity during match-play as indicated by selected physical variables (total distance, distance per minute, HI distance, HI distance per minute) during soccer games. It is therefore feasible to suggest that this method of assessing HRV may not be appropriate to use as a surrogate measure of physiological status in elite soccer players during the recovery period following match play. It may also suggest that this approach at a more general level may not be useful from a practical perspective within the sport.

HRV has been utilised in numerous studies to assess changes in the balance of the ANS as a result of an exercise stimulus. Stanley *et al.* (2013) suggested that the intensity of the stimulus has the largest impact on the ANS and subsequent assessment of HRV when compared with other variables such as the duration of the stimulus and the type of exercise employed. In previous studies the intensity of the exercise used to stimulate a disturbance in homeostasis was quantified through the assessment of the HR response elicited during the activity. For example, participants were required to complete 7x3min bouts of treadmill running at an average HR of ~91% (Kaikkonen *et al.,* 2008). These variables, such as average HR and the amount of time spent in HR zones (>85% of max HR), provide clear indications of the internal demands placed on the cardiovascular system during the exercise stimuli undertaken during these studies. Such procedures to assess internal load were unable to be applied in the current investigation as at the time of data collection the use of HR monitors during competitive soccer matches was not permitted by the governing body. Other data would suggest that the average HR during soccer match play has been reported to be approximately 81-87% of max HR depending on playing position and competitive level (Dellal *et al.,* 2012). Helgerud *et al.* (2001) support these values by suggesting that players spend around 40% of match-play above 85% of maximum HR. These values are however probably highly variable and may change significantly with factors such as training history and age. Previous research in this area (Thorpe *et al.,* (2015) would suggest that the stimulus associated with soccer match play is enough to disturb autonomic balance during the subsequent recovery period in a similar way to that observed in previous research (Kaikkonen *et al.,* 2008; Stanley *et al.,* 2013). The inability to accurately quantify the intensity of the exercise (from an internal load perspective) in the current study impacts the degree of certainty with which the results can be interpreted. If the exercise load associated with the games did not provide a high internal physiological response there may not have been an associated change in HRV post game. This issue in the design of the investigation may therefore increase the likelihood of a type II error. Variations in external variables, such as distance covered and distances covered at particular speed thresholds, seem however to correlate well with changes in internal variables such as average HR (Asian *et al.,* 2012; Tang *et al.,* 2018). This would suggest that the methods used in this study may not be limited in this way and so still allow for a good assessment of the effectiveness of HRV monitoring following soccer match play.

The current study has used 3 variables (distance per minute, HI distance, HI distance per minute) to assess the relationship between the 'intensity' of games and the resulting HRV (MD+1 and MD+2). This relationship may provide insight into the physiological status of players during the recovery period. This information may provide rationale for subsequent training schedules. No significant effects were found between any of these variables and HRV ($p$<0.05) and all effect sizes were deemed to be trivial (<0.2). To provide some perspective to this analysis, a 33% increase in HI distance (310m – 1x SD for this variable, see table 1) would have brought about a 0.06 reduction in HRV MD+2. Considering the SWC for HRV is between 2-3% (a change of 1.75-2.76 in HRV MD+2), it is apparent that the change in HRV (0.06) that would potentially occur as a result of a relatively large change in HI distance (33%, 310m) would be insignificant in the attempt to assess changes in physiological status. This may suggest that observing the effect of the intensity of soccer match play on post-match HRV collected using the ithlete method is somewhat redundant when attempting to inform the decision-making process around the potential recovery of players following games.

Although previous research has suggested that the volume of exercise has a lesser impact on autonomic balance when assessed using methods such as ECG, it is still important to assess the relationship between volume of exercise and HRV collected through the ithlete method here to ensure the findings are consistent across the various methods of assessing HRV (Stanley *et al.,* 2013). The variables investigated in this study that are indicative of the volume of the physical loads completed during games are duration and TD. Similarly to the markers of intensity investigated in this study no significant effects were found between duration or total distance and HRV MD+1 or HRV MD+2 ($p$<0.05). ES for TD and HRV were also found to be trivial on both MD+1 and MD+2 (<0.2) whereas the relationships between duration and HRV MD+1 (0.23) and duration and MD+2

(0.40) were deemed to show moderate effects. These findings may not be surprising given the expected impact of volume of exercise on HRV observed by other groups in previous research (Seiler *et al.,* 2007). Although the models that use duration as an indicator of volume show there to be a moderate effect on HRV on both MD+1 and MD+2, it is important to note that the findings around duration may in this case be erroneous. This may be due to the fact that only data from completed games were included in this study. This means there is a much smaller range within which all data points for the duration of exercise will exist (i.e. 93-100 minutes) when compared with other variables such as TD (8738-12727m). Therefore, a 1 min change in duration (raw coefficient MD+2 = 0.511) will account for a much larger change in HRV than a 1 metre change in TD (raw coefficient MD+2 = -0.001). However, these relationships are a function of the numerical constraints on this variable rather than a result of any physiological changes. Overall, these findings suggest that there is no real relationship between markers of volume and HRV collected through the ithlete method. It seems this method can therefore contribute little in terms of supporting the decision making process around tailoring the recovery period in soccer to individual players.

Buchheit (2014) states that utilising an individualised approach to monitoring physiological status through HR measures (resting, exercising and recovery) is not commonplace in soccer. The author suggested that this is a result of a negative portrayal of the effectiveness of such measures in the literature. However, it is also suggested that the basis for this negative portrayal is more likely to be a reflection of methodological inconsistencies rather than being a "true" representation of the usefulness of HR based measures (Buchheit 2014). This can be related to the limitations associated with the methodology used in the current study. These limitations include the method used to obtain HRV measurements and the structure of when measurements were taken within the recovery period. There are various methods of collecting HRV that have been validated and utilised in previous research studies including ECG (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996) and chest belt heart rate monitors (Gamelin *et al.,* 2006). There is also research which has shown the effectiveness of using these methods with elite soccer players (Thorpe *et al.,* 2015; Thorpe *et al.,* 2017). Recent advancements in technology have allowed new methods for the assessment of HRV to be developed. These new methods have focussed on developing a flexible method of assessing HRV using as little as 60 seconds of HR data. The development of these methods is a result of a requirement to obtain a measurement from a large group of players (~20) in a short period of time where the use of ECG may be impractical. The method utilised in this study (ithlete) can be included in this category of new technologies. To the authors knowledge, there is some limited validation work around this method (Flatt & Esco, 2013; Heathers, 2013; Esco *et al.,* 2016), however, investigation into the effectiveness of this method with soccer players is lacking. Due to other limitations discussed below, it is not surprising that the findings of this study suggest that this method of assessing HRV is not effective with soccer players despite previous research showing the method to be a valid measure of HRV.

The other methodological issue associated with the design of the current study that may have had an impact on the outcomes is around when measurements are taken. The timings of the measurements used (MD+1 and MD+2) may be inappropriate to detect changes in autonomic balance resulting from soccer match play. In previous studies, measurements of HRV have been recorded at a number of time points including immediately post-exercise, 1 hour, 2 hours, 3 hours, 4 hours, 24 hours, 36 hours, 48 hours, and 72 hours post exercise. Given that the magnitude of the displacement in autonomic balance and/or the duration that this displacement may last following soccer match play is currently unknown, it may be logical to suggest that more frequent measurements could have been implemented within the current study. The inclusion of measurements during the earlier stages of recovery may be needed to evaluate their effectiveness. Although it may be beneficial to implement more frequent assessments during the earlier stages of the recovery period, the practical considerations associated with attempting to integrate this during the recovery process may be problematic. For example, within elite level soccer it is difficult to allocate enough time to obtaining good quality measurements of HRV immediately following the cessation of match play due to various commitments such as media appearances, travel arrangements, and recovery strategies. Other opportunities for contact with players is likely to be the following day (MD+1) when it is common for players to be given a days rest away from the training ground. Previous research with elite soccer players has presented similar issues with regards to the timings of measurements citing the impact of the predetermined schedule and contact time within a soccer club (Thorpe *et al.,* 2016). With this taken into consideration it may therefore be impractical to implement more frequent assessments of HRV during the recovery period despite knowing that more frequent data collection would provide a better insight into the time-course of recovery following soccer match play. Finally, it may have been beneficial to have measured HRV through a more conventional method (HR belt) simultaneously in order to provide a comparison between the HRV data collected though the ithlete method and methods which have been more robustly assessed for validity.

In conclusion, no significant relationships between any of the physical loading variables (total distance, distance per minute, HI distance, HI distance per minute) assessed in this study and smartphone derived HRV MD+1 or HRV MD+2 were found. This suggests that measurements of HRV through the ithlete method may not be suitable for use in monitoring the progress of the reestablishment of autonomic balance following soccer match play. Buchheit (2014) proposed that other HR based measures such as HRR or exercising HR may offer a better alternative to assessing autonomic function during the recovery period in comparison to HRV. However, these measures may require an exercise stimulus in order to collect the required data. These results may therefore support the requirement for the development of a practical tool or method that can be used during the recovery period following soccer match play to accurately assess the physiological status of players using exercising HR and HRR.

# Chapter 5

## The Development of a Standardised Exercise Protocol to Evaluate Physiological Status in an elite soccer playing population

## 5.1 Introduction

The recovery period following soccer match play is a crucial time where the focus is to return the body to the pre-game homeostatic state (Nedelec *et al.,* 2012). There are numerous methods currently utilised in elite soccer that attempt to accelerate the recovery process (Nedelec *et al.,* 2013). Similarly, there are a variety of methods that are implemented to quantify and monitor the progress of recovery during this period (Smart *et al.,* 2008; Cortis *et al.,* 2013; Morgans *et al.,* 2014). Unfortunately, many of the monitoring tools currently in use have features that may not facilitate the regeneration process. These include things such as demanding physical loads, risk of injury, or invasive methodologies to track regeneration. These features make them unfeasible for use in the real world with elite soccer playing populations. With this in mind, there is a need to develop a suitable monitoring tool that is able to provide information on physiological status without adverse considerations.

Heart rate monitoring is commonplace during training sessions within elite soccer clubs and is frequently utilised to quantify training loads and assess players' adaptation to training (Achten & Jeukendrup, 2003). More recently, HR monitoring has been used to assess internal stress resulting from physical loads during recovery periods through HRV and HRR (Buchheit *et al.,* 2007; Buchheit *et al.,* 2012; Buchheit, 2014). Monitoring of HRV, HRR, and %MAXHRr can indirectly assess changes in autonomic function that occur following training and/ or match play. This is done by the quantification of changes in cardiac performance and haemodynamics which are thought to reflect exercise induced changes in autonomic function (Douglas *et al.,* 1987; Murrell *et al.,* 2007; Stanley *et al.,* 2013). Chapter 4 investigated the use of smartphone derived HRV with elite soccer players. The findings suggested that HRV recorded in this way may not be suitable for the continuous monitoring of physiological status following match play. However, this does not mean that the assessment of physiological status through fluctuations in the ANS is not a useful tool. In contrast to the use of HRV, HRR only requires the peak HR (~85-90% [Lamberts & Lambert, 2009]) from an exercise bout and the HR at the end of a 60 second rest period starting immediately after the cessation of the exercise bout. However, this means an exercise bout must be completed at each time point of HRR data collection. This may be problematic with elite soccer players during the recovery period following games due to the physical demands associated with the required exercise bout. However, if the correct exercise stimulus is employed which utilises minimal physical loads, this may eradicate any issues associated with conducting this type of test during the recovery period. The criteria outlined for any developed protocol to adhere to would include: (i) a short duration, (ii) low physical demands, and (iii) a suitable HR response (>85%). Furthermore, an exercising HR within an appropriate range (85-90%) may itself be useful as a marker of physiological status similar to HRR.

This may suggest that there is a requirement to develop an appropriate exercise protocol that is designed within the specified criteria above. This would allow for the developed protocol to be utilised within the recovery period following soccer match play. Such a protocol would also need to permit repeatable measurement of HRR and %MAXHRr, that can be easily integrated into the training schedule of an elite soccer team. Therefore, the aim of this study was to develop a standardised exercise protocol (SEP) that can be used for the assessment of HRR and %MAXHRr with elite soccer players while adhering to the specific characteristics of an exercise test that would facilitate completion with an elite soccer team.

## 5.2 Methods

### *5.2.1 General Study Design*

With the aim of the investigation in mind, this study was split into three distinct phases (see figure 5.1). Phase 1 incorporated the initial development of the SEP. This involved trialling different exercise protocols to understand the make-up of protocols that were practically suitable for the determination of HRR. Phase 2 involved assessing a smaller number of protocols (n=6) that were refined as a result of the findings of Phase 1 with the aim of identifying a select number of protocols that could be used in Phase 3. Phase 3 investigated the reliability of the protocols. Both %MAXHRr and HRR data were collected for all protocols throughout all phases of this study in order to evaluate each protocols ability to assess autonomic balance. During the development phases (phases 1 and 2), %MAXHRr was utilised more prominently for analysis. This is due to the aim of these phases being focussed on assessing the suitability of each protocol with regards to the HR response elicited which was an important prerequisite for accurate assessment of HRR (Lamberts & Lambert, 2009).

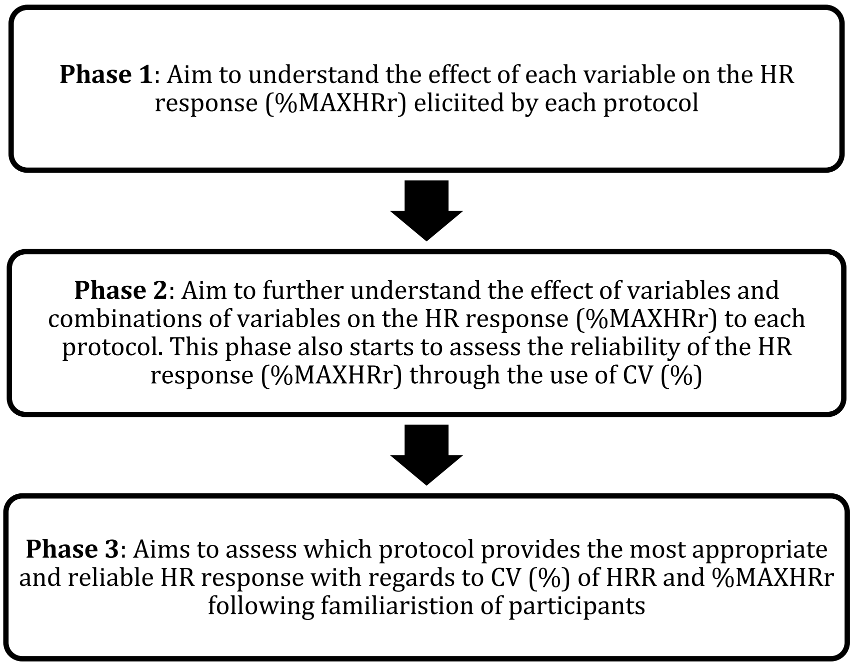


**Figure 5.1.** An overview of the three distinct phases utilised to fulfil the aims of this chapter.

During all phases participants were required to complete a series of exercise tests that incorporated a number of straight-line runs over varying distances at a predetermined speed. Within each exercise protocol repetitions of straight-line runs were separated by a specific period of stationary rest that allowed for the control of exercise to rest ratios (see figure 5.2.). Following the completion of the exercise component of each protocol, participants were required to remain standing in a stationary position for a 1 min recovery period (Gnehm *et al.,* 1997). This static period allowed for the calculation of HRR. Different exercise protocols were completed on the same day though each discrete exercise protocol was separated by a minimum of 30 min of seated rest. Throughout all data collection periods all participants wore a GPS unit (Viper 2, STATSports, Belfast, UK) and HR monitor (Polar T31, Polar Electro, Kempele, Finland). Participants wore the same

GPS unit and HR monitor for all protocols in order to eliminate inter-unit variability (Aughey, 2011). Ratings of perceived exertion (RPE) were collected immediately following the completion of all protocols during phases 1 and 2 (Borg, 1982). Participants were instructed to refrain from physical activity, smoking, and consumption of alcohol and caffeine throughout the duration of the study.

