THE PHYSIOLOGICAL DEMANDS OF PROFESSIONAL SOCCER REFEREEING ACROSS A SEASON

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A thesis submitted in partial fulfilment of the requirements of Liverpool John Moores University for the degree of Master of Philosophy

October 2019

Abstract

Professional soccer referees are tasked with officiating the highest profile and most watched competitive soccer matches in the world. Accurate determination of their match play demands is key to understanding how to programme their training, whilst making sure they continue to be able to successfully officiate over matches. There is little match play data from elite level officials and thus being able to prescribe training regimes and determine physiological prerequisites of successful officials is difficult.

Twenty elite level soccer referees, 10 from the Premier League (45.5 yr, 180 cm, 79 kg), and 10 from the Championship (35.6 yr, 178 cm, 79 kg), had their data collected from 330 competitive matches over the course of the 2017/2018 season via the use of an integrated GPS and heart rate monitoring system. The data collected was broken down into 2 different categories; the effects of competition level and season quarter and the effects of match ranking using teams final league positions. Within these categories specific focus was applied to; internal match demands, external match demands, time spent in varying heart rate zones, player loading™, accelerations and decelerations.

This thesis considered the differences between Premier League and Championship match officials over a season. Premier League matches induced a higher absolute HR response compared to Championship matches, but despite a lower absolute HR, Championship officials spent more time between 85-100% of their maximum HR ($P < 0.05$). In addition, Championship referees performed more accelerations and decelerations compared to that of their Premier League counterparts ($P < 0.05$) at the expense of less walking and more jogging ($P < 0.05$). Across the playing season, HR, walking ($P < 0.01$) and running ($P < 0.01$) were higher in the last quarter of the season whereas total distance covered ($P < 0.02$), jogging ($P < 0.01$) and sprinting ($P < 0.01$) were lowest in the last quarter of the season. There were more accelerations and decelerations in the first quarter of the season ($P < 0.05$). When considering the effect of the position in the league of the two teams playing particular matches, top ranked (teams that finished in the top 7) Premier League games influenced physiological load

of officials via increased total distance ($P < 0.01$), high-speed running and sprint distance ($P < 0.05$).

These findings provide a range of important information for referees and their coaches/trainers at the highest levels for the optimal preparation for competitive officiating across the Premiership and Championship leagues. Findings from this thesis allow us to suggest that regarding physical training of officials specific focus to those aspiring to work in the Premier League should consider these greater physiological demands. More acutely, considerations regarding training should include the level of the two teams playing each other in upcoming fixtures.

Acknowledgements

Firstly I would like to express my upmost gratitude to my director of studies, Dr. Thomas Brownlee and supervisory team of Professor Barry Drust and Dr. David Low. Without these three incredible people, this project would not have been thought of, implemented and completed. Each one of them showed unwavering levels of support and patience with me, especially when times were difficult. They were not afraid to give me some constructively stern words that were always meant with the best of intentions in order to get the project back into the right direction. The level of knowledge and professionalism from each one in their respective field was not only needed, but also great to have been able to see and be involved in every step of the way. Juggling a full time role at a football club, a part time role outside of football, completing an MPhil and personal life struggles was not only testing for me, but also at times, testing for each of them, they were lenient when times were tough, and so directed and driven when they knew it was time to knuckle down. The achievement for me to complete this piece of work has only been possible because of each of these three tremendous figures.

Secondly I would like to thank everyone involved at the Professional Game Match Officials Limited. Mike Riley and Alan Wiley for allowing me in to the organisation and offering the chance to be involved in an elite level atmosphere. To the exceptional Sports Science team of Simon Breivik, Francis Bunce and Vicky Smith, all of whom were so welcoming through every camp and helpful beyond the parameters of their role when offering support. You were all key figures in not only getting this project over the line, but also helping me develop as a practitioner and a sports science student. And to the officials who took part in the study, through all the initial teething problems, and then taking it upon themselves to make sure the data was successfully collected and able to be used in the study. To everyone in the organisation for the hours and hours of anecdotes to life at the highest level of professional sport and feedback sessions over breakfast and dinner at each camp, I can't thank you enough.

Finally, I'd like to thank my friends and family for being so supportive throughout my undergraduate degree and then this MPhil project. The toughest of times will always

test a person’s resolve and character, without my family around me I would not have been able to complete this and would not be the person I have become at the end of it. Their constant belief in me will be something that drives me through my personal and professional career for the rest of my life.

Declaration

I declare that the work within this thesis is entirely my own.

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CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

Soccer is one of the most watched sports in the world; therefore, the level of scrutiny of a 90-minute game can be huge. In addition, the financial rewards of professional competition can also be lucrative. The amount of money gained for being promoted from the Championship to the Premier League, or playing in the Champions League is hugely significant. Consequently, the need for the accurate decisions made by match officials is incredibly important. During a 90-minute match officials face significant perceptual-cognitive demands when making these key decisions. In fact, an elite level referee will be required to make approximately three decisions per minute during a game (Helsen & Bultynck, 2004). Many of these decisions have the potential to alter the course and/or result of the game.

In addition these high cognitive demands officials experience high levels of physiological stress. Early investigations into the physical demands of match officials showed that the average distance covered was ~9,000 m (Catterall *et al.*, 1993). Over the past fifteen years the pace of the game appears to have increased, which has been reflected in the increased physical demands placed on the players (Barnes *et al.*, 2014). Given that a referee's physical match load has been found to be associated with player match demands (Weston *et al.*, 2011b) the physiological burden on a referee is now higher than ever. Despite this assumption, when compared to the understanding of the physical demands of players less is known about the demands placed upon the officials. Previous studies have often been conducted on a small number of matches from a small part of the playing season. This may not accurately reflect the typical demands placed upon a referee. This has implications around official training and match preparation considering they play such a pivotal match role and at times their workload can be even greater than the players (Helsen & Bultynck, 2004). Beyond the direct implications of the increasing physical loading on a referee, this may also influence the accuracy of their decision-making. Specifically, there is evidence of a relationship between the velocity of the referee immediately prior to or at the time of a decision and the accuracy of that decision (Mascarenhas *et al.*, 2009; Elsworthy *et al.*, 2014). Studies have reported accuracy rates of match decisions of 64% and 86% for national (Mascarenhas *et al.*, 2009) and international (Mallo *et al.*, 2007) level referees, respectively. Although a superior accuracy of decision making with more elite level referees is not surprising, the role of differences in physical loading between different standards of refereeing is not clear. These findings are of practical relevance as the intensity of the game may negatively affect complex cognitive functions, meaning decision making capabilities are prone to error (Weston *et al.*, 2012). Despite this reasonable understanding of the broad physical activity profile of a referee there is limited data regarding the effect of playing standard and time of season on physiological demands placed upon referees. Consequently, the aim of this literature review is to consider in greater detail the current data regarding physiological demands placed on match officials with particular attention to the level of official and also the stage of the playing season. It is hoped this will provide more detailed data that may be able to be utilised when considering their training, recovery and development.

1.2 Physiological Capacity of Referees

The physiological capacity of referees has largely been determined through the application of standardised physiological assessments of physical fitness. It has been found that top officials possess well-developed aerobic and anaerobic capacities to cope with the demands of the game (Stolen *et al.*, 2005; Castagna *et al.*, 2007; Weston *et al.*, 2012). Clearly though, evaluation using a specific test to measure a particular fitness variable cannot propose how that system is stressed during refereeing. Commonly used tests include maximal aerobic capacity tests such as $\dot{V}O_{2max}$ testing, the YO-YO intermittent recovery test, maximal aerobic speed and blood lactate threshold assessments. The section below will briefly outline the performance of referees in these tests and summarise what this might mean for their physical capabilities.

1.2.1 Aerobic Capacity

The need for an official to have a high $\dot{V}O_{2max}$ is considered important for success within professional officiating. A higher $\dot{V}O_{2max}$ has also been found to positively affect match physical performance in soccer referees (Castagna *et al.*, 2002). Officials in World Cup tournaments (who could be considered the highest standard of referee) have $\dot{V}O_{2max}$ values that are generally higher than their non-selected counterparts

(Castagna *et al.*, 2017). Although these levels may be high for referees some studies consider elite referees to have a moderate $\dot{V}O_{2max}$. Values of 49.3 ± 8.0 mL/kg/min^{-1} in elite Italian referees, are considerably lower than their playing counterparts (59.2 ± 4.3 mL/kg/min^{-1}) (Castagna *et al.*, 2011). Similar values 46.3 (range 40.9 – 56) mL/kg/min^{-1} were reported by (Krustrup & Bangsbo, 2001) when assessing the $\dot{V}O_{2max}$ of 10 Danish officials. The Federation Iternationale de Football Association (FIFA) and the Union Europe en de Football Association (UEFA) consider a high $\dot{V}O_{2max}$ as a requirement for good refereeing. This is likely based on the assumption that a higher $\dot{V}O_{2max}$ will allow the referee to be closer to play, thereby providing an improved view (Harley *et al.*, 2001). Despite referees having a good $\dot{V}O_{2max}$ scores it seems that improvements, which may lead to improved refereeing performance would be advantageous.

It might be argued that the varying levels of $\dot{V}O_{2max}$ present at the highest level of refereeing in different countries suggests that a high aerobic capacity is important, though not critical, for soccer refereeing. In fact, although it may be a good indicator of successful officiating (and a requirement from football governing bodies) it is not an underlying necessity for a top level official to have. In the English Premier League for example, officials tend to be older. Correspondingly, some of their $\dot{V}O_{2max}$ are likely to have decreased with age as found by Castagna et al., 2005, though they are officiating over some of the highest profile games in world soccer. Taken together it might be considered that officiating over a soccer match successfully at the highest level may be predicated on factors beyond merely possessing a high $\dot{V}O_{2max}$. Continued successful performances are likely not only dependent on aerobic fitness but also a contribution from the anaerobic system (identified via an individual's lactate threshold), which will be discussed below.

1.2.2 Lactate Threshold

Professional elite level soccer matches have been shown to be undertaken at an intensity of around 68% of $\dot{V}O_{2max}$ (D'Ottavio & Castagna, 2002). Correspondingly, matches have been shown to elicit 80-90% of officials maximum heart rate (HR)

(Castagna *et al.*, 2007). This is coupled with peak reported blood lactate concentrations above 12 mmol/L (Krustrup & Bangsbo, 2001). Therefore, beyond $\dot{V}O_{2max}$ lactate threshold (a physiological situation where anaerobic respiration becomes more dominant over aerobic respiration) may be a good predictor of physical match performance in elite soccer referees (Castagna *et al.*, 2002). Previously, 14.0 $km \cdot h^{-1}$ and 37.3 $mL \cdot kg^{-1} \cdot min^{-1}$ have been reported in an individual case study on an English Premier League official with regard to speed and $\dot{V}O$ at lactate threshold, respectively (Weston *et al.*, 2010). In addition, in Danish referees correlations have been found between total match distance covered and oxygen uptake corresponding to a fixed blood lactate concentration of 3 mmol/L (Bangsbo & Lindquist, 1992). Similar findings of a relationship between blood lactate measures and the physical performance of elite level referees have also been reported elsewhere (Castagna *et al.*, 2002). The idea that lactate threshold may be important during soccer match play has been questioned due to the variable exercise intensity during games, as it is typically above lactate threshold (D'Ottavio & Castagna, 2001b). These studies suggest a high lactate threshold and tolerance for blood lactate may provide the endurance capacity required for elite level soccer match play. Although the data from these studies provide important information regarding physiological demands of refereeing a better approach to understand match demands would involve data collected during matches. This would allow more specific understanding of the physiological loading experienced. Also, considering the associations seen between some of the above markers and match play it seems reasonable that more direct, but perhaps less invasive variables may be considered.

To conclude, there is a high understanding of the physiological capability of elite levels officials and the need for aerobic and anaerobic fitness to successfully officiate over an elite level match (Weston et al., 2007). However, in comparison to the soccer players they officiate an official’s match play has more aspects than just straight-line running ability or a well developed cardiovascular system. An elite level official is required to be able to change direction as quickly as the players, it has already been shown that the movement patterns of officials are partly related to those of the players (Weston et al., 2007). Should a change of possession occur and a counter attack take place the official has to decelerate, change his position, accelerate and catch back up with play, whilst trying to keep the ball and surrounding players in his line of vision. Officials constantly have to think about how to gain a better vantage point, so changes in position are constantly occurring in part due to the 20 outfield players affecting their line of sight and their ability to successfully make a decision. Within a game a player will perform between 100-1400 activities, most of which are mainly short, and through varying movement patterns (Mohr et al., 2003) with the most critical match aspects happening at the higher velocity actions. Whilst having to keep up with play and gain the best vantage point for every aspect of the game, the official also has to interpret the rules and make critical decisions during a match. An official's actions over the course of a 90-minute match have been examined further with the advancements in technology, breakdowns in how the distance during a game is covered, first half and second half comparisons, heart rate data, sideways movements, backwards movements, walking, jogging, high speed running (HSR) and sprinting have all given a greater understanding of the demands placed upon an official. The section below will give a more explicit breakdown of the demands faced by an elite level official.

1.3 Physical demands of the game

1.3.1 Heart Rate

Heart rate has been researched extensively as has been shown as one of the best methods to gain an understanding of physiological stresses placed upon the body during exercise. Specific to soccer refereeing, studies have demonstrated that at an elite level, referees work at ~ 85% of HR_{max} during match play (155 ± 16 bpm, (Helsen & Bultynck, 2004). Furthermore officials can reach up to 95% of their age-predicted maximal heart rate (HR_{max}) (165 ± 8 bpm, (Catterall *et al.*, 1993)). Although a subtle difference, using age predicted HR max can be considered inaccurate as a predictor of maximum heart rate and subsequently HR data expressed as a % of maximum. As well as considering HR_{max} it is also important to contemplate time spent in different HR zones especially given the intermittent nature of refereeing. One study completed on high-level officials (Castillo *et al.*, 2018) concluded that officials spent approximately 90% (40 mins) of the first half and 84% (37 min) of the second half officiating above

80% of their HR_{max}, they also found that less than 5% of the match is officiated below 71% HR_{max}. Despite these data, there are minimal specific HR data when considering demands across a more detailed breakdown of HR zones during matches. There is also limited data comparing these variables across varying standards of referees and regarding the level of matches being officiated.

1.3.2 Distance Covered

In order to characterize the physical demands placed on officials, initial investigations examined distances covered by referees at various running speeds. This was done by using simple hand notation or video analysis systems. One of the earliest studies into profiling match official physiological loading used a grid method and notational analysis of the movement actions and distances covered. Technological development of cameras and computers in the 1990s and 2000's allowed greater ease of analysing loading of officials. Specifically, using computerised time motion analysis. A breakdown of these distance coverages can be seen in Table 1. Further advancements meant that beyond having quantifiable data of total distances, a breakdown of the specific time spent, or distances covered at different intensities is another approach in assessing physiological stresses during a match. Despite this improved understanding, data available on distance covered is either dated or just taken from the highest level. There is no comparison between levels e.g. within the same country or different competitions (i.e. World Cups). Such a data set within the same country of the top two leagues would allow for comparisons to be drawn about the potential differences between different standards of refereeing. This may then have implications for training programmes and talent identification.

Table 1. Showing the breakdown of distances covered by officials with the changes in technology.

	Study	**Total Distance Covered (m)**	**Walking**	**Low Intensity Running**	**Medium Intensity Running**	**High Intensity Running**	**Sprinting**
Grid Analysis Method	Catterall et al. (1993)	9348					
	Johnson & McNaughton (1994)	9408 ± 838					
Computerised Time Motion Analysis	D'ottavio & Castagna (2001b)	11376 ± 1600					
	Krustrup & Bangsbo (2001)	10070 (Range 9200-11490)	63.2 %	30.2 %		6.6 %	
	Weston et al., (2011)	11770 ± 808				889 ± 327(m)	30.5 ± 21.3(m)
	D'ottavio & Castagna (2001)	9011	889(m)	4174(m)	2585(m)	1556(m)	608(m)

The range of physical activities during matchplay highlights the multi-faceted physical demands of refereeing. Not only is a high general aerobic capacity required but also the ability to repeatedly perform high-intensity actions. Furthermore, although data on the various exercise intensities required of a referee provide important information on the physical demands of an official the constant changes in intensity (and even direction), in particular accelerations, are vital for referees to keep up with play and optimal positioning (Riiser *et al.*, 2017). Such accelerations increase metabolic demand and are a vital component of high-intensity running (Osgnach *et al.*, 2010). There is scarce information on the frequency and magnitude of accelerations (and especially decelerations) in soccer referees. Such information would further improve the understanding of the physical demands of referees and training prescription.

Beyond the relative narrowness of looking at one group of referees in isolation, the majority of research typically involves a small/moderate number of games within a discrete period of the playing season. A referee can officiate 40-60 games per season over 8-9 months, which could represent significant chronic physiological stress. Whether the physical demands of a referee change across a season with changes in physical capacity, phase of a competition and influence of different playing styles of teams remains unclear. With regards to soccer players there is quite high match-to-match variability of high-speed running and total sprints in English Premier League players (Gregson *et al.*, 2010). Weston et al., found a range of variability for differing indices of physical demands over short (8 weeks) and long (5 years) periods of time for referees (Weston *et al.*, 2011a). High variability was evident for high-speed running distance (25.9+/-10.1%), explosive sprints (34.3+/-16.6%) and total number of sprints (54.0+/-20.7%) whereas lower variability was observed for total distance covered (3.8+/-1.5%) and top sprinting speed (5.6+/-10.9%). Therefore, the need for a longitudinal study across one playing season to analyse the games of officials of varying standards becomes more evident due to common variability seen in officials and players alike.

1.3.3 Decision Making

An elite level referee will be required to make approximately 3 decisions per minute during a game (Helsen & Bultynck, 2004); a select few of which may significantly alter the course and/or result of the game. Past studies have reported accuracy rates of 64% and 86% for national (Mascarenhas *et al.*, 2009) and international level referees (Mallo *et al.*, 2012), respectively. Due to the high volume of decisions required during a 90-minute match the perceptual-cognitive demands of officiating are significant to the match outcome.

Evidence suggests that the physical loading of a referee can influence decision-making. Decision-making can have an affect on match outcomes, however, the exact relationship (or lack of) between physiological load and decision-making accuracy/performance of referees is not entirely clear. Verheijen et al., (1999) compared correct and incorrect decisions of a small sample (n = 3) of elite youth league referees during 20 minutes of match play and reported they moved more slowly just before when they made correct decisions. Conversely though, analyses of senior referees showed that the velocity of the referee at the time of the decision was not related to the accuracy of the decision (Mascarenhas *et al.*, 2009). In a study of Australian Rules Football referees a negative relationship was evident between the average velocity in the 5 s prior to a decision and the accuracy of the decision (Elsworthy *et al.*, 2014). D'Ottavio & Castagna (2001b) also concluded that the match intensity officials are subjected to is likely to exceed 75-80% of max HR, therefore, during high level match play, decision making could be negatively affected. These findings suggest that the physical load of a referee immediately prior to or at the time of a decision might affect the accuracy of that decision. Given the intermittent and random nature of physical activity of a soccer referee the velocity of a referee at the time of, or just prior to, a decision may not be the most appropriate index of the true physical load prior to/at the time of a decision given that repeated sprints or extended sprinting may have occurred in the 5-90 s prior to a decision. When observing a trend in the data over the past 10 years, the EPL has always shown the lowest fouls per match and the highest in attempted tackles per foul, however, with the number of fouls consistently declining year on year since 2006 in all 9 seasons analysed.

1.3.4 - Fatigue

There have been attempts to assess the possible occurrence of fatigue during matches in soccer referees with equivocal findings (Weston et al., 2012). Changes of the between half profile of high speed activities are thought to be an indicator of accumulated fatigue, but conflicting results have been found (Castagna, Abt and D’ottavio, 2007). One reason for this could be that a simple between half comparison may not permit the assessment of accumulated fatigue, as performance during the first half could be below the official’s physical capacity and/or have been affected by either teams’ tactical play. Another inconsistency could be the decrease of second half activity in officials who covered more high-speed distance in the first half compared to the officials who covered less distance in the first half (Weston et al., 2007). An analysis of Spanish officials of how the fatigue accumulates over the course of a 90 minute match using countermovement jumps (CMJ) has shown that unlike the players, an official’s CMJ performance is not affected by the physical match demands (Tessitore et al., 2007; Castillo et al., 2018). Observations of how a bout of high intensity exercise can affect the subsequent activity undertaken by an official have been examined as an alternative way to establish the fatigue experienced by officials. Acute fatigue analysis found that the amount of high speed running in the 5-minute period immediately after the most intense 5-minute interval has been reported to be less than the average for the entire match for officials (Mallo et al., 2007 & 2009). Weston et al., (2012) advised that when evaluating officials match activity profiles, they should be evaluated alongside those of the players in the same match otherwise it is difficult to discern whether the decreased intensities are a consequence of acute or accumulated fatigue, pacing strategies or simply a result of changes in player activity. The ability to use the Playerload variable and with the improved accuracy of GPS units accelerometry could lead to the development of being able to determine when an official is fatigued, and if their schedule or forthcoming match load should be changed/monitored.