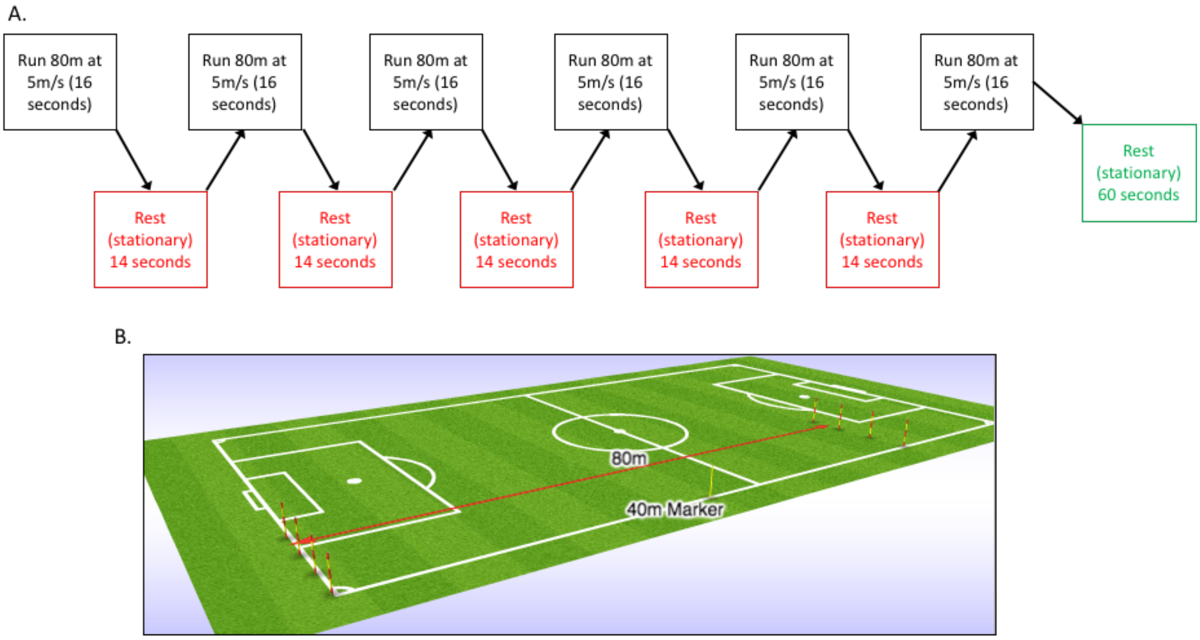


**Figure 5.2.** A. schematic diagram of an example exercise protocol utilised in this study. B. The pitch layout of the example exercise protocol.

### *5.2.2 Participants*

Fifteen male sub-elite competitive soccer players took part in the study. Six participants (Mean ± SD: age 26±3 years, height 1.7±0.6m, body mass: 73±8.4kg) took part in phases one and two of the study. Nine participants (Mean ± SD: age 19±0.6 years, height 1.7±0.9m, body mass: 63±9.0kg) took part in phase three of the study. All participants were informed of the procedures involved in the study and provided written informed consent. This study was conducted according to the requirements of the Declaration of Helsinki and was approved by the University Ethics Committee of Liverpool John Moores University.

### *5.2.3 Procedures*

#### *5.2.3.1 Phase 1: Initial Protocol Development*

The initial phase of development involved trialling different combinations of exercise prescriptions values found at the practical limits (i.e. the minimum and maximum feasible values viable for use with elite soccer players) available for each of the variables that were deemed important to the protocol development during this study (distance of each run, running speed, number of repetitions, work: rest ratio). As a general rule, the maximum value used for each variable were used initially in an attempt to ensure physical loads remained low enough for use during the recovery process following a soccer match. The minimum values selected, were based around the need to attain a HR around 80% of maximum. Each of these variables will have an effect on the HR response elicited by the exercise protocol. As a result, particular combinations of these variables will allow the HR response to be manipulated to an appropriate level for the assessment of physiological status within incurring high physical loads that may be detrimental to the recovery process. The range for each variable were: running distance – 20 to 80m, number of repetitions – 4 to 8, running speed – 4 to 6m/s, and exercise: rest ratio – 1:0.5 to 1:2. This resulted in a total of 16 different protocols that were investigated in this phase of the study. Participants completed 2 trials of each of the protocols. The trials were randomly assigned to one of 8 testing days. On each testing day participants completed 4 separate exercise protocols in a random order with 30 minutes of seated rest between each protocol. Each of the 8 testing days were separated by 7 days of rest. The aim of this phase was to ascertain the impact of each variable on the HR response during the exercise protocols. In this phase, the focus was on the percentage of maximum heart rate reached (%MAXHRr) rather than the subsequent calculation of HRR when assessing the suitability of protocols. The data collected in this phase would be used to inform decision making around which protocols were appropriate for assessment in phase 2 of the study.

*5.2.3.2 Phase 2: Further Protocol Development*

The second phase of the study was designed to continue the systematic investigation of the effects of varying distance of run, running speed, number of repetitions, and exercise: rest ratio on the HR response (%MAXHRr) during and following (HRR) various SEPs. Similarly to Phase 1, this phase also prioritised the use of %MAXHRr over HRR when assessing the HR response of protocols. This phase was a development of the research completed in phase 1 by including calculations to determine the repeatability of these protocols through the calculation of coefficients of variations (CV). The data collected in phase 1 was used to form the rationale for the 6 protocol variations to be investigated in this section. Table 5.1 outlines the specific details regarding each of the protocols used in this phase of development. Participants completed 2 trials of each protocol. The trials were randomly assigned to one of 4 testing days. On each testing day participants completed 3 separate exercise protocols in a random order with 30 minutes of seated rest between each protocol. Each of the 4 testing days were separated by 7 days of rest. The aim of this phase was to determine which 3 protocols were most suitable for use in phase 3 of this study with regards to the HR response elicited and potential repeatability.

**Table 5.1.** Table showing the specific protocol details used in phase 2 of the developmental trials.

| Protocol | Repetitions | Distance (m) | Speed (m/s) | Work: Rest |
|---|---|---|---|---|
| **1** | 6 | 60 | 6 | 1:2 |
| **2** | 8 | 60 | 5 | 1:2 |
| **3** | 6 | 60 | 5 | 1:0.5 |
| **4** | 6 | 80 | 5 | 1:0.5 |
| **5** | 6 | 80 | 6 | 1:2 |
| **6** | 6 | 80 | 6 | 1:0.5 |

*5.2.3.3 Phase 3: Reliability of Selected Protocols*

Three exercise protocols were selected from the developmental phases of this study (phases 1 & 2) for use in this final phase. The aim of this phase was to assess the reliability of the selected protocols to ascertain the most suitable protocol for use with soccer players during the recovery period following soccer games. Participants completed one trial of all 3 exercise protocols on each of 5 designated testing days. Trials completed on the first 3 testing days were used to familiarise the participants with each of the protocols. The trials completed on days 4 and 5 were used for assessment of reliability. The order in which the protocols were completed were randomised for each day. On each of the testing days the 3 protocols were separated by 30 minutes of seated rest. Each of the 5 testing days were separated by 7 days of rest. The details of the 3 exercise protocols used in this phase are outlined in table 5.2.

**Table 5.2.** Table showing the specific protocol details used in phase 3 for assessment of reliability.

| Protocol | Repetitions | Distance (m) | Speed (m/s) | Work: Rest (s) |
|---|---|---|---|---|
| **1** | 6 | 60 | 6 | 10:20 |
| **2** | 6 | 80 | 5 | 16:14 |
| **3** | 6 | 60 | 5 | 12:8 |

*5.2.4 Statistical Analysis*

All data were presented as average ± SD where possible. HRR was calculated using the following equation:

Equation 1:

HRR (%) = ([Maximum HR during exercise protocol – Minimum HR during recovery period] ÷ Maximum HR during exercise protocol) × 100

For assessment of reliability, data were analysed using calculation of standard error of measurement (SEM), CV, and paired sample t-tests. The significance level for t-tests was set at $p<0.05$. Statistical analysis were completed using SPSS 21.0 (IBM, Chicago, IL, USA). The SEM and CV were calculated using the following equations:

Equation 2:
SEM = Standard deviation of the differences between trails ÷ ($\sqrt{2}$)

Equation 3:
CV = (SEM ÷ Overall Mean for Both Trials) × 100

## 5.3 Results

### *5.3.1 Findings from Phase 1: Initial Protocol Development*

HR and RPE data collected during phase 1 of the study can be found in table 5.3. Profound differences in %MAXHRr were reported between the two distances investigated (20m – 69% vs. 80m – 79%). The subjective feedback (RPE) provided by participants following protocols (20m – 4 vs. 80m – 4) suggested that there was no perceptual difference between protocols over different distances. Changes in running speed also considerably impacted %MAXHRr when distance per run was set at 80m (4m/s – 74% vs. 6m/s – 85%) suggesting that faster speeds elicited a more suitable HR response (Lamberts *et al.,* 2011). Specific manipulations associated with the number of repetitions brought about a smaller change in %MAXHRr reached when distance per run was set at 80m (4reps – 77% vs. 8reps – 81%). Exercise: rest ratio also notably impacted %MAXHRr (1:2 – 74% vs. 1:0.5 – 85%) when the distance of each run was set at 80m. The data presented from phase 1 suggests that protocols utilising longer distances per run (60-80m) and higher repetitions (6-8reps) should be investigated further in the next phase. Further analysis of the impact of combining 6-8 repetitions of 60-80m runs with specific running speeds and work: rest ratios to elicit a desirable %MAXHRr is required in phase 2 of this study. The implementation of a higher work: rest ratio may allow for slower speeds to be utilised. This may make the associated physical loads more suitable for use during the recovery period following soccer match play.

**Table 5.3.** Average ± SD data for percentage of maximum heart rate reached (%MAXHRr), heart rate recovery (HRR), and rating of perceived exertion (RPE) for all protocols completed in phase 1.

| Protocol | %MAXHRr | HRR | RPE |
|---|---|---|---|
| **4x4m/s 20m 1:2** | 62 ± 1.5 | 21 ± 6.2 | 2 ± 0.0 |
| **4x6m/s 20m 1:2** | 71 ± 2.1 | 31 ± 8.4 | 6 ± 0.0 |
| **4x4m/s 20m 1:0.5** | 60 ± 4.1 | 24 ± 7.6 | 2 ± 0.0 |
| **4x6m/s 20m 1:0.5** | 61 ± 6.7 | 6 ± 2.3 | 5 ± 0.4 |
| **8x4m/s 20m 1:2** | 65 ± 1.8 | 25 ± 7.2 | 2 ± 0.0 |
| **8x6m/s 20m 1:2** | 85 ± 2.4 | 42 ± 5.4 | 6 ± 0.8 |
| **8x4m/s 20m 1:0.5** | 75 ± 3.1 | 32 ± 8.9 | 2 ± 0.0 |
| **8x6m/s 20m 1:0.5** | 72 ± 1.1 | 12 ± 3.6 | 7 ± 1.0 |
| **4x4m/s 80m 1:2** | 68 ± 6.2 | 28 ± 4.3 | 1 ± 0.0 |
| **4x6m/s 80m 1:2** | 77 ± 4.7 | 28 ± 3.3 | 3 ± 1.0 |
| **4x4m/s 80m 1:0.5** | 79 ± 6.2 | 30 ± 2.1 | 3 ± 1.0 |
| **4x6m/s 80m 1:0.5** | 87 ± 9.1 | 25 ± 4.8 | 7 ± 1.0 |
| **8x4m/s 80m 1:2** | 69 ± 3.7 | 29 ± 4.1 | 1 ± 0.0 |
| **8x6m/s 80m 1:2** | 83 ± 7.6 | 24 ± 10.3 | 6 ± 2.0 |
| **8x4m/s 80m 1:0.5** | 79 ± 2.3 | 30 ± 6.3 | 4 ± 0.0 |
| **8x6m/s 80m 1:0.5** | 93 ± 4.8 | 21 ± 2.5 | 9 ± 1.0 |

*5.3.2 Findings from Phase 2: Further Protocol Development*

The %MAXHRr and HRR from each of the six protocols used in phase 2 are outlined in table 5.4. Data from all protocols were also used to calculate CVs for %MAXHRr and HRR (see table 5.5). It is clear from the available data that a speed of 5m/s was sufficient to attain a %MAXHRr above 80% when used in conjunction with the appropriate manipulations of the other variables. However, simply increasing the number of repetitions (>6) did not elicit an increase in %MAXHRr. To align with the prerequisites outlined above, the number of repetitions for the chosen protocol should not exceed 6. Most interestingly, exercise: rest ratio appeared to considerably impact %MAXHRr and looked to be a useful tool in the development of an exercise protocol that is low in physical load that elicits a relatively high HR response. Higher exercise: rest ratio (1:0.5) combined with a slower running speed (5m/s) brought about a similar %MAXHRr (82%) to the combination of a faster running speed (6m/s) with lower exercise: rest ratio (1:2) (84%). To meet the practical requirements of a developed protocol, it may therefore be beneficial to utilise a slower running speed with higher work: rest ratio. The data collected during this phase suggested that protocol number 1, 3 & 4 were the most suitable for use in the third phase of this study to ascertain the most reliable protocol for future use.

**Table 5.4.** Average ± SD data for percentage of maximum heart rate reached (%MAXHRr), heart rate recovery (HRR), and rating of perceived exertion (RPE) for all protocols completed in phase 2 of development.

| Protocol No. | Details | %MAXHRr (%) | HRR (%) | RPE |
|---|---|---|---|---|
| **1** | 6x6m/s 60m 1:2 | 84 ± 5.1 | 28 ± 6.1 | 6 ± 1.1 |
| **2** | 8x5m/s 60m 1:2 | 76 ± 4.3 | 29 ± 7.5 | 4 ± 0.5 |
| **3** | 6x5m/s 60m 1:0.5 | 83 ± 2.2 | 30 ± 4.7 | 5 ± 0.0 |
| **4** | 6x5m/s 80m 1:0.5 | 80 ± 1.4 | 29 ± 7.8 | 5 ±0.5 |
| **5** | 6x6m/s 80m 1:2 | 88 ± 3.2 | 26 ± 6.5 | 6 ± 1.1 |
| **6** | 6x6m/s 80m 1:0.5 | 91 ± 4.6 | 31 ± 7.1 | 8 ± 1.1 |

**Table 5.5.** Coefficient of variation (CV) (%) for percentage of maximum heart rate reached data (%MAXHRr) and average heart rate recovery data (HRR) from all protocols completed in phase 2 of development.

| Protocol No. | Details | CV (%) for %MAXHRr | CV (%) for HRR |
|---|---|---|---|
| **1** | 6x6m/s 60m 1:2 | 1.6 | 6.1 |
| **2** | 8x5m/s 60m 1:2 | 4.6 | 10.4 |
| **3** | 6x5m/s 60m 1:0.5 | 0.3 | 7.4 |
| **4** | 6x5m/s 80m 1:0.5 | 1.1 | 7.1 |
| **5** | 6x6m/s 80m 1:2 | 3.5 | 7.9 |
| **6** | 6x6m/s 80m 1:0.5 | 4.4 | 8.4 |

*5.3.3 Findings from Phase 3: Reliability of Selected Protocols*

Average HRR and %MAXHRr data for all testing trials for all protocols are provided in Table 5.6. All 3 protocols brought about an average %MAXHRr above 80%. HRR data appeared to show similar consistency to the values reported in phase 2 for this study following protocol number 1 and 2. On the other hand, protocol number 3 was associated with a much larger variation in HRR (trial 1 – 22% vs. trial 2 – 30%).