1.4 Effect of stage of game

In order to gain a more detailed understanding of the physiological demands of officials during matches it is useful to partition the analysed periods into two halves. Officials have been found to cover shorter distances while jogging, running and high-speed running in the second half compared to the first half (Johnston & McNaughton, 1994; Krustrup & Bangsbo, 2001; Di Salvo *et al.*, 2011). Weston *et al*., (2007) also reported that officials who covered greater first half distances, had a greater second half decrement in distance covered. The changes or inconsistencies in high-speed activities between halves could be indicative of fatigue, but when splitting halves up further conflicting results have been reported (Castagna *et al.*, 2007). Specifically, within half changes in activity profile are evident, when halves are split into three 15-minute periods. The first period sees generally more activity with subsequent periods showing a decrease in medium-intensity running and total distance covered in the last third (D'Ottavio & Castagna, 2001a) and possibly in high-intensity running as well (Johnston & McNaughton, 1994; Krustrup & Bangsbo, 2001). In contrast, high-intensity, maximal-speed runs and high-intensity activities were not found to be any different within the 15-minute timeframes in Italian officials with higher aerobic capacities (Castagna *et al.*, 2004). Alongside their higher aerobic fitness this was also attributed to the strategy of sparing lower intensity activity to ensure high-intensity activity could be repeated at the end of each half. Between-half or even within-half comparisons may not permit the assessment of accumulative fatigue during a match however as the level of required physical performance from the first or second half, or within a half, may be below the physical capacity of the official (Carling *et al.*, 2008). Further studies using standardised methodologies would allow for a greater understanding of the patterns of activity experienced during matches.

Findings from these studies highlight that demands placed on officials can vary both within and between games. While the link between the physical demands of officials and players is unsurprising given that officials have to react to the player’s actions. Longitudinal data on the physical demands of refereeing is sparse unlike in players. It is considered that some of the variables presented above would add further value if they were examined over a longer period of time in match officials.

1.5 Technological Advances in the Assessment of Physical Demands of Referees

As briefly eluded to above advances in technology have allowed for a more detailed analysis of match physical performances in officials (Weston *et al.*, 2007; Weston *et al.*, 2009; Weston *et al.*, 2011a; Weston *et al.*, 2011b; Weston *et al.*, 2012; Riiser *et al.*, 2017; Castillo *et al.*, 2018). The introduction of multiple cameras placed around stadia allowed tracking of an individual throughout a 90-minute match. Specifically, these semi-automated match analysis systems permitted a more detailed evaluation of specific elements of a referee's match performance over an extended period of time (Di Salvo *et al.*, 2011). Beyond this, more modern telemetry systems (e.g., GPS tracking systems) can provide a more precise characterization of the physiological demands of officiating. For example, the quantification of velocity, distance and accelerations, over a high sampling rate. This advancement brought with it the ability to create the kinematic profile of a referee by means of a two-dimensional photogrammetric system and allowed for the determination of the position of the official on the field of play, and also more specific match details, i.e. when the ball is in play (Mallo *et al.*, 2007; Mallo *et al.*, 2009). These systems have also allowed for the quantification of HR data into specific categories whilst being captured and collated into sub sections of different intensities. Using this technology, when observing Spanish National Third Division level officials across the 2014/15 season, Castillo et al., (2017) found an average total distance covered of 9991 m with 2783 m of that being high-intensity. Data from the Spanish First Division has shown that referees covered 9989 m with up to 2873 m at a velocity greater than 13 km/h (Castillo *et al.*, 2018). These data are consistent with older methods of recording distance covered and modes of activity in soccer referees. This gives a much more efficient option for collecting desirable data that may aid in achieving some of the recommendations for future research.

As well as confidence in variables already being measured these technological developments allowed for detection of more precise changes in the plane of movement, the velocity of that movement, the length of time taken to complete the movement and the instantaneous rate of change divided by a scaling factor; an arbitrary unit termed PlayerLoad™. These opportunities led to quantification of elite level players demands and found that 1,200 to 1,400 activity changes and an accumulation of 150-250 short duration bouts (1-4 seconds) at a high-intensity were performed (Mohr *et al.*, 2003). It is likely that demands approaching these are placed upon a referee given the link between player and referee physical activity profiles (Weston *et al.*, 2011b). As of yet though, there are currently only a few studies quantifying such movements, e.g., accelerations and decelerations, with these sensors at the highest level of match play. Such knowledge would be useful as it would directly impart the energetic demands of the game. Osgnach et al., (2010) found that accelerations substantially increase the metabolic demand and are of a high importance for the successful execution of high-intensity match demands, which are often linked to the key actions of a game. Accelerations are very rarely measured in soccer referees however. Two studies compared referees to assistants and found referees performed less (Riiser *et al.*, 2017) or equal (Barbero-Alvarez *et al.*, 2012) number of accelerations, but cover greater distance during these accelerations, compared to assistants. Again, a greater understanding of these metrics, across a chronic period, would be advantageous.

1.6 Competitive Level of Match

Finally, this literature review will briefly cover how physiological demands may be impacted by the level of match that the referee is officiating over. Referees often progress from officiating lower-league matches and move up through the respective tiers. As with differences in technical and tactical demands between different playing levels, it is not surprising that there are variations in physical and technical demands when refereeing between different levels. The apparent difference between levels has been noted in previous research, with games played at a higher level (e.g., international matches) typically resulting in officials covering a greater distance (Catterall *et al.*, 1993; Mallo *et al.*, 2007). Furthermore, higher standard referees exhibit lower heart rates (155 bpm, (Helsen & Bultynck, 2004)) when compared to lower ranked referees (165 bpm, (Catterall *et al.*, 1993)). The level of referee has also been shown to differ when looking at agility and that agility can be used as a discriminating factor for differentiating between higher level and lower levels (Yanci *et al.*, 2016). The reason this metric demands greater attention is that much of the literature is less current and previous research has typically compared groups of referees with large differences in standards rather than compare levels of referees within the same leagues/divisions who are looking to improve their level via a promotion scheme. This would be especially advantageous when looking at training programmes and developing officials as they move up the tiers of refereeing. If there is an aim to develop such evidence-based programmes then we need a thorough, broad understanding of the demands of the game throughout the season and between playing/refereeing levels.

As well as understanding the potential differences that occur in physiological demands during match play between referees in different leagues it may also be useful to understand how the level of match within a league may be influential. Castillo et al (2018) grouped matches based on whether the two teams playing were in the top or bottom half of the table or a mixture of the two. It was found that when refereeing matches between two top-half teams referees covered more distance at a low walking speed and performed a higher percentage of high-intensity accelerations and decelerations than those who officiated between teams in the bottom half. Relatively though understanding of any differences between teams of varying rankings within the same league are limited. Such differences might be apparent due to the increased high-intensity activity in higher ranked teams relative to their lower ranked counterparts (Bradley *et al.*, 2016) and that a referee's physical response to officiating is strongly linked to the players physical activity (Weston *et al.*, 2011b). Again, a greater understanding of this variable would likely be advantageous.

This literature review has served to explore a number of variables that have been considered in previous literature as to what could be considered a prerequisite to become an elite level soccer official. Using this information, and an advancement in technology allowing more variables to be collected, we hypothesised that there would be a significant difference between the demands placed on the Premier League officials, and that top ranked games at both levels would illicit the highest physiological responses. Therefore, it was hypothesised that there would be greater amounts of high-speed running in the Premier League compared to the Championship. It was also hypothesised that matches between higher-ranked teams would yield a greater physiological response from those referees. The aim of this study was to examine the physiological demands of varying levels of professional soccer referees (Premier League vs. Championship) across a full competitive soccer season as well as the effect of a team's ranking on these demands.

CHAPTER 2

THE PHYSIOLOGICAL DEMANDS OF PROFESSIONAL PREMIER LEAGUE AND CHAMPIONSHIP SOCCER REFEREEING ACROSS A SEASON

2.1. Introduction

Soccer referees must ensure that the laws of the game are appropriately adhered to and subsequently the need for their decisions to be correct is fundamentally important (Helsen & Bultynck, 2004). Significant cognitive and physiological demands are therefore placed on a soccer referee during match play. Specifically, a referee's physical load has been shown to be linked to players' physical activity profiles (Weston *et al.*, 2011b). Therefore, a referee must repeatedly perform brief high-intensity exercise bouts against a background of low/moderate-intensity exercise during the 90 minute match. This is done while simultaneously making several decisions a minute, which could relate to foul play and or re-starting play for example. The physical loading of a referee may therefore influence the accuracy of their decision-making (Mascarenhas *et al.*, 2009; Elsworthy *et al.*, 2014).

The majority of research into the physiology of soccer referees has typically investigated movement characteristics of elite/professional level referees at the highest level of soccer play in several European leagues or at the international level (Castagna *et al.*, 2007). The differences, if any, in physical loading between different standards of refereeing within a professional league is not clear however. National referee programmes often have different levels of referee competence twinned to the different playing levels with the aim of referees to progress to the highest level. Quantifying the physiological demands of the two highest levels of English Professional soccer will allow a better understanding of the required physical capacity for officiating in the highest league for trainers/selectors and referees seeking promotion to this level. Moreover, most previous research has utilized heart-rate based and/or motion activity profile tools to quantify a referee's physical load (Catterall *et al.*, 1993; Johnston & McNaughton, 1994; Krustrup & Bangsbo, 2001; Weston *et al.*, 2007). The recent advent of GPS monitoring systems has facilitated a more detailed insight into the physical demands of soccer match-play, including metrics such as the frequency and severity of accelerations/decelerations (Mallo *et al.*, 2009; Castillo *et al.*, 2017; Riiser *et al.*, 2017). These systems would allow a more comprehensive assessment of the physical demands of a soccer referee.

The majority of previous studies of the physical demands of soccer referees have only examined the physical loads of referees in isolated matches or a small number of matches. The use of one/several match/es to characterise a referee's physical load might not provide an accurate representation of their overall physiological demands due to the high match-to-match variability of the physiological responses to refereeing (Weston *et al.*, 2011a). Collecting and examining physiological data from a larger number of matches across a playing season would allow a more robust representation of the typical physical load of a soccer referee. Furthermore, the examination of factors such as the transition from pre to early-season, congested fixtures over the Christmas/New Year period, post-season playoff games and the final stages of a league competition may moderate internal match loading across a season. This could also provide important information for prescribing/periodising training programmes and monitoring physical capacity across a prolonged competitive period. Similarly, although there are clear differences in the physical demands of players and referees of matches at clearly distinct playing levels (e.g., top vs. bottom division/leagues), the understanding of any differences between teams of varying rankings within the same league are limited. Such differences might be apparent due to the increased high-intensity activity in higher-ranked teams relative to their lower-ranked counterparts (Bradley *et al.*, 2016) and that a referee's physical response to officiating is strongly linked to the players physical activity (Weston *et al.*, 2011b). Information on the modulating role of a team's ranking on the physical demands on a referee might have important implications for training/competition load and monitoring fatigue.

The aim of this study, therefore, was to, via the use of an integrated GPS and heart rate monitoring system, examine the physiological demands of varying levels of professional soccer referees (Premier League vs. Championship) across a full competitive soccer season as well as the effect of a team's ranking on these demands. It was hypothesised that there would be greater amounts of high-speed running in the Premier League compared to the Championship.

It was also hypothesised that matches between higher-ranked teams would yield a greater physiological response from those referees.

2.2. Methods

2.2.1. Participants

Twenty elite level officials (40.5 ± 6.4 years, 179 ± 5.5 cm, 25 ± 3.3 kg/m^2 BMI, 37 ± 8.6 mm sum of 7 skinfolds) were randomly selected as ten Premier League (45.5 ± 7 years, 180 ± 2.2 cm, 79 ± 3.6 kg) level referees and ten Championship level (35.6 ± 2.8 years, 178 ± 6.4 cm, 79 ± 7.2 kg) referees who were all Professional Game Match Officials Ltd (PGMOL) officials who officiated soccer matches of the 2017/2018 season. In total, the 20 participants officiated over 330 Premier League and Championship games during the season. There were in total 126 games analysed at the Premier League level and 105 at the Championship Level. Of the officials selected all 20 were contracted as full-time employees of PGMOL. The Premier League officials were entering their second full season as full time, whereas this was the first season for the 10 Championship officials. As these officials were all full-time employees, they were required to train twice per day, depending on their schedule of games. All officials were informed in writing and orally of the procedures and provided their verbal consent prior to the study. Participants had at least 8 years experience of refereeing in the Premier League and 2 years experience of refereeing in the Championship. This investigation was performed in accordance with the Declaration of Helsinki (2013) and was approved by the Liverpool John Moores Universities Ethics Committee.

2.2.2. Experimental Design

Participants match activities were monitored using microsensor units containing a 10 Hz global positioning system (GPS) and a 100 Hz triaxial accelerometer (Optimeye S5, Catapult Innovations™, Melbourne, Australia). Microsensor units were harnessed in a vest provided by the manufacturer. These were recommended to be worn as tight as comfortable. The GPS devices were activated 15 min prior to warm up, in line with the manufacturers recommendations to allow for signal acquisition with satellites. Data were downloaded post-match and were analysed using a custom software package

(Openfield, Version 1.1, Catapult Innovations™). All game data were checked for any ‘spikes’ that were caused by a loss of signal between the GPS unit and a satellite. The reliability and validity of these microsensor units has been reported elsewhere (Boyd *et al.*, 2011; Varley *et al.*, 2012). Heart rate was recorded continuously during the matches with a belt strap fitted around the chest (Polar, Kempele, Finland), with warm up and half-time data removed from the final analysis.

2.2.3. Data Analysis

Physical loading was quantified for each match via the following variables as described previously (Di Salvo *et al.*, 2011). The total time spent and total distance covered in the following movement activities were quantified:

Walking (< 7.1 km/h) (0-2.0 m/s)
Jogging (7.2–14.3 km/h) (2.03-4.0 m/s)
Running (14.4–19.7 km/h) (4.02-5.5 m/s)
High-speed running (19.8–25.1 km/h) (5.52-7.0 m/s)
Sprinting (> 25.1 km/h) (>7.0 m/s)

High-Intensity Running (HIR) was classified as any speed above 19.8 km/h. The number of accelerations and decelerations were recorded as the total amount of efforts performed per match and the total distance (m) covered during these accelerations and decelerations were also recorded. The magnitude of the accelerations and decelerations were quantified and grouped into the following bands:

0-1.0 m/s^2
1.0-1.5 m/s^2
1.5-2.0 m/s^2
2.0-2.5 m/s^2

Playerload was computed as a vector magnitude representing the sum of accelerations recorded in the anterior-posterior, mediolateral and vertical planes of movement measured by the units’ 100 Hz piezoelectric linear (Kionix:

KXP94).

$$Playerload^{\text{TM}} = \frac{\sqrt{(a_{y1} - a_{y-1})^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2}}{100}$$

Absolute and percentage of heart rate maximum (HR_{max}) for each game were recorded. The latter were calculated based on each officials true maximum HR that they had achieved on prior fitness testing. These tests were conducted by the PGMOL sports science staff during a YO-YO Intermittent Recovery 1 run test, the use of which as an assessment for physical performance in intermittent sports has been evaluated by Bansgbo, Iaia & Krustrup (2008). The maximum HR that was recorded was then monitored for any changes across the season and adjusted accordingly. HR responses were grouped into five intensity categories: (a) 50-60% of HR_{max}; (b) 61-70% of HR_{max}; (c) 71-80% of HR_{max}; (d) 81-90% of HR_{max}; (e) 91-100% of HR_{max} (Costa *et al.*, 2013).

The season was split into four equal quarters (1,2, 3, 4) and data were compared between the two levels of referees across the four quarters of the season. Within each referee level the effect of a team's ranking was examined in line with previous work (Castillo *et al.*, 2018) and as follows. Teams in both the Premier League and Championship were ranked according to their final league position of the 2017/2018 season. Matches that involved both teams finishing in the top seven or bottom seven positions of the Premier League/Championship were classed as Top or Bottom, respectively. Matches involving both teams finishing in-between the top and the bottom seven league positions were classed as Middle ranked matches. Data from the Top, Middle and Bottom matches were compared within and between each level of referee. Season quarter was not analysed for the Top, Middle and Bottom matches as this was not the *a priori* aim of this analyses.

All data analyses were conducted using statistical software (SPSS Inc., Chicago, USA). Descriptive statistics were calculated for each variable and data normality was assessed. A General linear mixed model factorial design (unstructured repeated covariance) was used to examine main effects of variables between level of official across the season (quarters 1, 2, 3, 4) and level of official across the ranks of matches (Top, Middle, and Bottom). The data variables were then analysed against each of the factors that had been predetermined. Level of officials, quarter of the season in which the games were played and the ranking of the specific games were compared against each other through the model. Data was manually examined before analysis took place for any errors which might have occurred. The exclusion factors were; HR data continually too high due to the belt not being worn or synced up to the GPS sufficiently, no HR trace due to no HR belt being worn or a flat battery, GPS battery dying due to issues with the charging ports and faulty GPS units where the data trace was too high or too low, Where differences were found Tukey's *post hoc* tests were used to determine localized effects. Where data were not normally distributed non-parametric equivalents were used, e.g., Kruskall Wallis tests. For univariate analyses unpaired T-Tests or the non-parametric equivalent were used. For maximum heart rate values, an independent T-Test was used to compare differences between the two referee levels. Statistical significance was accepted at $P < 0.05$.

2.3. Results

2.3.1. Effects of Competition Level and Season Quarter

2.3.1.1. Time Spent in HR Zones

The breakdown of the amount of time spent in each of the HR zones is displayed in Table 1 below. There was no significant difference for the level of official for the time spent in 30-60% of HR max ($F = 2.76$, $P=0.09$) and no difference across the season quarters ($F = 0.49$, $P=0.69$). There was, however, a significant league*quarter interaction ($F = 2.67$, $P<0.05$) with the Premier League officials spending less time in this HR zone during the 2nd quarter of the season, whereas the Championship officials spent longer in this HR zone during the 2nd quarter of the season.

There were no differences for time spent at 60-75% of HR max between level of official ($F = 0.42$, $P=0.52$), across the quarters of the season ($F = 0.80$, $P=0.49$), nor was there a league*quarter interaction ($F = 1.36$, $P=0.26$). For time spent at 75-85% of HR max there were no difference for level of official ($F = 0.29$, $P=0.59$), quarter of the season ($F = 0.27$, $P=0.85$), nor was there a league*quarter interaction ($F = 1.83$, $P=0.14$). There was a significant difference in time spent at 85-90% of HR max for level of official ($F = 4.02$, $P<0.05$) with the Championship officials spending longer in this HR zone than the Premier League officials. There was no difference across the quarters of the season ($F = 1.70$, $P=0.17$), nor was there a league*quarter interaction ($F = 0.85$, $P=0.47$).

For time spent at 90-95% of HR max there was a significant difference for level of official ($F = 7.20$, $P<0.01$) with the Championship officials spending longer in this zone. There were no difference across the quarters of the season ($F = 1.26$, $P=0.29$) nor was there a league*quarter interaction ($F = 0.54$, $P=0.66$). For time spent at 95-100% of HR max there was a significant difference for level of official ($F = 7.66$, $P<0.01$) with the Championship officials spending longer in this zone. There were no difference across the quarters of the season ($F = 0.16$, $P=0.92$) nor was there a league*quarter interaction ($F = 1.22$, $P=0.30$).

Table 2. Total amount of time (min) spent at 30-60, 60-75, 75-85, 90-95 and 95-100% of maximum heart rate across a full season for Premier League and Championship officials. *P<0.05, Prem vs. Champ.

		Season Quarter				ANOVA results		
% HR Max	League	1	2	3	4	Level	Quarter	Level*Quarter
30 - 60	Prem	2.6 ± 1.1	1.8 ± 0.7	2.8 ± 0.7	2.9 ± 1.0	0.10	0.69	0.05
	Champ	3.3 ± 0.8	5.4 ± 0.8	3.0 ± 0.7	2.4 ± 0.6			
60 - 75	Prem	41.7 ± 6.3	45.3 ± 4.1	49.7 ± 4.1	43.7 ± 5.6	0.52	0.49	0.26
	Champ	44.1 ± 4.7	50.3 ± 4.5	39.2 ± 3.9	38.3 ± 3.7			
75 - 85	Prem	43.9 ± 4.9	44.9 ± 3.2	38.0 ± 3.2	40.6 ± 4.4	0.59	0.85	0.14
	Champ	41.2 ± 3.7	34.9 ± 3.5	42.1 ± 3.0	43.5 ± 2.9			
85 - 90	Prem	6.8 ± 2.7*	3.7 ± 1.7*	3.5 ± 1.7*	7.3 ± 2.4*	0.05	0.17	0.47
	Champ	7.4 ± 2.0	5.3 ± 1.9	9.7 ± 1.6	10.3 ± 1.6			
90 - 95	Prem	0.9 ± 0.8*	0.2 ± 0.5*	0.4 ± 0.5*	1.5 ± 0.7*	0.01	0.29	0.66
	Champ	1.7 ± 0.6	1.2 ± 0.5	2.3 ± 0.5	2.1 ± 0.4			
95 - 100	Prem	0.2 ± 0.1*	0.0 ± 0.1*	0.0 ± 0.1*	0.1 ± 0.1*	0.01	0.92	0.30
	Champ	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0.2 ± 0.1			

2.3.1.3. External Match Demands

The total distance covered by the Premiership and Championship referees across the season is displayed below in Figure 2. There was a tendency towards significance in distance covered across the season (F = 2.13, P=0.096) with a slightly lower distance covered in quarter 4 vs. quarter 3. There was no difference between level of referee (F = 2.19, P=0.14) nor was there a league*quarter interaction (F = 1.19, P=0.34).