**Table 5.6.** Average ± SD heart rate recovery (HRR) and percentage of maximum heart rate reached (%MAXHRr) data for all testing trials for all protocols.

| Protocol No. | Details | HRR (%) | | %MAXHRr (%) | |
|---|---|---|---|---|---|
| | | TRIAL 1 | TRIAL 2 | TRIAL 1 | TRIAL 2 |
| **1** | 6x6m/s 60m 10:20s | 26 ± 5.5 | 26 ± 6.4 | 82 ± 6.7 | 83 ± 5.5 |
| **2** | 6x5m/s 80m 16:14s | 19 ± 4.0 | 24 ± 2.6 | 86 ± 4.4 | 85 ± 2.6 |
| **3** | 6x5m/s 60m 12:8s | 22 ± 6.8 | 30 ± 10.2 | 90 ± 3.7 | 89 ± 3.0 |

SEM, CV, and *p* values are shown in Table 5.7. Coefficient of variation showed that protocol 2 had the least variation between trials for both HRR (9.95%) and %MAXHRr (2.57%) while protocol 3 presented a larger variation for HRR (40.41%) but a much smaller CV for %MAXHRr (2.62%) with protocol 1 showing a moderate CV for HRR (21.99%) and a larger variation for %MAXHRr (4.08%). No significant differences were found between trial 1 and 2 for HRR or %MAXHRr for any of the protocols investigated ($p<0.05$). The data presented suggests that protocol 2 provides the most suitable HR response that is reliable for further use in the calculation of HRR with elite soccer players.

**Table 5.7.** Overall average, standard error of measurement (SEM), and coefficient of variation (CV) data for HRR and %MAXHRr calculated from heart rate data obtained during testing trials.

| **Protocol No.** | **Details** | **HRR** | | | | **%MAXHRr** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Overall Av. (%) | SEM (%) | CV (%) | *p* value | Overall Av. (%) | SEM (%) | CV (%) | *p* value |
| **1** | 6x6m/s 60m 10:20s | 26 | 5.7 | 21.9 | 0.770 | 82 | 3.3 | 4.1 | 0.288 |
| **2** | 6x5m/s 80m 16:14s | 21 | 2.1 | 9.9 | 0.864 | 86 | 2.1 | 2.6 | 0.116 |
| **3** | 6x5m/s 60m 12:8s | 26 | 10.4 | 40.4 | 0.122 | 89 | 2.3 | 2.6 | 0.501 |

## 5.4 Discussion

The aim of this study was to develop a reliable exercise protocol for the assessment of HRR and %MAXHRr that could be used practically during the 48-hour recovery period following soccer match play. A prerequisite for the protocol was for it to be practically operational within the limits of the physical demands of training patterns implemented by elite soccer teams in the 72 hours following match play. The initial stage of protocol development (Phase 1) was used to assess the effect of each exercise prescription variable (distance per run, number of repetition, running speed, exercise: rest ratio) on the HR response of each exercise protocol. Phase 2 of protocol development assessed the suitability and reliability of 6 protocols that were selected from those trialled in phase 1. Phase 3 of this study evaluated 3 protocols from Phase 2 namely 6x60m at 6m/s (10:20s), 6x80m at 5m/s (16:14s), 6x60m at 5m/s (12:8s). In addition to eliciting a suitable level of physical demands it was important for the exercise protocol to elicit a consistent HR response that was similar to that required (>85%) for reliable measurement of HRR suggested by Lamberts and Lambert (2009). The most appropriate exercise protocol to fulfil the required criteria consisted of 6 repetitions of an 80-metre straight line run, at an average speed of 5m/s (16 seconds exercise period), with each repetition separated by 14 seconds of standing rest (6x80m at 5m/s [16:14s]) (see figure 5.3.). This protocol brought about a %MAXHRr of 86%, that falls in line with the above criteria. This protocol also presented the lowest CV for %MAXHRr (2.6%) and HRR (9.9%) in comparison to the other 2 protocols assessed. The data therefore would suggest that this protocol provides an accurate measure of HRR as a result of producing a reliable HR response through a consistent attainment of a given %MAXHRr. This may allow this protocol to be used for the future investigation of the usefulness of HRR or %MAXHRr as markers of physiological status of players following activity.

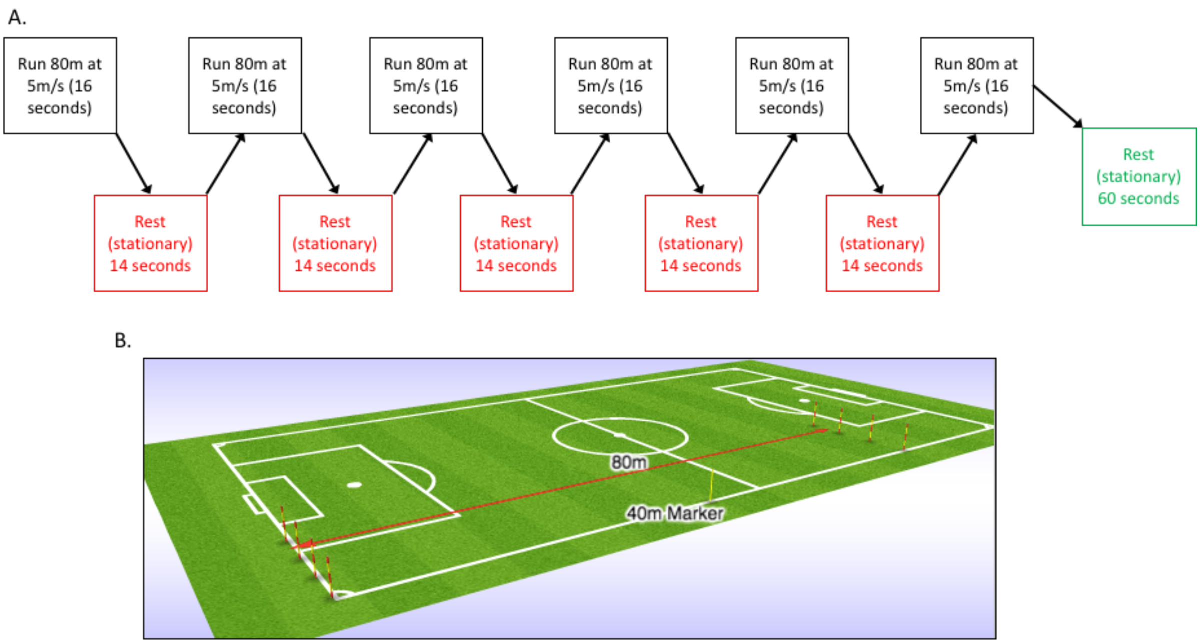


**Figure 5.3.** A. schematic diagram of the selected protocol. B. The pitch layout of the selected protocol.

It is important to compare the chosen protocol with other similarly styled protocols that are available in the current literature to understand if the developed protocol is a more suitable method of collecting %MAXHRr and HRR data. The most similar exercise protocol to have been previously used with elite soccer players is the *5'-5' test* previously used by Buchheit *et al.* (2008, 2010a, 2010b, 2012). Although the approaches to monitoring HRR in the current study and those by Buchheit *et al.* (2008, 2010a, 2010b, 2012) are similar, there are differences in the resultant HR response. The *5'-5' test* is reported to illicit a peak exercise HR ~73% of maximum HR which is considerably lower than the 86% %MAXHRr in the protocol developed in this study. Previous research suggests that a moderately high HR response (≥86%) is an important characteristic of an accurate protocol as it facilitates maximum sensitivity when assessing changes in HR measures (Lamberts *et al.*, 2011). This may be of paramount importance when attempting to utilise HRR to monitor physiological status following soccer match play. Small changes in the HR response to these protocols may translate into meaningful changes in autonomic function and overall physiological status (Stanley *et al.*, 2013). Furthermore, the high HR response associated with the developed protocol may be of particular importance due to the findings of research by Lamberts and Lambert (2009). The authors suggest that a HR response between 85-90% of maximum HR is optimal for the reliable measurement of HRR. The repeatability of this HR response is a key factor with regards to the implementation of this protocol into the weekly schedules of elite soccer. A repeatable measure of HRR would allow for numerous measurements to be taken over the course of a soccer season (e.g. following each soccer match). In turn, this would provide practitioners with comparable data around physiological status following each game as the same stimulus has been administered to provide a HR response. This can allow for any changes in the HR response to be attributed to changes in physiological status rather than variability within the exercise stimulus.

The HR response associated with the developed protocol seems to be suitable (>85% of MAX HR) for assessment of HRR with elite soccer players. The ability of this protocol to provide a more suitable HR response in comparison to previously used protocols such as the *5'-5' test* may be a reflection of the structural differences between the protocols. These differences are obvious when the associated activity profiles of both protocols are examined. The current protocol appears to more effectively utilise the demands placed on players through repeated bouts compared with the more continuous running experienced during the *5'-5' test.* This would seem to result in a higher %MAXHRr in the current protocol due to the type of exercise pattern used (Tang, 2018).

One of the key criteria taken into consideration during the development of the exercise protocol in this study was the practicality of implementing the developed protocol into the recovery sessions undertaken by elite soccer players following match play. The third chapter of this thesis outlines the amount of time spent undertaking pitch based active recovery sessions on MD+1 and MD+2. When looking to implement a SEP that could be used to assess physiological status, it would seem that MD+2 is the day which shows the greatest possibility as a point for monitoring. This is a result of the average duration of these sessions and the consistency with which these sessions are completed throughout the soccer season. The findings of chapter 3 show that on average pitch based recovery sessions lasted for 44 minutes with players covering a TD of 2230m at an intensity of 62.1 meters per minute with a maximum speed of 5.2 m/s. The general structure of these sessions would be a prolonged warm up focussed on mobility of the lower limbs, 8-10 repetitions of self-paced straight line running, and a soccer specific technical exercise. In theory the developed SEP could directly replace the self-paced straight line running that is currently utilised both in practical terms and from a physical load point of view (i.e. 480m TD with a maximum speed of 5m/s). This would suggest that this protocol could be seamlessly integrated into the current recovery sessions outlined above.

When considering the findings of this study, it is important to assess the potential limitations that may impact the data. In the current study, this focusses around the quality of the data collected due to the equipment used. The HR monitors used for data collection during this study had a sampling frequency of 0.2Hz. As this means that a value for HR is collected every 5 seconds, it is feasible that there may be some variance from the true HR value collected at the end of the exercise protocol (%MAXHRr) and at the end of the recovery period (HRR). It may also be beneficial for this research to be conducted assessing the reliability of the developed protocols using HR monitors with a better sampling frequency (>1Hz).

In conclusion, the data presented in this study suggests that the most suitable exercise protocol with regards to the reliability of the HR response and adherence to the physical loads used during the recovery period with elite soccer players would involve 6x80m straight-line runs at 5m/s with an exercise: rest ratio of 16:14s. This protocol presented CV, SEM and physical loading data that were superior to data associated with other similarly styled protocols considered throughout this study. Furthermore, it is apparent that the chosen protocol showed a better HR response and better reliability of the HR response for use in assessing the physiological status of soccer players. With this in mind, it is suggested that this protocol may be used to further understand if a player is 'fatigued' following match play or is able to return to normal soccer specific training. The next stage of research in this area should attempt to determine the validity of the HR response to the chosen protocol under controlled conditions and following actual soccer match play. This process may provide scope to assess the real world application of this protocol with elite soccer players with regards to its ability to detect changes in physiological status.

# Chapter 6

## Determining the Face Validity of the Heart Rate Response to a Standardised Exercise Protocol: The Impact of High and Low Physical Loads during Simulated Soccer Training Sessions

## 6.1 Introduction

The recovery period following soccer match play is vitally important for the maintenance and improvement of physical condition, the quality of subsequent match performance, and avoiding overtraining throughout the duration of an entire soccer season. Previous research into the physiology of soccer reflects this statement as many studies have attempted to enhance the recovery process using methods such as cold-water immersion, nutritional strategies, massage therapy, and active recovery (Nedelec *et al.,* 2013). The efficacy of these methods is debated in the current literature and implications associated with the practical application within the environment of elite soccer may further impact on the applied effectiveness of each method. It therefore seems logical that future focus for research should be on developing methods to monitor the recovery period following soccer match play.

From a physiological perspective, the recovery process following soccer match play involves the body returning to its normal homeostatic status (Reilly & Ekblom, 2005). This involves various components comprising the repair of muscle fibres, addressing biochemical imbalances, restoration of glycogen stores and rehydration. Various monitoring tools have been previously used to assess certain aspects of the recovery process. For example, a range of jump tests including countermovement or squat jumps have been used to assess neuromuscular fatigue (Andersson *et al.,* 2008), heart rate based measures such as HRV have been used to evaluate the autonomic nervous system (Buchheit, 2014), and blood sample assessment of creatine kinase and myoglobin have been used to monitor muscle damage (Scott *et al.,* 2016). However, each of these methods focus on one specific part of recovery and do not give a global overview of complete physiological recovery.

The previous chapter of this thesis focused on the development of a method for monitoring physiological status through the use of HR variables during and following an exercise stimulus. The developed SEP seemed to demonstrate good reliability for measurement of HRR and %MAXHRr. In order for this method to be used in a real-world setting, it is also useful to evaluate its face validity as a surrogate measure of physiological recovery. It is also important to ensure that the method used would be able to detect small changes in physiological status. With this in mind, the aim of this study was to assess the face validity of the HR response to the SEP in response to manipulated changes in the preceding training load. This involved assessing differences in physiological status (%MAXHRr, HRR) following a simulated soccer training session carrying high physical loads (HSSTS) and a simulated soccer training session carrying low physical loads (LSSTS). Based on previous research, we would expect to see differences in both %MAXHRr and HRR between trials. We hypothesise that %MAXHRr will be lower following the HSSTS in comparison to the LSSTS and that HRR will be faster following the LSSTS than following the HSSTS.

## 6.2 Methods

### *6.2.1 General Study Design*

Participants were required to attend the testing facility for 1 preliminary testing session, 2 separate experimental testing sessions (LSSTS and HSSTS) and their respective SEP (n=2). Exactly 48 hours of rest separated the testing session and its respective SEP. Seven days of rest separated each testing session. Participants were required to rest completely between sessions and avoid consuming caffeine or alcohol. The preliminary testing session was designed to assess participants' ability to participate in this study (see section 6.2.2). This session required participants to complete a maximum speed test and the Yo-Yo Intermittent Recovery Test Level 1. The maximum speed test involved 3x100m self-paced runs during which participants were instructed to aim to attain their maximum running speed. Participants were allowed to rest for 3 minutes between repetitions. The Yo-Yo Intermittent Recovery Test Level 1 was completed to exhaustion (when participants failed to make the required distance for two consecutive signals on the audio track). The inclusion criteria for this study required participants to be able to attain a minimum running speed of 8m/s during one of 3x100m self-paced sprints and to reach level 15.1 during the Yo-Yo Intermittent Recovery Test Level 1. These criteria were set to ensure all participants could tolerate the demands of the simulated soccer training sessions utilised in this study.

The two experimental testing sessions involved participants completing a low and a high physical load simulated soccer-training session in a balanced order (5 participants completed the LSSTS first, 5 participants completed the HSSTS first). These sessions aimed to stimulate significantly different physiological demands and subsequently disturb physiological status to different extents. This would theoretically provide the opportunity to assess the ability of the HR response to the SEP to detect changes in an individual's physiological status. At 48 hours following each testing session participants completing the subsequent SEPs. A standardised warm up was completed at the start of all testing sessions. All sessions were completed using custom made audio files to ensure consistent timings for all participants during all testing sessions. GPS units (Statsports Technologies, Ireland) and HR monitors (T31, Polar, Finland) were worn by all participants during all testing sessions. To avoid any inter-unit discrepancies that have been reported in previous research, participants wore the same GPS unit and HR monitor throughout this study (Jennings *et al.,* 2010).

*6.2.2 Participants*

Ten semi-professional soccer players (Age: 26.7±3.4 years, Weight: 76.6±9.5kg, Height: 1.79±0.08m) took part in the study. All participants provided written informed consent prior to the start of this study. Following the completion of the preliminary testing sessions (see above), 2 participants were withdrawn from the study due to their inability to meet the required criteria. This study was approved by the Ethics Committee of Liverpool John Moores University and conformed to the declaration of Helsinki.