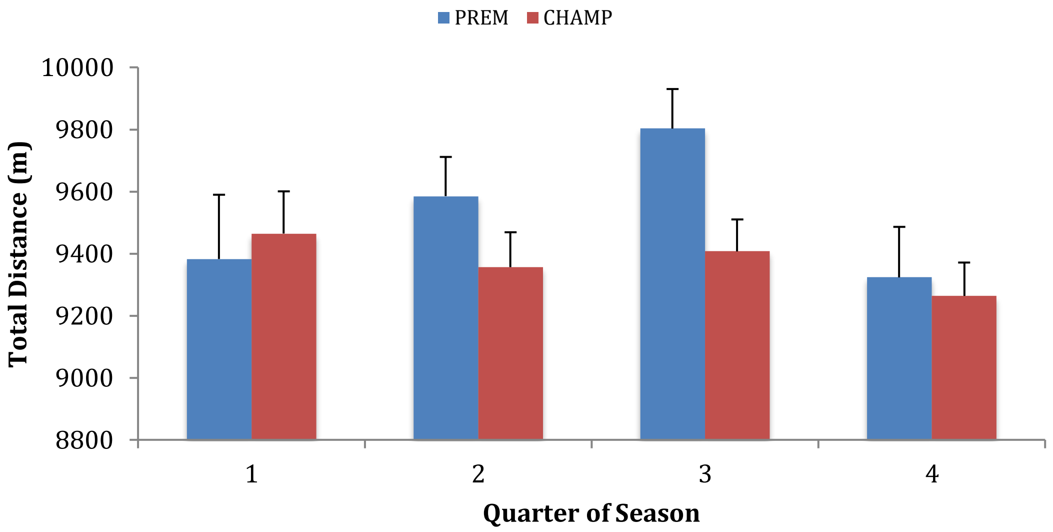

Figure 1. Total distance covered by Premier League and Championship officials during a full season.

The breakdown of distances covered by officials at Walking and Jogging speeds across the quarters of the season are presented below in Figure 6. There was a significant change in distance covered at walking pace (<7.1 km/h) across the season (F = 14.91, P<0.01) with a higher walking distance covered in quarters 3 and 4 vs. quarters 1 and 2. There was also a significant difference between the level of official (F = 20.52, P<0.01) with Premier League officials covering significantly more distance at a walking pace than the Championship officials. There was no quarter*league interaction for walking distance (F = 1.19, P=0.34).

At Jogging pace (7.2-14.3 km/h) there was a significant difference between the level of official (F = 7.07, P<0.01) with the Championship officials covering more distance at this pace than the Premier League officials. There was also a significant change across the season (F = 26.66, P<0.01) with less distance covered via jogging in the 3rd and 4th quarters of the season. There was no quarter*league interaction (F = 1.19, P=0.34).

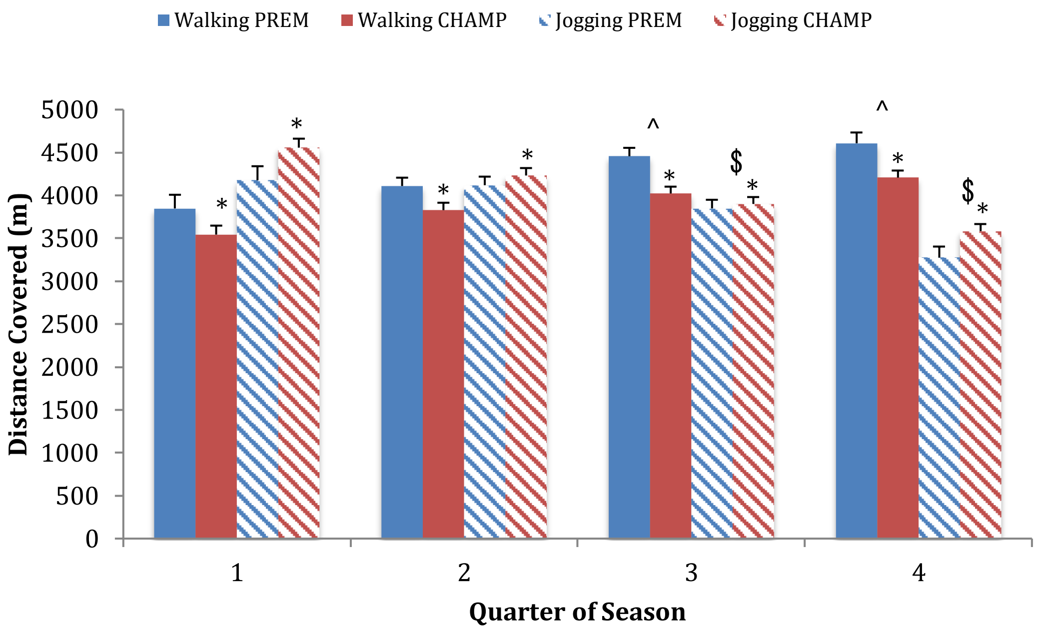

Figure 2. Walking and Jogging distances covered in each quarter of the season for Premiership and Championship Officials. *P<0.01 PREM vs. CHAMP. ^P<0.01 vs. Quarter 1 and 2. $P<0.01 vs. Quarter 1 and 2.

The breakdown of distances covered by officials at Running, High Speed Running (HSR) and Sprinting speeds across quarters of the season are presented below in Figure 7. There was a significant change in the distance covered at running pace (14.4-19.7 km/h) across the season (F = 14.35, P<0.01) with a higher distance covered in quarters 3 and 4 vs. quarters 1 and 2. There was no significant difference for level of official (F= 0.28, P=0.61). There was no significant quarter*league interaction (F = 0.24, P=0.87). There was a significant change in distance covered at HSR pace (19.8-25.1 km/h) across the season (F = 2.60, P=0.05) with less distance covered at this speed in quarter 4 vs. quarter 3. There was no significant difference for the level of official (F = 0.16, P=0.69) nor was there a significant quarter*league interaction (F = 0.95, P=0.42). At sprinting speed (25.1+ km/h) there was a significant change across the season (F = 23.58, P<0.01) with significantly less distance covered in quarters 3 and 4 vs. quarter 1. There was no difference for the level of official (F = 0.02, P=0.90). There was no significant quarter*league interaction (F = 1.14, P=0.33).

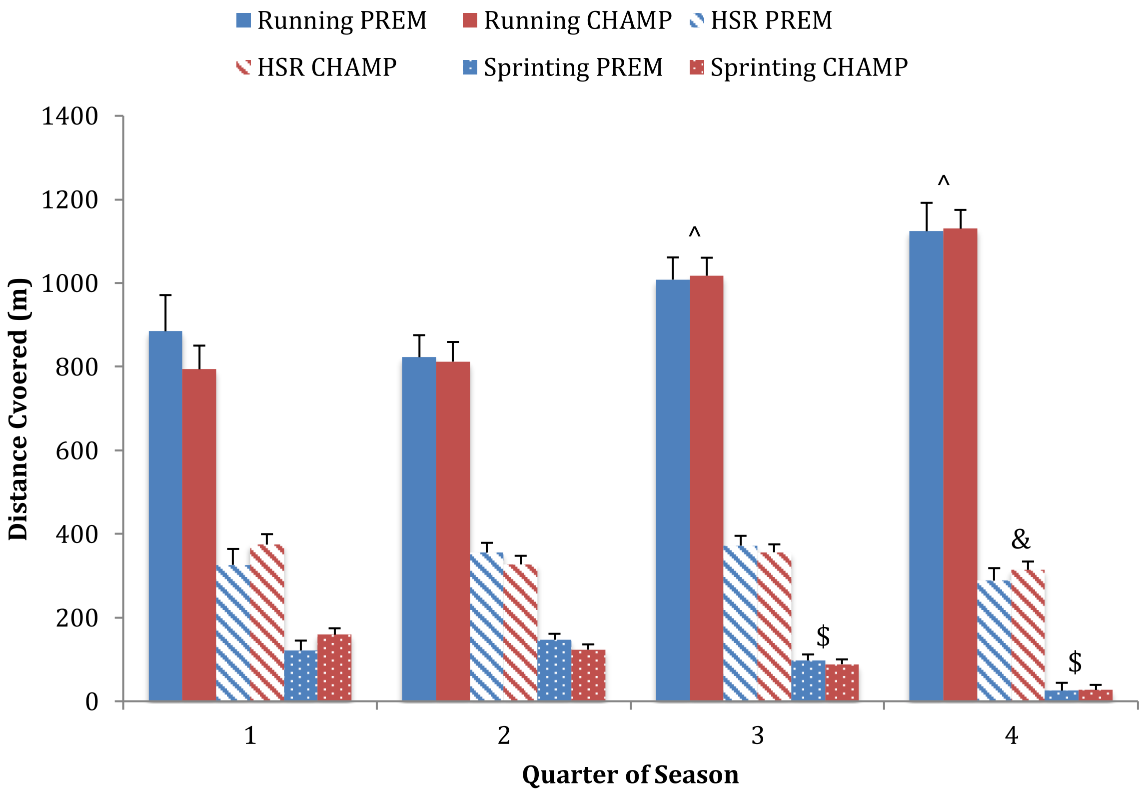

Figure 3. Showing the amount of distance Running, HSR and Sprinting distances covered in each quarter of the season for Premier League and Championship officials. ^P<0.01 vs. Quarter 1 and 2. &P<0.05 vs. Quarter 3. $P<0.01 vs. quarter 1.

2.3.1.4. Player Loading

There was no difference in Playerload between level of official (F = 0.35, P=0.55), across the quarters of the season (F = 1.28, P=0.28) nor was there a league*quarter interaction (F = 0.42, P=0.74).

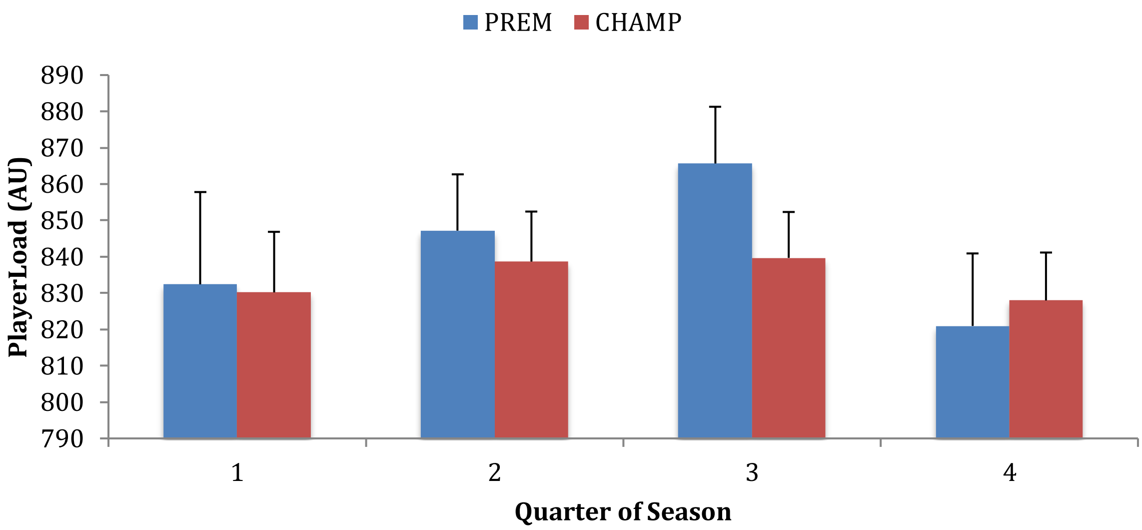

Figure 4. Playerload for Premier League and Championship officials during each quarter of the season.

2.3.2. Effects of Match Ranking

2.3.2.1. External Match Demands

There was no significant difference between ranks for total distance covered (F = 1.13, P=0.32). There was a league*rank interaction effect (F = 6.22, P<0.01), Premier League officials covered more total distance during the top ranked games, whereas the Championship officials total distance was not different across the three rankings.

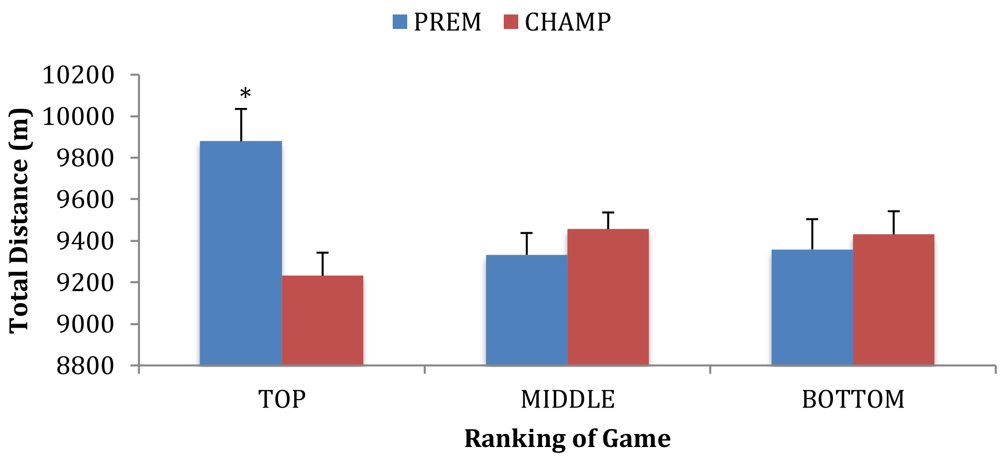

Figure 5. Total distance for Premier League and Championship officials during a full season for top, Middle and Bottom ranked games. *P=0.002 League*Rank interaction.

The breakdown of distances covered by officials at Walking and Jogging speeds during the three ranks of games are presented below in Figure 9. There was a tendency towards significance in distance covered at walking pace (F = 2.41, P=0.092) with slightly more distance being covered in the top ranked games versus middle and bottom ranked games. There was also a significant league*rank interaction effect (F = 2.90, P<0.05) with the Premier League officials covering more distance in the TOP ranked matches, whereas, the Championship officials covered similar distances across the 3 ranks of games. At jogging pace there was no difference between the ranking of games (F = 0.05, P=0.95). There was a slight League*Rank interaction effect (F = 2.38, P=0.095) with Premier League officials covering more distance in the TOP ranked games, whereas Championship officials covered a similar distance Jogging across the ranking of games.

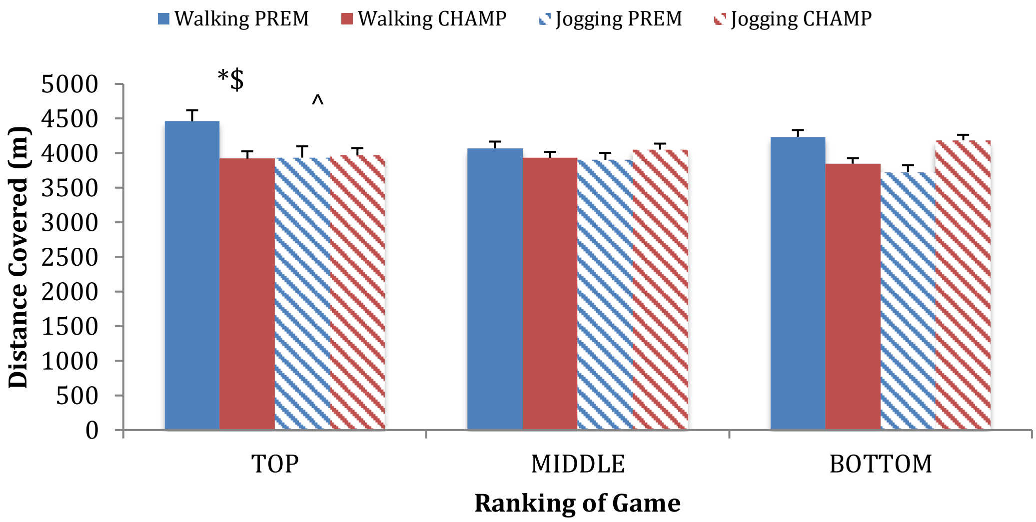

Figure 6. Distance covered at Walking and Jogging speeds for Premier League and Championship officials during a full season for different ranks of games. *P=0.092 for Walking Top vs Middle and Bottom ranks; $P=0.057 LEAGUE*RANK INTERACTION at Walking pace; ^P=0.095 LEAGUE*RANK INTERACTION at Jogging pace**.**

The breakdown of distances covered by officials at Running, HSR and Sprinting speeds during the three ranked games are presented below in Figure 10. There was no significant difference between ranks of games (F = 0.08, P=0.92) nor was there a league*rank interaction effect (F = 1.84, P=0.16) for Running distance. There was no difference for HSR distance covered between ranks of games (F = 0.47, P=0.63) nor was there a league*rank interaction effect (F = 0.97, P=0.38). There was no difference in distance covered at sprinting speed between ranks of games (F = 0.08, P=0.92) whereas there was a significant league*rank interaction effect (F = 3.15, P<0.05) with the Premier League officials covering more distance at this speed during the TOP ranked games and the Championship officials covering similar distances across the ranks of games.

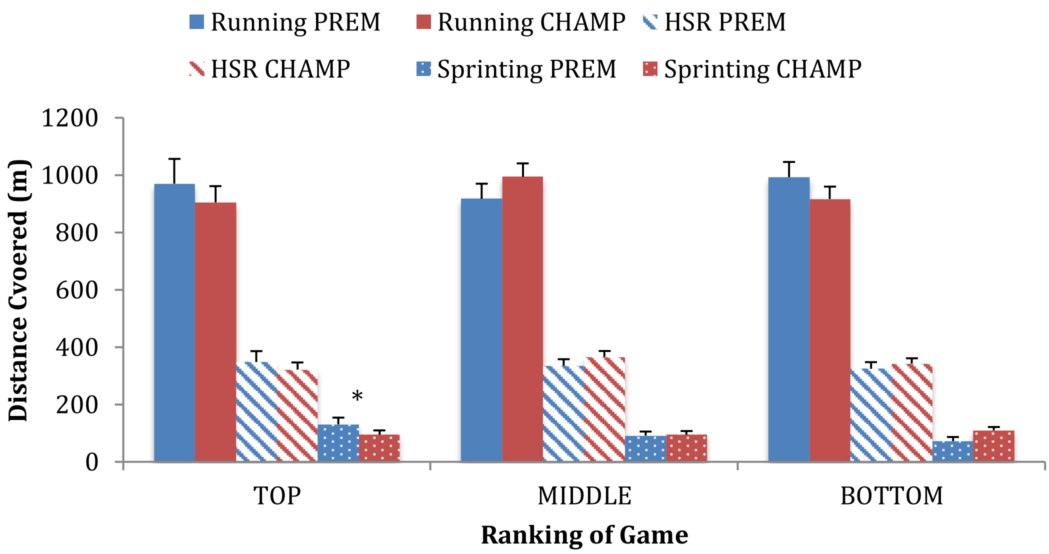

Figure 7. Distance covered at Running, HSR and Sprinting speeds for Premier League and Championship officials during a full season for different ranks of games. *P=0.044 LEAGUE*RANK INTERACTION for Sprinting.

2.3.2.2. Time Spent in HR Zones

The breakdown of amount of time spent in each of the HR zones between the three ranks of games are presented in Figures 13-15 below. There was no difference between the ranks of games at 30-60% of HR max (F = 0.20, P=0.82) nor was there was a league*rank interaction (F = 1.20, P=0.30).

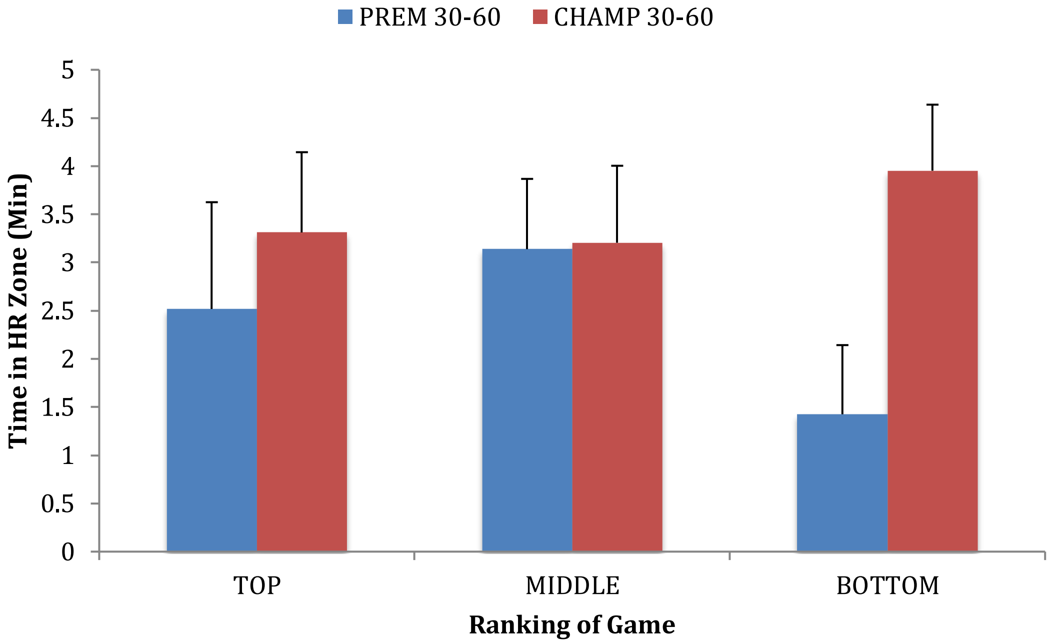

Figure 8. The amount of time spent at 30-60% of HR max for Premier League and Championship officials in Top, Middle and Bottom ranked games.