*6.2.3 Simulated Soccer Training Sessions*

The aim of the low and high physical load simulated soccer training sessions was to create two discrete exercise sessions that carried "low" and "high" physiological demands respectively while still maintaining some ecological validity to the movement pattern of a soccer training session. The concept of the 'low' and 'high' physiological demands was to disturb autonomic balance by different amounts which could potentially be detected through the assessment of HR measures using the SEP. The terms 'low' and 'high' do not refer to the achievement of any threshold as such. In order to standardise this approach as much as possible a track including straight-line running at various speeds and 180-degree changes of direction was utilised (see figures 6.1 and 6.2). These sessions involved participants completing each section of the track at varying speeds (2, 4, 6 m/s) in an exercise pattern that replicated the intermittent nature of soccer. The selected speeds represented approximately 25, 50 and 75% of the maximum speed (8m/s) participants were required to attain for inclusion in this study. Only 180° changes of direction were used. This decision was made in an attempt to include some of the mechanical demands associated with soccer whilst also being able to control the intensity of these components throughout data collection. Pilot work was undertaken to develop these simulated training sessions. The aims of the pilot work were: (i) to ensure the selected sessions carried distinctly different demands whilst remaining within the boundaries of the standardised track (figures 6.1 & 6.2), (ii) to ensure these demands were repeatable, and (iii) to ensure the demands of the sessions would be realistically suited to participants who met the criteria outlined in the preliminary testing session. A custom made audio file provided signals for the start, midpoint, and end of each section of the track in order to maintain consistent timings throughout. Participants were informed of the specific details (see below) around what speeds were to be used in each part of the track prior to the start of the session.

As stated above, participants wore GPS and HR monitors during all sessions. The variables chosen to quantify the demands of the simulated soccer training sessions were: TD, distance per minute, maximum speed, HI distance (>5.5m/s), maximum HR, average HR, time spent above 85% of maximum HR, HR exertion, number of accelerations, and number of decelerations. These variables have been selected in order to give an overview of the volume (TD covered, number of accelerations/ decelerations) and intensity (distance covered per minute, average HR) of the sessions from both an external (GPS data) and internal (HR data) perspective.

*6.2.4 Low Physical Load Simulated Soccer Training Session*

Speeds of 2 and 4m/s were used in this session. One repetition of the track involved participants completing part A at an average speed of 2m/s (40 seconds), followed immediately by completing part B at an average speed of 4m/s (5 seconds), followed by part C at 2m/s (40 seconds), and part D at 4m/s (5 seconds).

The LSSTS included 4 sets of 10 repetitions. Each set was separated by 3 minutes of stationary rest. Within each set there was a 1-minute rest after 5 repetitions. The custom made audio file included an audio signal to mark the start, halfway and end point of each part (A, B, C, D) of the track as illustrated in figure 6.1.

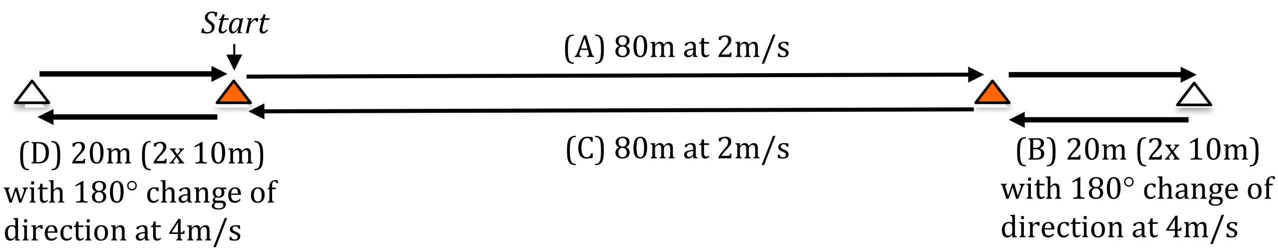


**Figure 6.1.** The pitch layout and appropriate speeds for the low physical load simulated soccer-training session.

*6.2.5 High Physical Load Simulated Soccer Training Session*

Speeds of 2, 4 and 6m/s were also used in this session. The HSSTS involved completing two different sets of timings for the track, set A and set B:

A. Set A required participants to complete part A of the track at an average speed of 4m/s (10 seconds), followed immediately by completing part B at an average speed of 2m/s (20 seconds), followed immediately by completing part C at an average speed of 6m/s (3.3 seconds). Part D was then completed at 4m/s, followed by part E at 2m/s and then part F at 6m/s. The above constituted 1 repetition of set A (see figure 6.2).

B. Set B involved participants completing part A at an average speed of 4m/s (10 seconds), followed by part B at an average speed of 6m/s (6.6 seconds), followed by part C at an average speed of 2m/s (10 seconds). Part D was then completed at 4m/s, followed by part E at 6m/s and then part F at 2m/s. This constituted 1 repetition of set B (see figure 6.3).

The HSSTS includes 4 sets of 10 repetitions (1. Set A, 2. Set B, 3. Set A, 4. Set B). Each set was separated by 2 minutes of stationary rest. Within each set there was a 1-minute rest after 5 repetitions. The custom made audio file included an audio signal to mark the start, halfway and end point of each part (A, B, C. D, E, F) of the track as illustrated in figures 6.2 and 6.3.

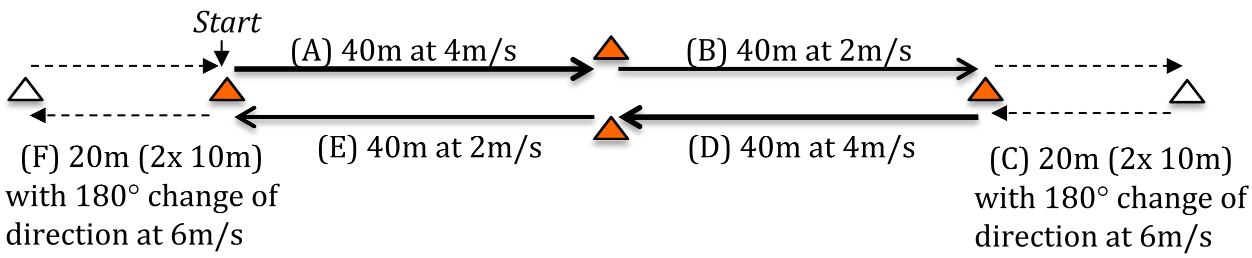


**Figure 6.2.** The pitch layout and appropriate speeds for set A of the high physical load simulated soccer-training session.

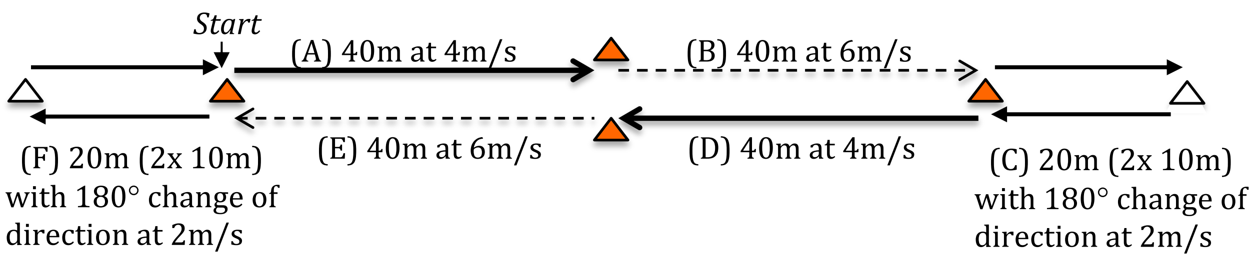


**Figure 6.3.** The pitch layout and appropriate speeds for set B of the high physical load simulated soccer-training session.

*6.2.6 Standardised Exercise Protocol*

The SEP developed in chapter 5 was used at 48 hours following each testing session. This time point was selected as a result of the findings of chapter 3. This data highlighted that pitch based active recovery sessions (an appropriate opportunity for the SEP to be completed) are most frequently completed on the 2nd day following match play. The protocol involved participants completing six repetitions of an 80m straight-line run. Participants had 16 seconds to complete each repetition and 14 seconds stationary rest between repetitions. A custom-made audio file included a five second countdown to the start of each of the six repetitions and an audio signal to mark the start, halfway and end point of each repetition to ensure consistent timings for all sessions. Following the completion of the 6th repetition participants were required to remain stationary for 1 minute in order to obtain a recovery HR.

*6.2.7 Statistical Analysis*

Paired sample t-tests were used to assess 3 separate objectives during this study: (i) the difference between the demands of the LSSTS and the HSSTS, (ii) to ensure there were no differences in the exercise stimulus received by each participant in the SEP following the LSSTS and the SEP following the HSSTS (in theory, if a consistent stimulus was not delivered to participants during each of the SEPs during testing, any changes in HRR or %MAXHRr may be attributed to the differing stimulus rather than to any potential changes in physiological status), (iii) to assess differences between HRR and %MAXHRr data obtained following the LSSTS and the HSSTS. Level of significance was set at $p$<0.05. All statistical analyses were completed using SPSS 21.0 (IBM, Chicago, IL, USA). The SWC for HRR and %MAXHRr was calculated as 0.2 times the between subjects SD. Average, SD, and CV data were calculated for physical loading variables recorded during all four testing sessions. CV data was used to show within participant variation of the physical loads elicited by each session. This was important to ensure a level of consistency was applied to the sessions throughout the testing period across all participants. CVs were calculate using the following equation:

CV = (SEM ÷ Overall Mean for Both Trials) × 100

(*SEM [Standard Error of Measurement] = Standard deviation of the differences between trails ÷ [$\sqrt{2}$])*

## 6.3 Results

Average, SD, and CV data calculated for physical loading data collected from all participants during the HSSTS and LSSTS is presented in table 6.1. This data highlights that differences in physical loads between participants were small (i.e. all participants experienced low physical loads during LSSTS, all participants experienced high physical loads during HSSTS, all participants experienced the same physical loads during the SEP following the HSSTS [HL SEP] and following the LSSTS [LL SEP]). This data also shows that the LSSTS and HSSTS sessions were significantly different ($p<0.01$) for certain variables (duration, total distance, distance per minute, HI distance, maximum speed) in order to stimulate different physiological responses (average HR, max HR, time in red zone) (all $p$ values are presented in table 6.1). Average, SD, and CV data calculated for physical loading data collected from all participants during the HL SEP and LL SEP is presented in table 6.2. Paired sample t-tests were also completed to ensure that there were no significant differences ($p>0.05$) in physical load between the SEP following the HSSTS and the SEP following the LSSTS (with the exception of the expected change in HR response [Max HR - $p<0.001$]) (all $p$ values are presented in table 6.2). It was important to show consistent physical loads experienced during all of the SEP completed throughout this study. This can then allow for any changes in HR response (%MAXHRr and HRR) to be attributed to a change in physiological status rather than a change in the demands of the SEP.

Table 6.3 presents the average, SD, minimum, and maximum for HR data collected during the SEPs conducted following the LSSTS and HSSTS. This data aimed to show the capability of the SEP to detect change in physiological status. The %MAXHRr during the SEP following the HSSTS (92±2%) was significantly higher than following the LSSTS (90±2%) ($p$<0.001). On the other hand, HRR following the HSSTS (17±5%) was significantly lower than following the LSSTS (22±5%) ($p$<0.001). The SWC was calculated for HRR (1.08%) and %MAXHRr (0.49%) to understand the magnitude of variance that represents a meaningful change in these variables. It would appear that the differences in HRR (5%) and %MAXHRr (2%) between trials (HSSTS vs. LSSTS) were larger than the respective SWC. Table 6.4 presents individual data for each subject's %MAXHRr and HRR obtained during the SEP following the HSSTS and LSSTS. This data shows individual changes in response to the different physiological demands placed on subjects.

**Table 6.1.** Average (Av), standard deviation (SD), standard error of measurement (SEM), and coefficient of variation (CV) data calculated from GPS and HR variables collected during HSSTS and LSSTS. *p* values are also presented from paired sample t-tests ran for each variable between HSSTS vs. LSSTS.

| Session | | Duration (mins) | Total Distance (m) | Distance per Minute | Max Speed (m/s) | HI Distance (m) | Max HR (bpm) | Av HR (bpm) | Time in RZ (hh:mm:ss) | HR Exertion | No. of Accels | No. of Decels |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HSSTS | Av | 33 | 3804 | 123.8 | 6.5 | 380 | 187 | 162 | 00:08:37 | 106 | 43 | 20 |
| | SD | 0 | 77 | 4.3 | 0.4 | 261 | 4 | 5 | 00:03:56 | 17 | 4 | 1 |
| | SEM | 0 | 54 | 3.0 | 0.3 | 185 | 3 | 4 | 00:02:47 | 12 | 3 | 1 |
| | CV (%) | 0 | 1 | 2 | 4 | 49 | 2 | 2 | 32 | 12 | 6 | 4 |
| LSSTS | Av | 44 | 3991 | 91.4 | 5.9 | 2 | 162 | 140 | 00:00:00 | 75 | 69 | 40 |
| | SD | 0 | 83 | 0.8 | 0.3 | 1 | 7 | 8 | 00:00:00 | 14 | 4 | 1 |
| | SEM | 0 | 59 | 0.6 | 0.2 | 1 | 5 | 6 | 00:00:00 | 10 | 3 | 1 |
| | CV (%) | 0 | 1 | 0.6 | 3.1 | 31 | 3 | 4 | 0 | 13 | 4 | 2 |
| ***p* value** | | - | **<0.001** | **<0.001** | **<0.001** | **0.001** | **<0.001** | **<0.001** | **<0.001** | **<0.001** | **<0.001** | **<0.001** |

**Table 6.2.** Average (Av), standard deviation (SD), standard error of measurement (SEM), and coefficient of variation (CV) data calculated from GPS and HR variables collected during HL SEP and LL SEP. *p* values are also presented from paired sample t-tests ran for each variable between HL SEP vs. LL SEP.

| Session | | Duration (mins) | Total Distance (m) | Distance per Minute | Max Speed (m/s) | HI Distance (m) | Max HR (bpm) | Av HR (bpm) | Time in RZ (hh:mm:ss) | HR Exertion | No. of Accels | No. of Decels |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HL SEP | Av | 3 | 507 | 178.7 | 6.4 | 188 | 175 | 159 | 00:00:06 | 8 | 3 | 1 |
| | SD | 0 | 14 | 6.5 | 0.3 | 65 | 4 | 4 | 00:00:10 | 1 | 2 | 1 |
| | SEM | 0 | 10 | 4.5 | 0.2 | 46 | 3 | 3 | 00:00:07 | 1 | 1 | 0 |
| | CV (%) | 0 | 2 | 2.6 | 2.8 | 25 | 2 | 2 | 141 | 9 | 45 | 54 |
| LL SEP | Av | 3 | 493 | 174.9 | 6.2 | 164 | 172 | 158 | 00:00:01 | 8 | 4 | 2 |
| | SD | 0 | 6 | 1.8 | 0.3 | 47 | 4 | 7 | 00:00:02 | 1 | 1 | 1 |
| | SEM | 0 | 4 | 1.3 | 0.2 | 33 | 3 | 5 | 00:00:01 | 1 | 1 | 1 |
| | CV (%) | 0 | 1 | 0.7 | 3.8 | 20 | 2 | 3 | 141 | 8 | 16 | 28 |
| ***p* value** | | - | 0.071 | 0.062 | 0.162 | 0.201 | **<0.001** | 0.863 | 0.149 | 0.373 | 0.068 | 0.051 |

**Table 6.3.** Average (Av), standard deviation (SD), minimum, and maximum data for HR variables collected or calculated during the completion of the SEP following the HSSTS and LSSTS.

| | | Max HR Reached | Minimum Recovery HR | %MAXHRr | HRR |
|---|---|---|---|---|---|
| **HL SEP** | Average | 175 | 146 | 92 | 17 |
| | SD | 4 | 12 | 2 | 5 |
| | Maximum | 181 | 168 | 96 | 25 |
| | Minimum | 170 | 129 | 89 | 7 |
| **LL SEP** | Average | 172 | 135 | 90 | 22 |
| | SD | 4 | 10 | 2 | 5 |
| | Maximum | 177 | 155 | 95 | 29 |
| | Minimum | 169 | 120 | 87 | 13 |

**Table 6.4.** Individual subject's %MAXHRr and HRR calculated during the completion of the SEP following the HSSTS and LSSTS.

| **Subject** | **HL SEP** | | **LL SEP** | |
|---|---|---|---|---|
| | **%MAXHRr** | **HRR** | **%MAXHRr** | **HRR** |
| **1** | 93 | 25 | 91 | 29 |
| **2** | 91 | 17 | 89 | 21 |
| **3** | 96 | 7 | 95 | 13 |
| **4** | 89 | 20 | 88 | 23 |
| **5** | 89 | 19 | 87 | 24 |
| **6** | 93 | 17 | 92 | 20 |
| **7** | 91 | 13 | 90 | 18 |
| **8** | 95 | 12 | 91 | 19 |
| **9** | 93 | 15 | 91 | 20 |
| **10** | 89 | 23 | 88 | 26 |

## 6.4 Discussion

The aim of this study was to assess the face validity of the HR response to the SEP outlined in chapter 5 of this thesis under controlled conditions. This involved assessing differences in HR markers thought to be indicative of physiological status (%MAXHRr, HRR) following a HSSTS and a LSSTS. These simulated soccer training sessions carried significantly different physical loads ($p$<0.01). This ensured that distinctly different physiological responses were elicited during each training session. In turn, it is theorised that the differing physiological responses to these sessions would result in a variance in the subsequent physiological status following these sessions. The SEP was implemented following each of the simulated training sessions to assess physiological status. The data collected shows that %MAXHRr, a marker of overreaching in athletes as shown by Le Meur *et al.* (2016), was significantly higher during the SEP conducted following the HSSTS in comparison to following the LSSTS ($p$<0.001). These findings contradict the hypothesis outlined at the start of this study. On the other hand, the findings around HRR support the hypothesis as HRR was significantly lower following the HSSTS when compared with the LSSTS ($p$<0.001). This finding was expected and falls in line with the current literature in this area. Previous research in this area may also suggest that it is more important from the perspective of physiological status for there to be a meaningful change (>SWC) in these markers (HRR and %MAXHRr) rather than whether the value has increased or decreased. The data collected in this study show the changes in %MAXHRr and HRR between the HL SEP and the LL SEP to be greater than their respective SWC. This may suggest that the findings of this study with regards to both HRR and %MAXHR would be relevant to the assessment of physiological status. Overall, this suggests that the SEP is able to detect changes in physiological status through HR data as a result of "high" and "low" physical load simulated soccer training sessions.

An important factor in the design of this study was the manipulation of physical demands portrayed in the two simulated soccer specific training sessions (HSSTS & LSSTS). In order for this study to be able to achieve its aims it was important to ensure that these manipulations resulted in two distinctly different sessions to illicit different physiological responses. The data collected during these training sessions through GPS was compared to ensure that all key physical loading variables (see table 6.1) were significantly different between the two sessions ($p$<0.001). This data demonstrates that the HSSTS elicited higher distance per minute (123.8m/min), HI distance (380m), maximum speed (6.5m/s), maximum HR (187bpm), average HR (162bpm), time spent above 85% of max HR (00:08:37), and HR exertion (106) in comparison to the LSSTS. This data shows that all possible efforts were made to ensure these simulated soccer training sessions were able to deliver the desired physiological responses. It is also important to note that the between participants variation (standard deviations) for these variables during each session was relatively low. This means that all participants experienced the required demands during each session. This is particularly important as consistent physical loads were required throughout to allow for a robust assessment of the face validity of the SEP.

The restoration of autonomic balance following exercise is indicative of sympathetic and parasympathetic activity. Sympathetic drive is responsible for the increase in heart rate that occurs in response to an exercise stimulus. With this in mind, %MAXHRr can be seen as a marker of sympathetic activity during the exercise protocol undertaken. %MAXHRr was significantly higher ($p$=0.00005) during the protocol completed following the HSSTS (92%) than following the LSSTS (90%). Given that the SWC calculated for %MAXHRr was 0.49%, the difference between %MAXHRr obtained following the HSSTS and LSSTS (2%) can be deemed as a meaningful change. However, it was not hypothesised that there would be an increase in %MAXHRr following the more physiologically demanding training session.

It is clear that the difference in %MAXHRr attained during the SEP following each session shows there to be a degree of disturbance to homeostasis. With this in mind, the findings of this study with regards to %MAXHRr simply showed there to be a difference in the extent to which physiological status was affected following the HSSTS in comparison to the LSSTS. In theory, additional measurements of HR based measures (%MAXHRr and HRR) at different time points (+24, +36, & +72 hours) following these sessions may provide a better understanding of this process. Previous research by Le Meur *et al.* (2013)

reported that a decrease in %MAXHRr during a different SEP was associated with athletes in an overreached state (running performance & perceived fatigue). It is important to consider that while participants in the study conducted by Le Meur *et al.* (2013) completed an overloaded training programme to elicit an overreached state, the findings of the current study relate to the effects of participants completing a single session in isolation which is probably unable to effect participants' longer term physiological status. Further research is required in this area to fully understand change in the HR response to a standardised exercise protocol in response to more acute phases of fatigue.

HRR can be used as a marker of parasympathetic reactivation which can be calculated thanks to the period of rest employed immediately following the SEP (Stanley *et al.,* 2013). The data collected during the current study showed there to be a significant difference in HRR following the HSSTS (17%) in comparison to following the LSSTS (22%) ($p$=0.0001). SWC for HRR was calculated to be 1.08%. These findings suggest that the 5% difference in HRR following the HSSTS and LSSTS is likely a meaningful change. It would appear that the difference in HRR following each session shows that there is a specific physiological response to each session. Therefore, the subsequent recovery period required for a complete return to homeostasis following each session would be different. When interpreting these changes in HRR it is important to consider the previous research in this area. Daanen *et al.* (2012) found that a faster HRR was correlated with an improved training status whereas Le Meur *et al.* (2016) found that increased HRR was related to impaired physiological status (functional overreaching). This may suggest that a positive or negative change in HRR may relate to either an improvement or decrement to physiological status. Le Meur *et al.* (2016) suggested that despite the findings of their study, a faster HRR may not always be indicative of an improved physiological status when using these methods with athletes. With this in mind, it may be the magnitude of change that is of greater importance when assessing HRR data.

When interpreting the findings of this study it is important to consider the limitations associated with some of the approaches and equipment used. The simulated soccer specific training sessions were design to elicit demands in a similar way to the soccer training undertaken by players on a daily basis in the 'real world'. However, the potential issues with this approach are two-fold. Firstly, although the running speeds and the number of changes of direction undertaken were controlled during the HSSTS and LSSTS through the use of an audio file, it was not possible to control the rate of acceleration and deceleration exhibited by each participant. This may have implications for the actual activity profile experienced by each participant. Due to limitations associated with the GPS devices used in this study, it is difficult to quantify these variations accurately. Secondly, although these sessions have been found to be fit for the purpose of this study, it is important to consider that the findings from this approach may not fully represent the pattern that would be observed under 'real world' conditions. These sessions did carry some ecological validity due to the intermittent nature and the various running speeds used. However, these sessions did not involve a variety of actions that are commonplace in soccer such as ball contacts (passing, shooting, running with the ball), player contacts (tackling, aerial duels, shielding the ball), and multi-directional movements (jumping, landing, cutting, changes of direction at various angles). These actions may significantly alter the physiological response and it is therefore suggested that future research may aim to replicate this study using exercise stimuli that are more ecologically valid to soccer specific training methods. Finally, due to the nature of the schedule within elite soccer it was not possible for elite soccer players to participate in this study. The moderately trained individuals that were used as participants in this study may have responded differently to the soccer specific training sessions and the subsequent SEPs in comparison to elite soccer players. An example of this may be that elite athletes may be able to recover more quickly from an exercise stimulus than moderately trained athletes due to their training history and fitness levels (Nedelec *et al.,* 2012).

In conclusion, the findings of this study suggest that the HR response to the SEP developed in the previous chapter is a valid measure of manipulated changes in physiological status as a result of a high physical load and a low physical load simulated soccer training session. The %MAXHRr during the SEP was found to be significantly higher following the HSSTS (92%) in comparison to the LSSTS (90%). Furthermore, HRR was found to be lower following the HSSTS (17%) when compared to the LSSTS (22%). Future research should focus around the assessment of the ability of the HR response to the SEP to detect changes in physiological status under 'real world' conditions during the recovery period (<72 hours) following soccer match play.

# Chapter 7

## Determining the 'Real World' Effectiveness of the Heart Rate Response to a Standardised Exercise Protocol for the Assessment of Physiological Status Following Competitive Soccer Match Play

## 7.1 Introduction

Previous research has shown HR derived measures such as HRR and %MAXHR to be important tools when assessing the physiological status of athletes in response to training, competition, or recovery (Borresen & Lambert, 2007; Buchheit, 2014; Le Meur *et al.*, 2016). These measures can provide an insight into the modulation of HR and the involvement of the autonomic nervous system. The use of an exercise bout such as the SEP can allow for the monitoring of %MAXHR which can quantify the contribution of the sympathetic nervous system in driving an increase in HR. On the other hand, the use of a recovery period immediately following the cessation of the exercise bout can allow for the calculation of HRR which can assess sympathetic withdrawal and parasympathetic reactivation in their role of reducing HR back towards resting values.

Le Meur *et al.* (2016) present the concept that changes in the HR response and consequently markers such as %MAXHR and HRR correlate with changes in physiological status (functional overreaching). Although other previous research studies have suggested that faster HRR is associated with improved physiological status, Le Meur *et al.* (2016) suggest that this may not always be the case. With this in mind, it is feasible to suggest that it is the magnitude of change in HR measures that is of importance when monitoring physiological status rather than whether the change is positive or negative. Various factors such as the type, duration, and intensity of the preceding exercise undertaken (training or competition), training history, and individual fitness levels may affect the magnitude of changes in HR measures and also the direction in which the change occurs (positive or negative) (Stanley *et al.,* 2013).

To date there is limited research around the use of HRR and %MAXHRr with soccer players. Although some previous studies have assessed the usefulness of other HR based measures during the recovery period following soccer match play, it may be of particular importance to investigate the use of HRR and %MAXHRr with an elite population (Buchheit, 2014; Thorpe *et al.,* 2015). The SEP designed in chapter 5 of the thesis was developed with this in mind. It is important to continue the research around the efficacy of the HR response to the SEP which was undertaken in chapter 6. This research should include the assessment of the effectiveness of the HR response to the SEP during the recovery period (<72 hours) following competitive soccer match play. This may require measurements of physiological status to be taken at various time points during this period (e.g. MD+1, MD+2, MD+3).

Chapter 6 showed that the HR response to the SEP provided a valid measure of changes in physiological status using HRR and %MAXHRr under controlled conditions. However, that study utilised simulated soccer specific training sessions which only carried some ecological validity in reference to the actual demands of soccer training or games (it is important to consider that players do not exclusively run in straight lines during match play and they change direction through a variety of angles, not just 180 degrees). Although this was necessary to assess the face validity of the HR response to the SEP, it is equally important to understand the effectiveness of the HR response when used under 'real-world' conditions.

The aim of this study was to assess the effectiveness of HRR and %MAXHRr measured through the SEP on the first day (MD+1), second day (MD+2), and third day (MD+3) following match play as indicators of changes in the physical loads experienced by players during a preceding soccer game. The findings of this study are of particular importance for the potential implementation of a HR based monitoring tool to assess physiological status during the recovery period (<72 hours) following soccer match play.

## **7.2 Methods**

### *7.2.1 General Study Design*

Activity data for each player was collected during all competitive matches included in this study (see details below) to understand the demands placed on players during each game. In turn, this provided a marker of the extent to which each individual players baseline physiological status has the potential to be disturbed as a consequence of match play. All games took place between October 2017 – February 2018. Following each match, players were required to complete the SEP on MD+1, MD+2, and MD+3 when possible. These assessments were completed in an attempt to evaluate each individual players physiological status through HR based measures (HRR, %MAXHRr). Participants were required to rest completely between sessions and avoid consuming caffeine or alcohol. Previous research has suggested that autonomic balance may be disturbed for around 48 hours following HI exercise (Stanley *et al.,* 2013). However, other components of recovery such as neuromuscular function that may have an impact on the HR response to the SEP have been suggested to last up to 72 hours post-match (Andersson *et al.,* 2008). The aforementioned sampling time points were therefore selected to incorporate a broader time course of physiological recovery following soccer match play. In theory, data collection at these time points would allow for an assessment of any patterns in the return of physiological status towards homeostasis (i.e. MD+1 - suppressed physiological status, MD+2 – improvement in physiological status , MD+3 – return to normal values/ further improvement in physiological status). These types of patterns have been observed previously in literature assessing the time course of changes in neuromuscular function following soccer match play (Brownstein *et al.,* 2017). It is theorised that changes in the ANS may follow a similar pattern during this period. The SEP was not completed on designated days off when players were not required to attend the training facility. This was due to the lack of an ability to apply consistent procedures for the completion of the measurement. The predetermined team schedule and subsequent players' attendance to the training facility following games therefore influenced the data collection during this study. As such, three different categories of data collection seemed important: matches followed by the completion of the SEP on MD+1 (n=8), matches followed by the completion of the SEP on MD+2 (n=5), and matches followed by the completion of the SEP on MD+3 (n=12).

### *7.2.2 Participants*

Sixteen professional soccer players (Age: 19.2±1.3 years, Weight: 75.5±5.5kg, Height: 1.80±0.05m) from an English Championship soccer club took part in the study. All participants provided written informed consent prior to the start of the study. Participants included in this study completed at least three competitive matches during the 2017-2018 season (data from games when players were substituted on or off was excluded from the investigation) and completed the SEP for the measurement of %MAXHRr and HRR on at least one of the corresponding: (i) MD+1, (ii) MD+2, or (iii) MD+3. This study was approved by the Ethics Committee of Liverpool John Moores University and conformed to the Declaration of Helsinki.

### *7.2.3 Procedures for the Data Collection of Activity Profiles During Matches*

GPS units (APEX, STATSports, UK) were used to collect physical performance variables for each player during all competitive matches included in this study. Such GPS systems have been validated and shown to provide reliable and accurate data when quantifying the demands of soccer match play (Hoppe *et al.,* 2018). The variables that were selected for analysis were TD, distance per minute (TD divided by match duration), HI distance (distance covered between 5.5 – 7.0 m/s), HI distance per minute (HI distance divided by match duration), sprinting distance (distance covered above 7.0 m/s), and sprinting distance per minute (sprinting distance divided by match duration). These variables were selected in order to give a representation of the volume and intensity of the match demands experienced by players during each game. Previous studies have quantified the physical loads associated with soccer performance using similar methodology to this study (Abbott *et al.,* 2018; Winder *et al.,* 2018). All games included in this study commenced at 1pm.