There was no difference for time spent at 60-75% of HR max between the three ranks of games (F = 2.19, P=0.12). There was however, a tendency towards a significant league*rank interaction effect (F = 2.72, P=0.069) with Premier League officials spending less time in this HR zone during the TOP ranked games whereas there was no difference between ranks for Championship officials. For time spent at 75-85% of HR max there were no difference between ranks of games (F = 0.95, P=0.39), nor was there a league*rank interaction (F = 1.26, P=0.29).

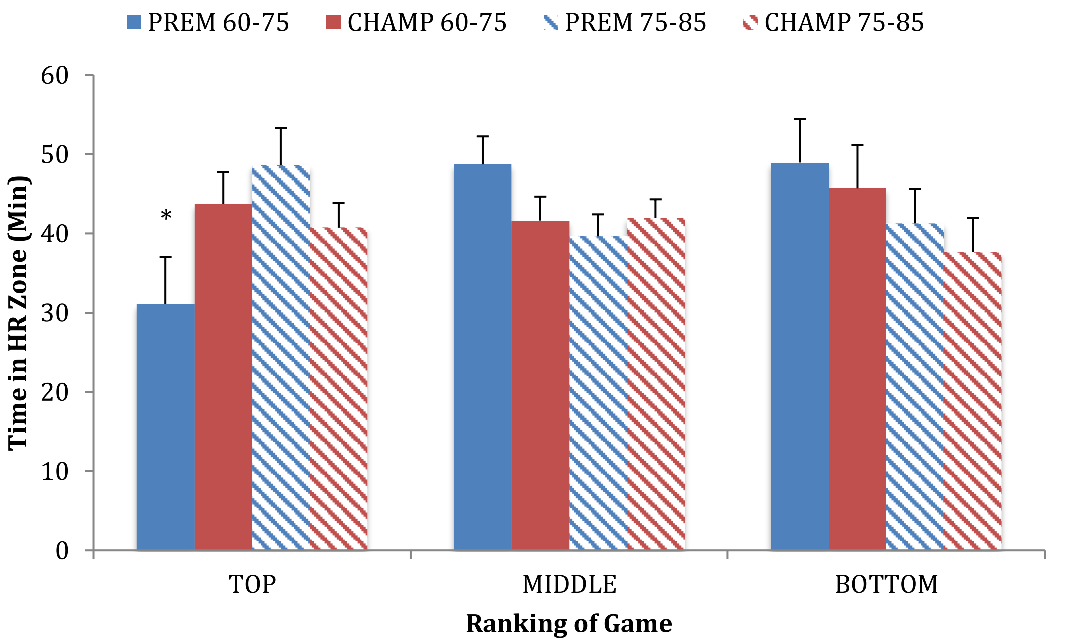

Figure 9. Time spent at 60-75% and 75-85% of HR max for Premier League and Championship officials in Top, Middle and Bottom ranked games. *P=0.069 LEAGUE*RANK INTERACTION for 60-75% HR max.

There was no significant difference for time spent at 85-90% of HR max between the three rankings of games (F = 2.20, P=0.11). There was however, a tendency towards significance league*rank interaction effect (F = 2.95, P=0.055) with Premier League officials spending longer in this HR zone during the TOP ranked games whereas Championship officials spent similar amounts of time in this HR zone across the three rankings. For time spent at 90-95% of HR max there were no difference between ranks of games (F = 0.63, P=0.54), nor was there a league*rank interaction (F = 1.32, P=0.27). At 95-100% of HR max there were no difference for time spent in this HR zone between the ranks of games (F = 0.37, P=0.69), nor was there a league*rank interaction (F = 0.13, P=0.99).

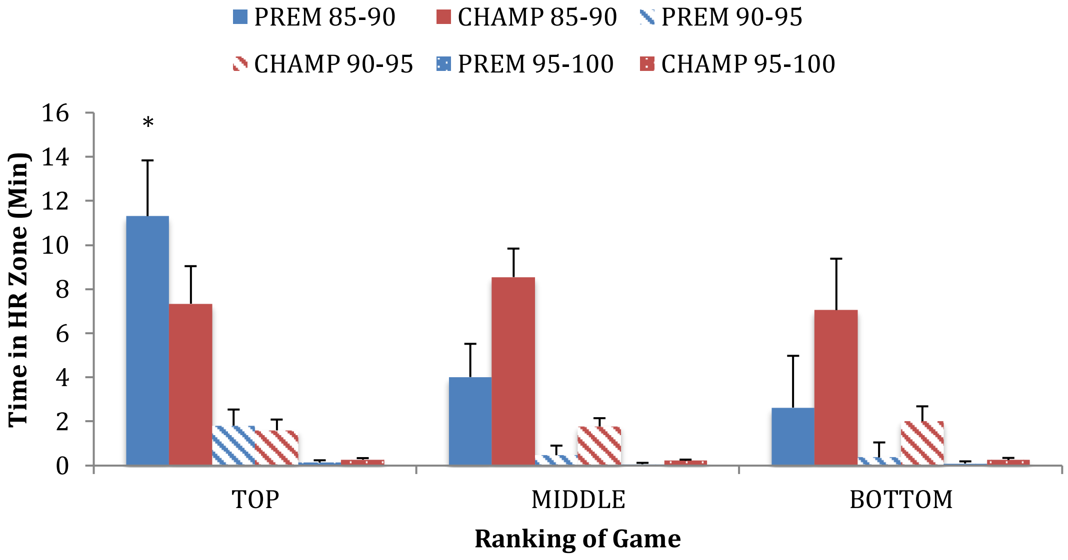

Figure 10. Time spent at 85-90%, 90-95% and 95-100% of HR max for Premier League and Championship officials in Top, Middle and Bottom ranked games. *P=0.055 LEAGUE*RANK INTERACTION for 85% HR max.

2.3.2.3. Player Loading

There was no significant difference in Playerload across the 3 ranks of games (F = 1.40, P=0.25). There was a significant league*rank interaction effect (F = 6.66, P<0.01) with the Premier League officials having a higher Playerload in the highest ranked games, whereas the Championship officials highest Playerload was during the lowest ranked games (Figure 16).

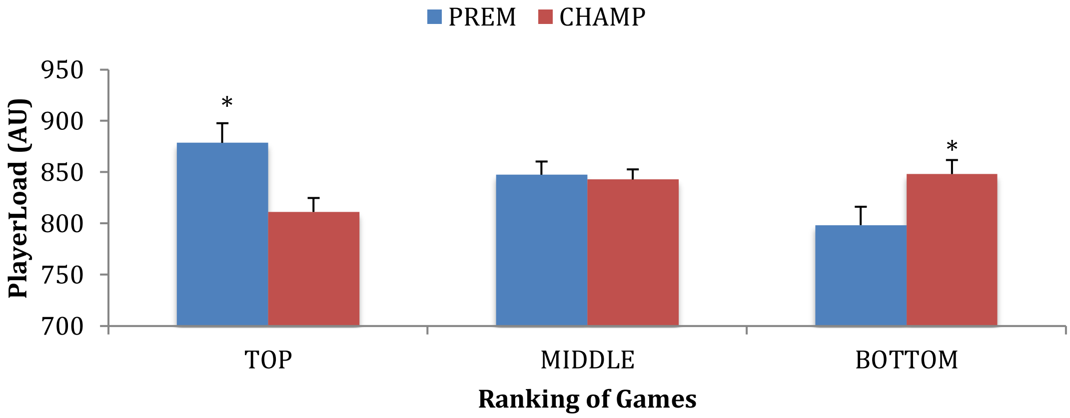

Figure 11. Playerload for Premier League and Championship officials for the different ranked games. *P=0.001 LEAGUE*RANK Interaction.

2.3.3. Accelerations and Decelerations during Quarters of the Season

2.3.3.1 Accelerations

2 to 2.5 m/s^2

There was a significant main effect of level (F = 25.67, P<0.01) for the total amount of accelerations between 2 and 2.5 m/s^2. Championship officials accelerated more times in this banding than the Premier League officials. There was no effect of season quarter on accelerations in this banding (F = 0.78, P=0.50) and no level*season quarter interaction (F = 0.24, P=0.87).

1.5 to 2 m/s^2

There was a significant main effect of level (F = 25.36, P<0.01) for the total amount of decelerations between 1.5 and 2 m/s^2. Championship officials accelerated more times in this banding than the Premier League officials. There was no difference between the quarters of the season (F = 1.38, P=0.25). There was also a significant interaction effect between level and quarter of the season (F = 2.92, P<0.05) for total amount of accelerations between 1.5 and 2 m/s. Premier League officials accelerated the most times in this banding in the 2nd quarter of the season, with the lowest being in the 4th quarter. The

Championship officials accelerated more times in this banding during the 1st quarter of the season.

1 to 1.5 m/s^2

There was a significant main effect of level (F = 10.54, P<0.01) for the total amount of accelerations between 1 and 1.5 m/s^2. Championship officials accelerated more times in this banding than the Premier League officials. There was also a significant main effect for quarter of the season (F = 3.30, P<0.05) with both sets of officials accelerating more times in this banding in the first quarter of the season than the other three quarters. There was no league*quarter interaction effect (F = 0.05, P=0.99).

0 to 1 m/s^2

There were no differences for amount of accelerations between 0 – 1 m/s^2 for level of official (F = 0.48, P=0.50), quarter of the season (F = 0.38, P=0.77) or a league*quarter interaction (F = 0.27, P=0.85).

Table 3. Total number of accelerations and decelerations across a full season for Premier League and Championship officials. *Main effect of Level, ^Main effect of Quarter, *Main effect of Level, $Level*Quarter interaction.

Accelerations	Season Quarter				ANOVA results		
League (m/s²)	1	2	3	4	Level	Quarter	Level*Quarter
Prem (0-1)	1142 ± 25	1169 ± 16	1150 ± 15	1159 ± 23	0.50	0.77	0.85
Champ (0-1)	1152 ± 17	1146 ± 14	1137 ± 13	1151 ± 13			
Prem (1-1.5)	52 ± 4*^	44 ± 3*	42 ± 3*	46 ± 4*	<0.01	<0.05	0.99
Champ (1-1.5)	59 ± 3^	50 ± 2	50 ± 2	53 ± 2			
Prem (1.5-2)	11 ± 2*	12 ± 1*	11 ± 1*	10 ± 2*	<0.01	0.25	<0.05
Champ (1.5-2)	19 ± 1$	14 ± 1	14 ± 1	15 ± 1			
Prem (2-2.5)	2 ± 1*	2 ± 0*	2 ± 0*	2 ± 1*	<0.01	0.50	0.87
Champ (2-2.5)	3 ± 0	3 ± 0	4 ± 0	3 ± 0			
Decelerations							
Prem (0-1)	1192 ± 23*	1183 ± 15*	1162 ± 14*	1177 ± 21*	<0.05	0.57	0.86
Champ (0-1)	1214 ± 15	1197 ± 13	1198 ± 12	1206 ± 12			
Prem (1-1.5)	36 ± 3*^	28 ± 2*	26 ± 2*	29 ± 2*	<0.05	<0.01	0.80
Champ (1-1.5)	38 ± 2^	30 ± 1	30 ± 1	34 ± 1			
Prem (1.5-2)	5 ± 1*	6 ± 1*	6 ± 1*	6 ± 1*	<0.01	0.57	0.81
Champ (1.5-2)	7 ± 1	7 ± 1	8 ± 1	8 ± 1			
Prem (2-2.5)	1 ± 0	1 ± 0	1 ± 0	1 ± 0	0.20	0.66	0.82
Champ (2-2.5)	2 ± 0	1 ± 0	1 ± 0	1 ± 0			

2.3.3.2 Decelerations

2 – 2.5 m/s^2

There were no differences found for amount of decelerations between 2 – 2.5 m/s^2 for level of official (F = 1.66, P=0.20), quarter of the season (F = 0.53, P=0.66) or a league*quarter interaction (F = 0.31, P=0.82).