### *7.2.4 Procedures for the Completion of the Standardised Exercise Protocol*

HRR and %MAXHRr were measured using the specially designed SEP (see chapter 5). The SEP involved 6 repetitions of an 80m straight line run at an average speed of 5m/s (16 seconds was allowed to complete each run). Each repetition was separated by 14 seconds of stationary rest. A custom-made audio file with signals for the start (with a 3 second countdown), mid-point, and end of each repetition was used to ensure consistent timings throughout this study. Following the completion of the 6 repetitions, players were required to remain stationary in an upright position with their arms by their sides for a 1 minute recovery period. Players were instructed to breathe normally during this period. The SEP was completed immediately following a standardised warm up at the start of the daily training session. All training sessions started at 10:30am. Upon arrival at the training ground on each testing day players were required to fit their HR monitor by 9:30am (1 hour prior to the start of the training session) with the application of ultrasound transmission gel (Aquasonic 100, Parker Labs, USA) to enhance consistent data collection. The maximum HR reached during the SEP and the minimum HR during the recovery period were recorded. The absolute maximum HR for each player was calculated using the method proposed by Tanaka *et al.* (2001):

Absolute Max HR = 208 – (0.7 x Age)

These values were then used to calculate %MAXHRr:

%MAXHRr = (Max HR during SEP ÷ Absolute Max HR) x 100.

The minimum HR during the 1 minute recovery period and the max HR reached during the SEP were used for the calculation of HRR using the following equation:

HRR = ([Max HR during SEP – Min HR during Recovery]) ÷ Max HR during SEP) x 100

*7.2.5 Statistical Analysis*

Data were analysed using linear mixed models, with HRR MD+1, HRR MD+2, HRR MD+3, %MAXHRr MD+1, %MAXHRr MD+2, and %MAXHRr MD+3 as the dependent variables. Physical loading variables (TD, distance per minute, HI distance, HI distance per minute, sprinting distance, sprinting distance per minute) were used as the independent variables. A random intercept was set for each individual player. Standardised effects were calculated to determine an ES (by multiplying the coefficients by two times the between-subject SD of the independent variable and dividing this by one times the between-subject SD of the dependent variable). The ES was evaluated according to the following thresholds: <0.2 = trivial effect, 0.2-0.6 = small effect, 0.6-1.2 = moderate effect, 1.2-2.0 = large effect, and >2.0 = very large effect. Due to applied nature of this study, statistical significance was set at $p<0.10$ (Field, 2012). The above analyses were completed using R, v3.0.3 (The R Foundation). The package used within R was 'nlme'. SWC for HRR and %MAXHRr was calculated as 0.2 times the between subjects SD (Hopkins, 2004).

## 7.3 Results

Average (±SD), maximum and minimum values for all match activity variables assessed in this study can be found in table 7.1. This data would seem to be typical for elite level soccer players during competitive games (Bangsbo, 2014). This data also seems to highlight the large variations in team and individual activity profiles between games due to within game factors such as tactical strategies, score line, and the technical quality of the opposition. These variations in physical loads may impact on the consequent disturbance to physiological status and subsequent recovery periods required by each individual player. This assumption is based on the similarity of the physical outputs here with previous research that has demonstrated the impact of such exercise demands on the post-game physiological status of the athlete (Andersson *et al.,* 2008).

**Table 7.1.** Average, standard deviation, maximum and minimum data for physical load variables recorded during games throughout this study.

| | Total Distance (m) | Distance per Minute (m/min) | High Intensity Distance (m) (>5.5 - 7m/s) | High Intensity Distance per Minute (m/min) | Sprinting Distance (m) (>7m/s) | Sprinting Distance per Minute (m/min) |
|---|---|---|---|---|---|---|
| **Average** | 10879 | 115.0 | 669 | 7.1 | 120 | 1.3 |
| **SD** | 793 | 8.9 | 230 | 2.5 | 79 | 0.8 |
| **Max** | 13062 | 139.1 | 1331 | 14.6 | 410 | 4.4 |
| **Min** | 9372 | 96.6 | 257 | 2.7 | 11 | 0.1 |

Average (±SD), maximum and minimum values for HRR measurements on MD+1, MD+2, and MD+3 can be found in table 7.2. There seems to be large inter-individual differences in HRR (see Figure 7.1.). These differences are more pronounced on MD+3 (range = 33.2% [15.7 – 48.9%]) than on MD+1 (range = 22.1% [19.6 – 41.7%]) or MD+2 (range = 28.2% [19.1 – 47.3%]). Average (±SD), maximum and minimum values for %MAXHRr on MD+1, MD+2, and MD+3 can be found in table 7.3. Similarly to HRR there seems to be large inter-individual differences (range = MD+1 – 21.4% [73.9 – 95.3%], MD+2 – 20.0% [74.3 – 94.3%], MD+3 -20.8% [74.4 – 95.2%]) but these seem to be consistent across all days (see Figure 7.2.).

**Table 7.2.** Average (±SD) data for HRR (%) measurements recorded on MD+1, MD+2, MD+3 during this study.

| Recovery Day | Average | Standard Deviation | Maximum | Minimum | SWC |
|---|---|---|---|---|---|
| **MD+1** | 33.4 | 5.2 | 41.7 | 19.6 | |
| **MD+2** | 29.5 | 7.2 | 47.3 | 19.1 | 1.30 |
| **MD+3** | 30.7 | 6.6 | 48.9 | 15.7 | |

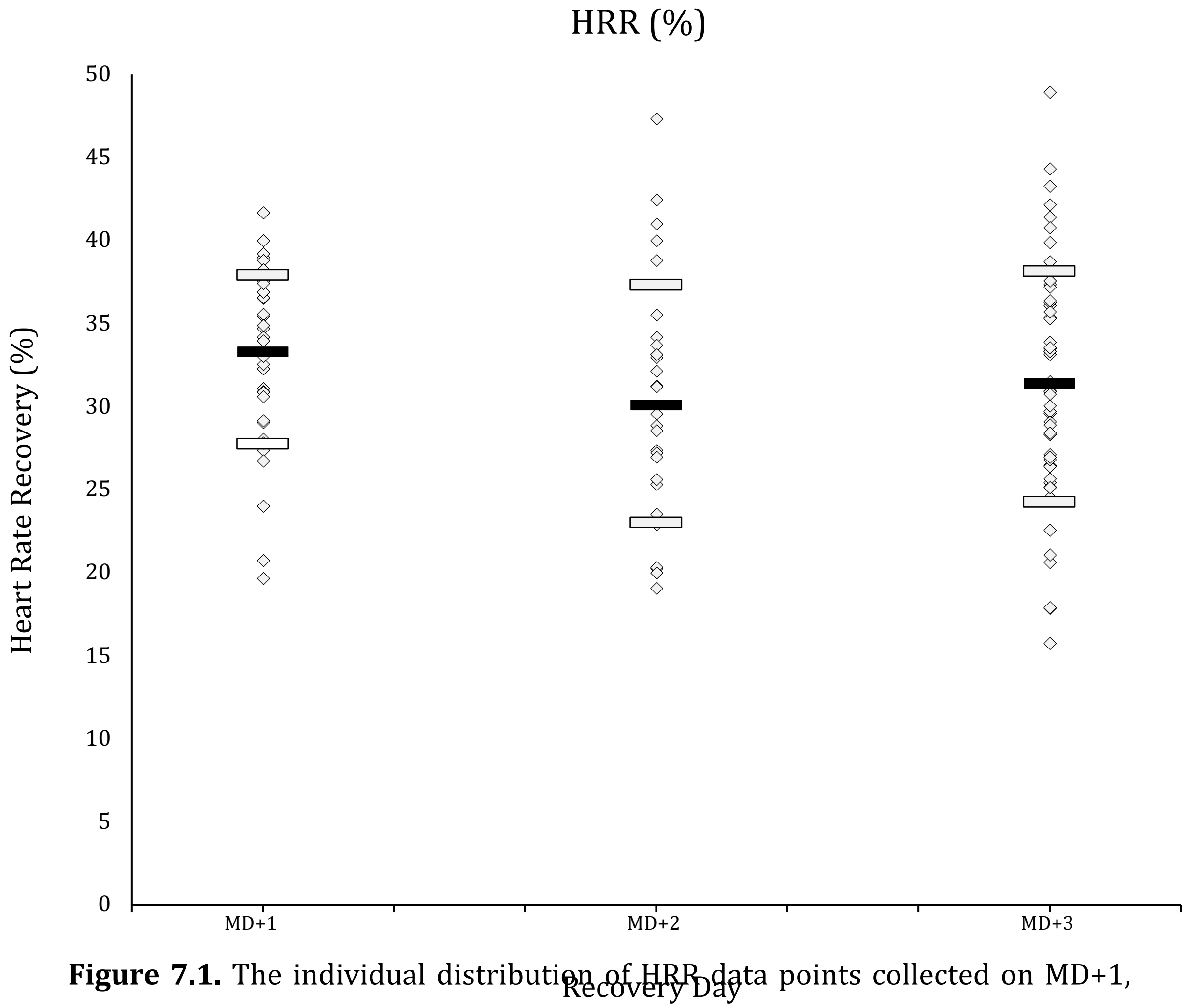


**Figure 7.1.** The individual distribution of HRR data points collected on MD+1, MD+2 and MD+3 during this study. Average (solid black line) and ±1 standard deviation (solid white lines) are also presented.

**Table 7.3.** Average (±SD) data for %MAXHRr (%) measurements recorded on MD+1, MD+2, MD+3 during this study.

| Recovery Day | Average | Standard Deviation | Maximum | Minimum | SWC |
|---|---|---|---|---|---|
| **MD+1** | 84.1 | 5.9 | 95.3 | 73.9 | |
| **MD+2** | 85.8 | 5.5 | 94.3 | 74.3 | 1.08 |
| **MD+3** | 86.3 | 5.0 | 95.2 | 74.4 | |

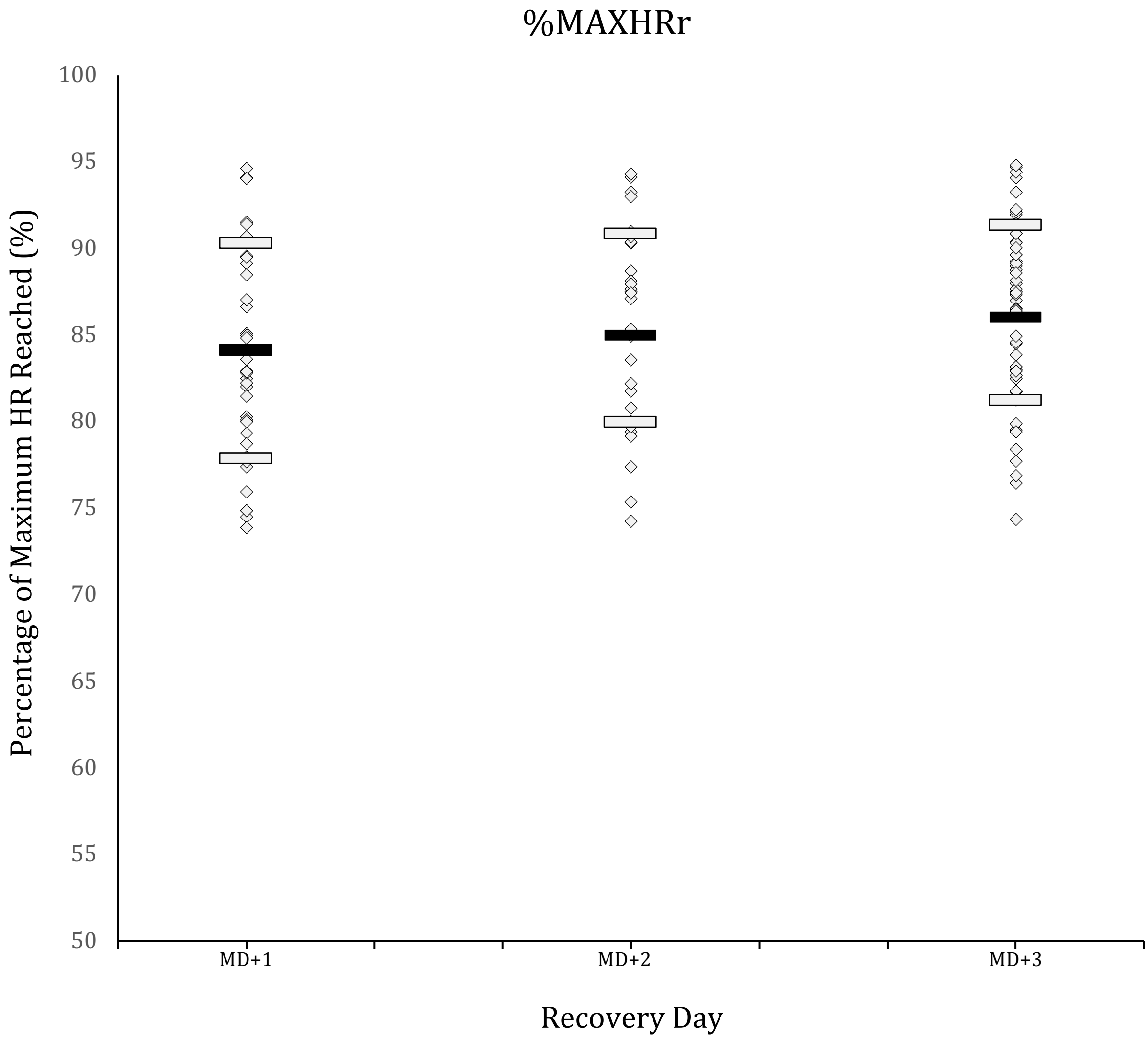


**Figure 7.2.** The individual distribution of %MAXHRr data points collected on MD+1, MD+2 and MD+3 during this study. Average (solid black line) and ±1 standard deviation (solid white lines) are also presented.

Table 7.4 presents the raw coefficients, ES and *p* values from all the statistical analysis undertaken during this study. In total, 126 unique data points were fitted to 36 separate linear mixed models. Of these models, 12 used data from MD+1 (n=37), 12 used data from MD+2 (n=30), and 12 used data from MD+3 (n=59). There was a significant, small effect between HI distance per minute and HRR MD+3 (*p*=0.08, ES=0.35). There were also trends towards significance between sprint distance and HRR MD+2 (*p*=0.12, ES=0.33), sprint distance per minute and HRR MD+2 (*p*=0.10, ES=0.35), and HI distance and HRR MD+3 (*p*=0.11, ES=0.33). All other relationships showed no significant effects between the dependant variables (HRR MD+1, HRR MD+2, HRR MD+3, %MAXHRr MD+1, %MAXHRr MD+2, or %MAXHRr MD+3) and the physical load variables investigated in this study. The raw coefficients show that the variable with the greatest impact on HRR on MD+2 was sprint distance per minute. An increase of 1m of sprint distance per minute would result in an increase in HRR of 2.64%. On MD+3 high intensity distance per minute carried the largest raw coefficient meaning a 1m increase in high intensity distance per minute would bring about a 0.66% faster HRR.

**Table 7.4.** Raw coefficients, effect sizes and *p* values for all linear mixed models ran between HRR, %MAXHRr and physical loading variables.

| | Independent Variable | Intercept | | Raw Coefficient | | Effect Size | | *p* Value | |
|---|---|---|---|---|---|---|---|---|---|
| | | HRR | %MAXHRr | HRR | %MAXHRr | HRR | %MAXHRr | HRR | %MAXHRr |
| **MD+1** | Total Distance | 47.3 | 79.3 | -0.00131 | 0.00043 | -0.33 | 0.14 | 0.2248 | 0.7677 |
| | Distance per Minute | 47.4 | 75.4 | -0.12491 | 0.07594 | -0.38 | 0.29 | 0.1766 | 0.5499 |
| | HI Distance | 33.7 | 86.0 | -0.00083 | -0.00303 | -0.04 | -0.19 | 0.8521 | 0.5753 |
| | HI Distance per Minute | 33.8 | 85.6 | -0.10044 | -0.23275 | -0.05 | -0.16 | 0.8086 | 0.6431 |
| | Sprint Distance | 31.7 | 83.1 | 0.01115 | 0.00720 | 0.23 | 0.19 | 0.3268 | 0.6179 |
| | Sprint Dist. per Minute | 31.8 | 83.1 | 0.99889 | 0.71808 | 0.22 | 0.20 | 0.3499 | 0.5959 |
| **MD+2** | Total Distance | 31.3 | 82.9 | -0.00019 | 0.00025 | -0.03 | 0.07 | 0.9038 | 0.8649 |
| | Distance per Minute | 15.9 | 82.7 | 0.11152 | 0.02482 | 0.23 | 0.10 | 0.3718 | 0.8445 |
| | HI Distance | 26.4 | 84.0 | 0.00389 | 0.00237 | 0.18 | 0.22 | 0.4593 | 0.6285 |
| | HI Distance per Minute | 25.8 | 84.1 | 0.43343 | 0.21466 | 0.22 | 0.22 | 0.3655 | 0.6360 |
| | Sprint Distance | 25.6 | 86.9 | 0.02642 | -0.00969 | 0.33 | -0.24 | 0.1253 | 0.5244 |
| | Sprint Dist. per Minute | 25.4 | 87.0 | 2.63747 | -0.95503 | 0.35 | -0.26 | **0.1000** | 0.5025 |
| **MD+3** | Total Distance | 35.5 | 75.6 | -0.00034 | 0.00099 | -0.07 | 0.35 | 0.7583 | 0.2155 |
| | Distance per Minute | 28.0 | 75.9 | 0.03286 | 0.09211 | 0.07 | 0.34 | 0.7464 | 0.2121 |
| | HI Distance | 27.1 | 86.6 | 0.00659 | 0.00010 | 0.33 | 0.01 | 0.1134 | 0.9732 |
| | HI Distance per Minute | 26.8 | 86.5 | 0.66353 | 0.01845 | 0.35 | 0.02 | **0.0867** | 0.9487 |
| | Sprint Distance | 31.3 | 85.9 | 0.00383 | 0.00507 | 0.06 | 0.14 | 0.7576 | 0.5661 |
| | Sprint Dist. per Minute | 31.2 | 85.9 | 0.44011 | 0.48353 | 0.07 | 0.14 | 0.7093 | 0.5645 |

## 7.4 Discussion

The aim of this study was to assess the effectiveness of using the HR response to the SEP to detect changes in physiological status. This was through the assessment of the relationship between HRR and %MAXHRr measured following match play (MD+1, MD+2, MD+3) and the physical loads experienced by players during the preceding soccer game. The data collected in this study appears to show that there is a relationship between intensity-based markers of physical loads during games and HRR collected during the recovery period. The findings of this study show there to be a significant effect of HI distance per minute on HRR MD+3 (an increase in HI distance per minute during the game resulted in a higher HRR on MD+3). Aside from this there were trends towards significance for the relationships between sprint distance and HRR MD+2, sprint distance per minute and HRR MD+2, and HI distance and HRR MD+3. Similarly to above, an increase in each of these physical load variables during match play resulted in an increased HRR on the respective recovery day. All other relationships showed no significant effects between the dependant variables (HRR MD+1, HRR MD+2, HRR MD+3, %MAXHRr MD+1, %MAXHRr MD+2, or %MAXHRr MD+3) and the physical load variables investigated in this study. These findings seem to suggest that there is a better relationship between HR based measures (HRR) and physical loading variables that are indicative of the intensity of the preceding match rather than those indicative of volume. The findings would also seem to suggest that the HR response to the SEP may be more effective in detecting changes in HRR when used later in the recovery period following match play (MD+2 or MD+3 rather than MD+1). This could have implications for the timing of measurements in future use of the SEP.

As previously mentioned, the assessment of physiological status during the recovery period following soccer match play may be of importance when attempting to understand the time course of the return to homeostasis. The findings of this study show there to be a significant relationship between a marker of match intensity (HI distance per minute) and HRR. These findings seem to align with the findings in the literature (Buchheit *et al.,* 2010; Bonaiuto *et al.,* 2012; Stanley *et al.,* 2013). Bonaiuto *et al.* (2012) found that players who typically covered more distance at higher intensities during games presented a faster HRR following a standardised exercise bout (*note:* in the study by Bonaiuto *et al.,* an incremental cycle ergometer based test was utilised as the standardised exercise bout). With regards to HI distance per min, the raw coefficients (see table 7.4) show that in theory a 1m/min increase in HI distance per minute during match play would result in a 0.7% faster HRR on average when assessed on MD+3. Given that the SWC for HRR has been previously calculated as 1.3%, a change in HI distance per minute of 2m/min would result in a meaningful change in HRR. The change required in HI distance per minute (2m/min) to potentially bring about a worthwhile change in HRR is smaller than the normal range observed between soccer games in this study (SD for HI distance per minute = 2.5m/min). It is therefore feasible to assume that game-to-game variations in HI distance per minute may impact upon physiological status during the subsequent recovery period. It would appear that these changes in physiological status may remain for up to 72 hours post game (MD+3).

In theory, under normal homeostatic conditions an individual would respond in the same way to a standardised bout of exercise each time it was completed. There may be various environmental factors that could elicit small changes in the HR response that are therefore not representative of a change in physiological status. However, more substantial changes in the HR response to a standardised bout of exercise may be representative of a change in physiological status. These changes in autonomic function that are represented by HRR may be associated with either improved or impaired physiological status (Daanen *et al.,* 2012; Le Meur *et al.,* 2016). It is not clear from the previous literature in this area as to whether an increase or decrease in HRR or %MAXHRr is associated with an improved or supressed physiological status. With this in mind, it appears that a secondary performance measure such as a CMJ test may be required to be conducted alongside the use of the HR response to the SEP to fully understand the changes in the physiological status of players following match play. On reflection, this may be one of the main limitations of the design of this study as a secondary performance measure was not implemented during data collection.

While the above paragraph highlights the use of HRR to assess physiological status, it is also important to take in to account %MAXHRr. As a consequence of the standardised exercise bout that is required to calculate HRR it is also possible to analyse the exercising HR data collected to better understand the physiological status of players. No significant effects or trends towards significance were found between any of the physical load variables and %MAXHRr obtained on MD+1, MD+2, or MD+3. The findings of the current study show only small insignificant variations in %MAXHRr during the recovery periods investigated. On face value this may seem like an insignificant finding. However, using the two HR based markers in conjunction may also be able to provide some context to the information collected relating to physiological status. The value of combining these markers may be a result of the different perspective these measures provide (%MAXHRr represents the sympathetic branch and HRR represents the parasympathetic branch of the ANS). In theory, the use of two separate HR based markers (HRR and %MAXHRr) together may start to provide some insight in to whether the observed changes in physiological status are positive or negative. As mentioned previously, it is difficult to understand the impact of a change in HRR or %MAXHRr on physiological status when one marker is used in isolation. This theory is supported by the work of Le Meur *et al.* (2016) who found that whilst a faster HRR and reduced %MAXHRr was associated with functional overreaching, a faster HRR and maintained %MAXHRr was associated with a control group who maintained a normal training status (undertaking habitual training). The findings of the current study show that the relationship between HR based measures on MD+3 and intensity based markers of the physical load of the previous match (an increased HRR but unchanged %MAXHRr) can relate to the findings of Le Meur *et al.* (2016). This may actually suggest that players have recovered sufficiently by MD+3 from the perspective of the autonomic nervous system.

Due to the applied nature of this study, there are associated limitations that may have had an impact on the findings. For example, this study does not take into consideration the training loads experienced by players and any other demands or stresses placed on players away from match play. It must be considered that these factors outlined above may impact on the autonomic balance of each individual player. Future research could attempt to assess the effect of weekly physical loads (training load and game loads combined) on markers such as HRR and %MAXHRr at various time points during the training week. A similar approach has been employed in previous research when assessing the effectiveness of measurements of HRV (Flatt & Esco, 2015). This study utilised variations from rolling averages over various periods (3, 5, 7 days) to assess disturbances to physiological status. Another key limitation to this study is the effect of the predetermined schedule in place at the soccer club from which the data was collected. This schedule resulted in only certain days (MD+1, MD+2, MD+3) following match play being available for the implementation of the SEP. It would be interesting for future research to allow for the SEP to be implemented on all 3 days (MD+1, MD+2, MD+3) follow every match included in any future research. This would allow for a better assessment of any patterns in HR data which may be able to track the return of homeostasis during the recovery period following soccer match play. Finally, it is important to consider the use of predicted maximum HR for each subject rather than collecting a 'true' maximum value from an appropriate exercise test. Although this was standardised for all subjects, the training history and fitness levels of the individuals who took part in this study may result in their 'true' maximum HR being much higher than the predicted maximum calculated through the methods of Tanaka *et al.* (2001) as this method of predicting maximum HR was developed using a moderately active population. Utilising 'true' maximum HR values may have a significant impact on the usefulness of %MAXHRr as a marker of physiological status through the methods employed in this chapter.

In conclusion, the findings of this study show the HR response to the SEP to have limited capabilities in the detection of changes in HRR and %MAXHRr on MD+1, MD+2, or MD+3 as a result of changes in physical loads variables from the preceding soccer match. There was a significant effect of HI meters per minute on HRR collected on the third day following soccer match play. There were also trends towards significance between sprint distance and HRR MD+2, sprint distance per minute and HRR MD+2, and HI distance and HRR MD+3. Overall, the data presented may suggest that the SEP is most suited for implementation on MD+2 or MD+3. Furthermore, it seems that HRR is the more sensitive variable in comparison to %MAXHRr and is more effective in detecting changes in intensity-based markers from the preceding game rather than volume based markers. Future research may aim to replicate this study using the global weekly demands placed on soccer players (training loads and match loads) whilst also incorporating a secondary performance measure such as a CMJ alongside the HR based measures currently assessed.

# Chapter 8

## Synthesis of Findings

The purpose of this chapter is to ascertain if the aims and objectives outlined at the start of the thesis were achieved throughout. This is followed by a general discussion around the theoretical and practical implications for the findings of the thesis. Finally, there is a section outlining potential future research that is recommended to support and further investigate the work completed in this thesis.

## 8.1 Achievement of Aims and Objectives

The aims of this thesis were to understand the structure of the period following soccer match play that is dedicated to recovery and to understand the potential for using HR based measure to monitor the physiological impact of soccer games in elite players. In order to attain the above, 5 separate studies were undertaken, each with a discrete aim that would contribute to achieving the overall aims of the thesis:

1. **To provide an overview of the activities undertaken by soccer players during periods of the training week dedicated to recovery following match play (Chapter 3).**

The current literature provides little insight into the activities undertaken by soccer players during the period following match play that is designated for recovery (~48 hours). It is currently unclear as to what types of activity should be completed during this period in order to accelerate recovery and what methods can be used to monitor the effectiveness of any methods implemented. The findings of this study demonstrated that pitch based active recovery accounted for the largest duration of all activities investigated whilst also being the activity completed on the most consistent basis. This suggested that it may be beneficial to design any novel method of monitoring during the recovery period to be integrated into these pitch-based sessions to ensure easy and consistent use throughout a soccer season.

2. **To determine if HRV obtained through a purpose built smartphone application measured on the first day (MD+1) and second day (MD+2) following match play can detect changes in the physical loads associated with the preceding soccer match (Chapter 4).**

In order to be able to say with confidence that a novel method of monitoring physiological status could integrate with pitch based active recovery, it was important to assess the effectiveness of passive measures of physiological status. HRV has a significant amount of supporting research highlighting its ability to indirectly measure the activity of the ANS. This has resulted in various 'user-friendly' methods of collecting HRV being developed for use in 'real-world' settings. The findings of study 2 suggest that HRV collected on MD+1 or MD+2 through the ithlete method was unable to detect changes in physical load from the preceding soccer match. Although these findings show this method of collecting HRV to be ineffective, this does fulfil the objective of this study – to show there was a requirement for a novel method of monitoring physiological status.

3. **To develop a reliable exercise protocol that can be used for the assessment of HRR and %MAXHRr with elite soccer players while adhering to the specific characteristics of an exercise test that would facilitate completion with an elite soccer team (Chapter 5).**

Following on from the findings of study 1 and 2, it was deemed important to develop an exercise protocol to provide a novel method of monitoring physiological status with elite soccer players. In order to develop a reliable exercise protocol that adhered to the specified criteria, 3 stages of development were used (see chapter 5). Protocols were assessed with regards to their ability to elicit an appropriate (>80%) and repeatable HR response whilst also imposing relatively low physical demands. The findings of this study show that 6 repetitions of an 80m straight-line run at an average speed of 5m/s (16 seconds) with stationary rest between each repetition (14 seconds) was the most suitable and reliable exercise protocol for use in the calculation of HRR and MAXHRr.

4. **To determine the face validity of the HR response to the developed standardised exercise protocol and its ability to detect changes in physiological status under controlled conditions following a high physical load simulated soccer training session and a low physical load simulated soccer training session (Chapter 6).**

It was important to assess the efficacy of the HR response to the SEP (%MAXHRr, HRR). It seemed important to firstly understand how the HR responded to manipulated changes in physiological demands. The findings of this study suggest that changes in physiological status can be detected as a result of a high physical load and a low physical load simulated soccer training session. The %MAXHRr was significantly higher following the high physical load session whereas the HRR was significantly higher following the low physical load session. It is suggested that it is the fact that there is a change detected in these markers that is important to assessing physiological status rather than whether it is a positive or negative change.

5. **To assess the effectiveness of using HRR and %MAXHRr measured through the SEP on the first day (MD+1), second day (MD+2), and third day (MD+3) following match play to detect changes in physical loads experienced by players during the preceding soccer game (Chapter 7).**

Following on from the previous aim, it seemed important to assess the effectiveness of the HR response to the SEP when used in the 'real world' with elite soccer players. The environment which surrounds soccer match play is unique and provides many challenges with regards to accurate data collection. The findings of this study presented there to be a significant effect of HI distance per minute on HRR MD+3. There were also trends towards significance for the relationships between sprint distance and HRR MD+2, sprint distance per minute and HRR MD+2, and HI distance and HRR MD+3. This seems to suggest that the effectiveness of using the HR response to SEP to assess ANS activity during the recovery period following soccer match play is limited when used under the conditions outlined. The results would also seem to show that the SEP may be more suited for use on MD+2 or MD+3 and seemed to be more sensitive to markers indicative of the intensity of soccer match play.

## 8.2 General Discussion of Findings

It would appear that the findings of the studies undertaken as part of this thesis show there to be a need to monitor physiological status during the recovery period following soccer match play. The findings from the earlier chapters of this thesis show that the structure of the recovery period and the types of activities that are undertaken at the soccer club in question may have an impact on the type of monitoring tools that may be effective for continued use over the course of a season. Due to the consistent use of pitch-based recovery sessions it was suggested that monitoring physiological status through the use of HR based measures may be appropriate. However, some of the previously used methods around HR based measures may be unsuitable for use with soccer players for various reasons. With this in mind, it was suggested that an appropriate method for the assessment of physiological status through HR based measures with elite soccer players should be developed. Previous research has shown there to be good efficacy around the use of HR measures to assess physiological status. It was important that that the developed method provided similar efficacy whilst also providing greater effectiveness when implemented under the 'real world' conditions experienced within elite soccer clubs.

It is known that under controlled conditions HR based measures such as HRR and %MAXHRr can detect changes in physiological status that occur as a result of an exercise stimulus. When utilising the SEP developed in this thesis, the aforementioned HR based measures were able to detect changes in physiological status at +48 hours following distinctly different simulated soccer specific training sessions. This data suggests that the protocol developed may be used to understand the physiological status of soccer players following match play. However, it is important to consider the differences between the findings when the protocol was used under controlled conditions and in the 'real world' environment. These findings may suggest that the data collected through the protocol is important when attempting to assess physiological status but does not provided a complete understanding. This may be a result of many factors that contribute to 'noise' around the measurement which makes the signal harder to distinguish. A secondary measure may be a possible method of overcoming these issues. The findings from the later studies of this thesis show the HR measures outlined above to be sensitive to changes in the preceding physical loads experienced by players. However, it would appear that it is the magnitude of these changes that is of greater importance rather than the direction in which the value has changed (e.g. increase or decrease in HRR). This falls in line with some of the other research studies that have been undertaken in this area (Le Meur *et al.,* 2016). However, there is also the potential to use the interaction between %MAXHRr and HRR to better understand changes in physiological status. An example of this could be that in theory a higher %MAXHRr reached during the SEP and an improved subsequent HRR combined could suggest an improved physiological status. However, either of these changes in isolation may not be able to definitively suggest an improved or supressed status. On the other hand, modifying the methods utilised by including a secondary performance measure alongside the SEP may also be able to provide more context to the HR data obtain and to the underlying effect on physiological status.

The findings of this thesis have contributed to the general understanding of the methods used to assess physiological status through HR based measures with elite soccer players. Previous research around HRR has suggested that a high HR response above 85% of maximum is required to ensure that a reliable measurement is possible (Lamberts & Lambert, 2009). It was important for the work undertaken in this thesis to firstly challenge this concept and also find the most effective way to illicit the required HR response through a repeatable bout of exercise. It was theorised that the use of intervals of straight line runs would allow for the manipulation of work: rest ratios in order to facilitate a high HR response while not contributing to high external physical loads. This was vitally important to ensure the exercise bout was suitable for implementation at various stages of the recovery process while not preventing the primary aim of this period - the reestablishment of homeostasis. From a methodological standpoint, the later chapters of the thesis highlighted that there may be a need for a multimodal approach to support the use of HR based measures to understand physiological status during the recovery period following soccer match play.

It is important to consider the various issues associated with the approach to this project that may have skewed the findings. Firstly, there are many limitations that are associated with conducting research within the environment that surrounds an elite soccer club. Many of these limitations are linked back to the predetermined schedules that are in place within elite soccer which may impact on the approach that can be taken to research in this setting. These schedules are dictated by various factors such as fixture scheduling as a result of the requirement for games to be televised, the training methodology implemented by the coaching staff, and contractual requirements placed on players by sponsors and the media etc. The schedules in place at the clubs utilised during this thesis impacted on when certain measurements could be taken. In theory, the findings of some of the studies undertaken in this thesis may have been different if additional measurements could have been taken at more appropriate time points during the recovery process. This is a result of the changes in autonomic balance that occur during the acute phase following soccer match play being transient in nature. These changes may not be detected by monitoring tools if they are not implemented at the correct times. The transient and subtle nature of the changes in autonomic function that occur following soccer match play dictates that high quality HR data is required to assess players' physiological status. Throughout the studies undertaken in this thesis the best sampling frequency of the HR monitor available was 0.2Hz. As these HR monitors only recorded a data point at 5 second intervals, there is the potential for the HR recorded as the maximum HR during the SEP and the minimum HR during the recovery period following the SEP to be inaccurate. The quality of the HR data collected and the certainty with which the findings of this thesis can be accepted could be improved by using HR monitors with a better sampling frequency (~1Hz). Unfortunately, there is a financial cost associated with this equipment that may make this unfeasible for many soccer clubs to implement.

From a practical perspective there are many considerations for the assessment of physiological status through HR based measures. As mentioned above, it appears important to utilise a performance measure alongside the assessment of HR based measures. A countermovement jump would be an appropriate measure that is relatively simple to implement during the recovery period. Depending on the equipment available, detailed information around performance markers such as jump height, peak power, and peak velocity can be obtained. These variables are able to give an insight into changes in neuromuscular function which may be impaired following soccer match play. It is clear that a reduction in these variables is associated with inhibited neuromuscular function (and therefore supressed physiological status) and vice versa. For this reason, the use of a CMJ alongside the SEP may be able to provide context to HR based data and better understand its effect on physiological status. Furthermore, it may also be beneficial to implement the use of a subjective questionnaire at the same time point as these objective measures in order to give a global approach to monitoring physiological status. Although the initial aim was to develop a method involving a single test to assess the physiological status of players, it is clear from the data presented in this thesis that utilising the three methods outlined above in conjunction with each other may allow practitioners to understand the physiological status of players better and make more informed decisions around acute training prescription in the lead up to the next match.

Implementing three different methods in order to assess physiological status on a recovery day following soccer match play may present various challenges. It is important to ensure that the correct processes are adhered to around each of these methods to ensure that accurate and reliable data is collected. A theoretical approach to implementing these methods is outlined in figure 8.1. This approach is designed for use on a typical recovery day within an elite soccer club. However, it must be noted that this approach may need to be altered to suit the pre-set daily routine of a particular soccer club on recovery days. It is important to ensure that the processes used are standardised so that the process can be repeated following subsequent games. It is also important that procedures are put in place to ensure that the highest quality data is collected on a consistent basis following all games. This will involve consistent calibration of the equipment used to monitor CMJs and the use of ultrasound transmission gel to maintain consistent data collection throughout the SEP and the subsequent recovery period. Whilst it is important to have a standardised approach to implementing the methods to monitor physiological status that is relevant to the soccer club in question (see figure 8.1.), it is also important to understand that these procedures may have to be adjusted to suit the length of recovery period available following each match (see figure 8.2.).

The findings of this thesis would suggest that these monitoring tools should be implemented at the latest possible point in the recovery period before players are required to return to normal soccer specific training. This will then allow practitioners to understand the player's physiological status through objective data at an appropriate time point that allows for the modification of workloads undertaken by players over the following days. The time point at which the SEP and CMJ are implemented may change significantly depending on the circumstances surrounding each game. This will be dictated by factors such as the amount of time between fixtures, the amount of time that can be dedicated to recovery, and the amount of time required to prepare for the next fixture. Figure 8.2. shows a theoretical model for the use of monitoring procedures following soccer match play. This figure endeavours to show the different strategies around monitoring that may be implemented as a result of a range of common fixture schedules that are seen within elite soccer (1 game per week, 2 games per week etc.).

With the above in mind, it is important to firstly ask the question: is there adequate time to allow for complete physiological recovery to occur (~72 hours) before commencing soccer training to prepare for the next game? If complete physiological recovery is possible before players return to normal soccer specific training, it is unnecessary to monitor the physiological status of players. In theory, in this scenario it may be more beneficial to focus on implementing effective strategies to aid the progress of the recovery process rather than attempting to monitor changes in physiological status. This scenario is likely to only occur when 1 game is played per week. These recommendations are presented in figure 8.2.

in the section highlighted in green. In contrast, the assessment of physiological status may become more important when fixture schedules are more congested. However, implementing the methods to assess physiological status may simultaneously become more challenging as a result of the time constraints that are imposed as a result of less time between games. Suggestions of how to implement methods to assess physiological status during different fixture schedules commonly seen in elite soccer can be found in figure 8.2. The frequency with which each scenario outlined in figure 8.2. occurs will depend on the competitions that the team in question are involved in. The recommendations outlined for each scenario are discussed further below.

The occurrence of 2 and 3 game weeks is more prevalent for teams that are more successful in cup competitions and teams from lower leagues where typically more games are played per season. This can result in teams regularly playing games every 3-5 days depending on scheduling for televised games etc. These fixture patterns would elicit more incidence of the approaches highlighted in yellow and orange in figure 8.2. During the shorter turn around between games in these scenarios it is important to be able to understand if players are able to recover to a point where they are able to perform effectively from a physiological perspective in the subsequent game. The information collected from the SEP and CMJ in this scenario may be able to help inform coaches when player rotation may be required or a change to training prescription may be needed. Under extraordinary circumstances there may also be situations where the approach highlighted in red (see figure 8.2.) may be implemented. This scenario would usually only occur around particular points in the season when teams are traditionally required to play twice in three days. As outlined in figure 8.2. it is suggested that the SEP is implemented on MD+1 as part of any pitch based preparations undertaken for the next fixture. However, under these circumstances it is important to consider the rationale for players completing a training session between the two games. In this situation the coaching staff at the club in question may choose not to train to allow players the maximum time possible to recover. In this situation, if players are required to complete a gym-based recovery session it may still be beneficial to use the CMJ test alone to provide some understanding of the players physiological status following the first game. However, due to the short amount of time between games in this instance and the inevitability that players will not have recovered fully before the next game, it may be more beneficial to purely focus on the implementation of effective methods to aid the recovery process rather than investing time in assessing physiological status.

In summary, it is recommended that the SEP is implemented at the latest time point in the recovery process before players return to soccer specific training. It would appear that from the data collected throughout this thesis the SEP is most effective for assessing physiological status when used later in the recovery process. However, the latest point at which these methods can be implemented may be influenced by the training philosophy in place at the club in question. Alongside the use of the SEP it is recommended that a CMJ test is also implemented to provide context to the HR data collected. These objective measures may also be supplemented by the collection of data through subjective questionnaires to give a fully rounded approach and global understanding of physiological status following soccer match play.

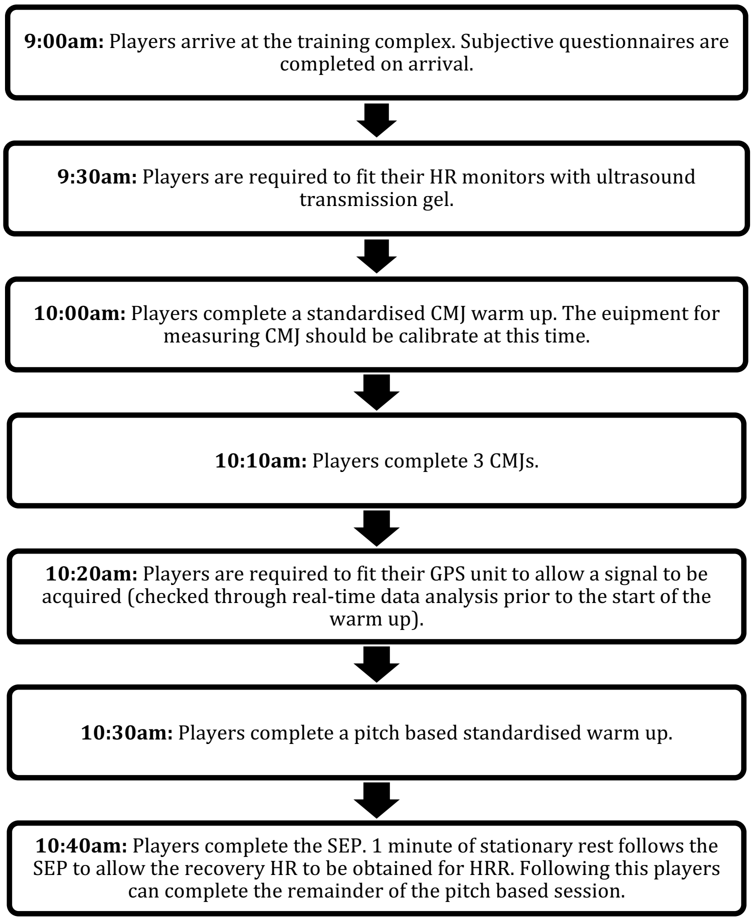


**Figure 8.1.** A theoretical approach to implementing the processes for monitoring physiological status on a typical day designated for recovery following match play.

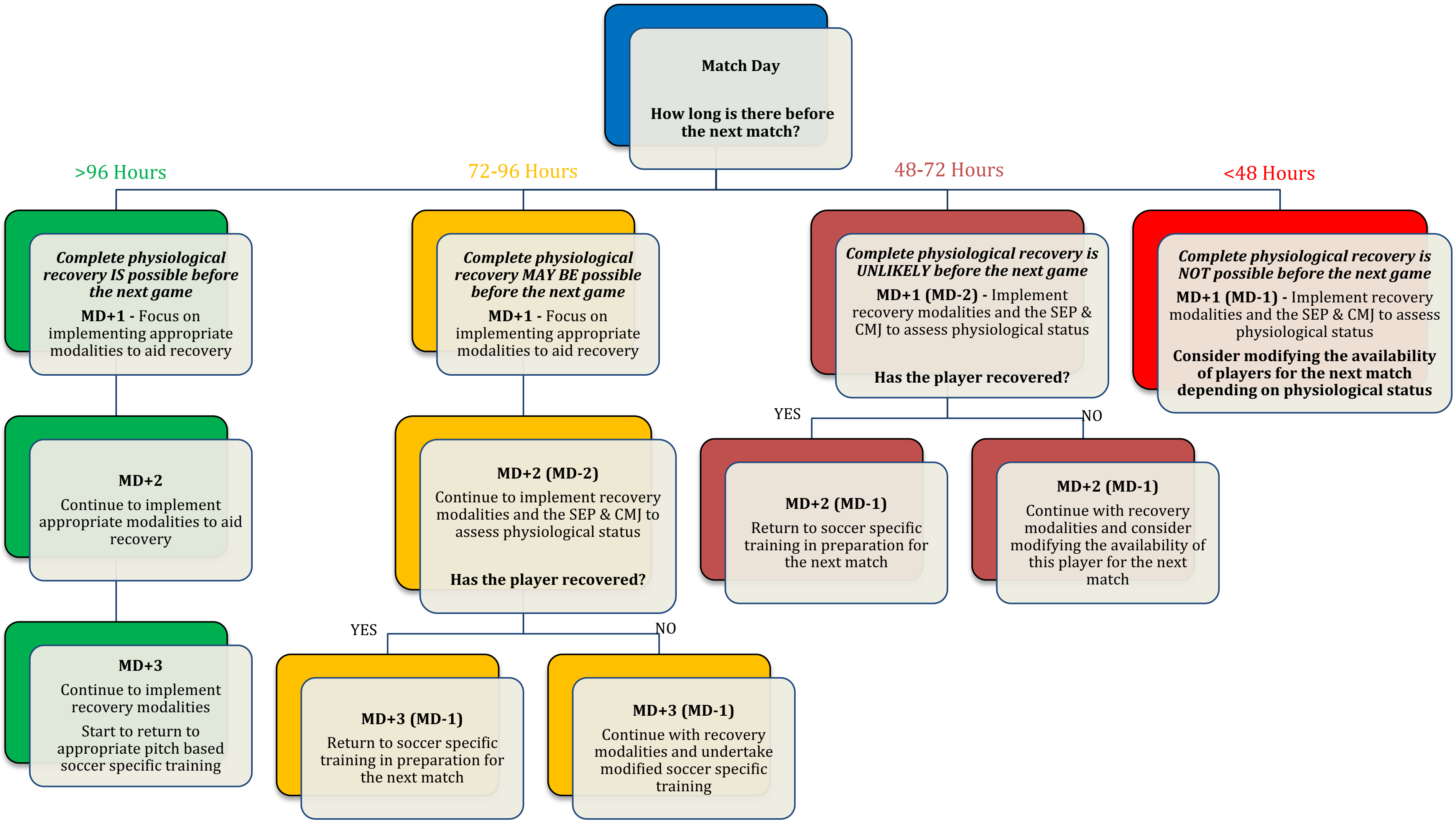


**Figure 8.2.** A theoretical approach to monitoring physiological status during the recovery period following a soccer match.

## 8.3 Recommendations for Future Research

Some of the findings and associated issues that have arisen as part of this thesis have resulted in various areas for future research. The details around these recommendations are outlined below:

1. *Chapters 5, 6, & 7* – It may be of importance to repeat some of the assessments of reliability, face validity, and effectiveness of the HR response to the SEP with HR monitors that have a better sampling frequency (~1Hz). This may provide more accurate HR data around the findings of these chapters.
2. *Chapter 6* – It may be important to repeat the investigation undertaken in chapter 6 using a more ecologically valid method of inducing different physiological responses. This method could include more soccer specific movements and actions to replicate the physiological response of soccer match play.
3. *Chapter 7* – It may be important to complete a similar study design as utilised in chapter 7 but assessing the difference between measurements of HRR & %MAXHRr following soccer match play (MD+1, MD+2, MD+3) and baseline measurements of HRR & MAXHRr to assess changes in physiological status. It would also be important to implement a secondary performance measure alongside the SEP in order to better understand changes to physiological status following soccer match play.
4. *Chapter 7* – it may be important to complete a similar study design as utilised in chapter 7 using measurements of HRR & %MAXHRr on all 3 days following soccer match play (MD+1, MD+2, MD+3). This may provide a better understanding of the pattern of the return to homeostasis following soccer match play and could influence the recommendations for when the SEP is implemented in practice.

# Chapter 9

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