1.5 - 2 m/s^2

There was a significant main effect of level (F = 7.86, P<0.01) for the amount of decelerations between 1.5 and 2 m/s^2. Championship officials decelerated more times in this banding than the Premier League officials. There was no difference across the season (F = 0.67, P=0.57) nor was there a league*quarter interaction effect (F = 0.32, P=0.81).

1 – 1.5 m/s^2

There was a significant main effect of level (F = 6.00, P<0.05) for the total amount of decelerations between 1 and 1.5 m/s^2. Championship officials decelerated more times in this banding than the Premier League officials. There was a significant main effect for quarter of the season (F = 8.33, P<0.01); both sets of officials decelerated more times in this banding in the first quarter of the season than the other three quarters. There was no league*quarter interaction effect (F = 0.34, P=0.80).

1 - 0 m/s^2

There was a significant main effect of level (F = 4.97, P<0.05) for the total amount of decelerations between 0 and 1 m/s^2. Championship officials decelerated more times in this banding than the Premier League officials. There was no difference between the quarters of the season (F = 0.68, P=0.57) nor was there a league*quarter interaction effect (F = 0.25, P=0.86).

2.3.4. Accelerations and Decelerations during Ranked Matches

2.3.4.1. Accelerations

2 – 2.5 m/s^2

There were no differences found for ranking of games (F = 0.38, P=0.69) or a league*rank interaction (F = 0.90, P=0.41).

1.5 – 2 m/s^2

There was no difference for ranking of games (F = 2.21, P=0.11). There was a significant interaction effect between level and ranking of games (F = 4.66, P=0.01) for total amount of accelerations between 1.5 and 2 m/s^2. Premier League officials accelerated less times in this banding in the TOP ranked games, whereas the Championship officials accelerated more times in this banding during the TOP ranked games.

1 – 1.5 m/s^2

There was no difference for ranking of games (F = 1.79, P=0.17). There was a significant interaction effect between level and ranking of games (F = 3.04, P<0.05) for total amount of accelerations between 1 and 1.5 m/s^2. Premier League officials decelerated less times in this banding in the TOP ranked games, whereas the Championship officials accelerated more times in this banding during the TOP ranked games.

0 – 1 m/s^2

There were no differences for ranking of games (F = 0.16, P=0.85) or a league*rank interaction (F = 1.23, P=0.28).

Table 4. Total number of accelerations and decelerations during different ranked matches for Premier League and Championship officials. ^Main effect of Rank, $Level*Rank interaction.

	Match Ranking				
League (m/s²)	TOP	MIDDLE	BOTTOM	ANOVA results	
Accelerations				Rank	Level*Rank
Prem (0-1)	1138 ± 20$	1162 ± 13	1166 ± 19	0.85	0.28
Champ (0-1)	1158 ± 14	1135 ± 10	1146 ± 12		
Prem (1-1.5)	39 ± 4$	50 ± 2	50 ± 3	0.17	<0.05
Champ (1-1.5)	54 ± 2	54 ± 2	52 ± 2		
Prem (1.5-2)	8 ± 1$	12 ± 1	13 ± 1	0.11	0.01
Champ (1.5-2)	16 ± 1	16 ± 1	14 ± 1		
Prem (2-2.5)	2 ± 1	2 ± 0	2 ± 0	0.69	0.41
Champ (2-2.5)	3 ± 0	4 ± 0	3 ± 0		
Decelerations					
Prem (0-1)	1149 ± 19	1189 ± 12	1198 ± 17$	0.48	0.07
Champ (0-1)	1214 ± 13$	1196 ± 9	1201 ± 11		
Prem (1-1.5)	26 ± 2	32 ± 1$	30 ± 2	0.43	<0.01
Champ (1-1.5)	36 ± 2$	32 ± 1	31 ± 1		
Prem (1.5-2)	6 ± 1	6 ± 1	6 ± 1	0.69	0.85
Champ (1.5-2)	7 ± 1	7 ± 0	7 ± 1		
Prem (2-2.5)	1 ± 0	2 ± 0^	1 ± 0	<0.01	0.44
Champ (2-2.5)	1 ± 0	2 ± 0^	1 ± 0		

2.3.4.2. Decelerations

2 to 2.5 m/s^2

There was a significant main effect of the ranking of games (F = 6.15, P<0.01) on the amount of decelerations between 2 and 2.5 m/s^2. Both sets of officials decelerated more times in this banding during the middle ranked games compared to the other two ranks. There was also a significant interaction between level and ranking of games (F = 2.30, P<0.05); officials decelerated more in this banding during the MIDDLE ranked matches.

2 to 1.5 m/s^2

There were no differences for total amount of decelerations between 1.5 – 2 m/s^2 for ranking of games (F = 0.37, P=0.69) or a league*rank interaction (F = 0.16, P=0.85).

1.5 to 1 m/s^2

There was no difference for total amount of decelerations between 1 and 1.5 m/s^2 for ranking of game (F = 0.84, P=0.43). There was however an interaction effect between level and ranking of games (F = 5.00, P<0.01) for total amount of decelerations between 1 and 1.5 m/s^2. Premier League officials decelerated more times in this banding in the MIDDLE ranked games, whereas the Championship officials decelerated more times in this banding during the TOP ranked games.

1 to 0 m/s^2

There was no difference for ranking of games (F = 0.73, P=0.48).There was however a tendence towards significance of an interaction effect between level and ranking of games (F = 2.66, P=0.072) for total amount of decelerations between 0 and 1 m/s^2. Premier League officials decelerated less times in this banding in the bottom ranked games, whereas the Championship officials decelerated more times in this banding during the top ranked games.

2.4. Discussion

The aim of this study was to examine the physiological demands of varying levels of professional soccer placed on referees across a full competitive soccer season. Secondly, we considered the effect of a team's ranking on these demands. The physiological demands of 20 professional soccer referees of two distinct levels (Premier League vs. Championship) were recorded across a competitive soccer season via the use of an integrated GPS and heart rate monitoring system. The effect of 'ranking' or level of game within a league was also examined using teams' final league positions. The main findings were that Premier League matches induced a higher absolute HR response compared to Championship matches. However, despite a lower absolute HR, Championship officials spent more time between 85-100% of their maximum HR. In addition, Championship referees performed more accelerations and decelerations and jogged more compared to their Premier League counterparts, which resulted in less walking. There were no differences in the amount of high-intensity activities between the league officiated in. Across the playing season, HR, walking and running were higher in the last quarter of the season whereas total distance covered, jogging and sprinting were lowest in quarter 4. There were also more accelerations and decelerations in the first quarter of the season. With regards to the effect of a team's ranking on physical demands the top ranked Premier League games caused officials to cover more total distance with more walking, jogging and sprinting, whereas the bottom ranked games caused Championship officials to cover more distance jogging. These findings provide a range of important information for referees and their coaches/trainers at the highest levels for the optimal preparation for competitive officiating across the Premiership and Championship leagues.

When comparing referee activity in the Premier League to Championship, we found that more distance is covered at walking pace in the Premier League compared to the Championship, but the Championship officials cover more distance jogging. Similarly, Championship officials had more total accelerations and decelerations at 0-2 m/s^2. An explanation for these data could be due to the higher competence, training and knowledge of the Premier League referees in choosing their positioning to observe match play. It has been shown that more experienced officials are more economical with their movements (Weston *et al.*, 2010), therefore, the Premier League officials will cover less ground as well as alter their running pattern less times than that of their Championship counterparts trying to find a good vantage point to observe play, as they already have the knowledge of where the best positioning could be during different phases of play. Despite previous research reporting higher levels of play/refereeing resulting in greater total distance (Catterall *et al.*, 1993; Mallo *et al.*, 2007) the present study did not find similar data. This difference could be due to the relatively small difference in referee technical ability between the Premiership and Championship compared to these previous studies.

The available literature suggests that officials usually attain mean HRs between 85-90% of their estimated/actual HR max (Catterall *et al.*, 1993; D'Ottavio & Castagna, 2001b; Krustrup & Bangsbo, 2001; Helsen & Bultynck, 2004). This is the first study to compare HR of officials in Premier League and Championship matches. It was found that the heart rate responses to elite soccer match play are higher in the Premier League compared to the Championship, which is inconsistent with previous studies that have reported lower HR for higher playing levels (Catterall *et al.*, 1993; Helsen & Bultynck, 2004). This difference in findings could be due to variance in playing levels and methodologies between studies. The higher HR in the Premier League games was not accompanied by an elevated high-intensity activity in the Premier League referees. This disconnect could be explained by the lack of a direct and 1:1 relationship between assessments of internal and external physical loading (Castillo *et al.*, 2017). Moreover, given the wide variation in age and fitness between individuals the examination of HR responses as a function of an individual’s maximal HR is important. The average age in the Premier League for this study was 43 years 8 months, ranging from 31-52 years. The Premier League officials had a higher average age, therefore likely a lower max HR. We found a tendency towards a significant difference ($P = 0.092$) for max HR, with officials in the Premier league only have a maximum HR of on average 181 bpm whereas the Championship was 186 bpm, indicating that the internal strain of refereeing is higher in the Premier League given the higher HR coupled with a lower maximum HR in the Premier League. Whether Premier League referees perform more high-intensity actions over shorter distances that would elevate HR in this group is unclear and/or if other external factors contribute to a higher HR require further consideration.

Although the Championship officials had a lower average HR, they spent more time in the higher heart rate zones of 85-100% HR_{max}. The increased amount of time spent in the higher HR zones could be caused by the inexperience of the official, in order to observe the more critical moments of the game; the positioning of the official is crucial. Lower levels of experience of the officials in the Championship could account for the extra movements and subsequent increased physiological loading experienced. Another reason for this increase in time spent in higher HR_{max} zones could be due to the significantly more acceleration and deceleration actions the officials in the Championship complete (Osgnach *et al.*, 2010). With regards to the acceleration and deceleration data collected; most accelerations and decelerations during match play occurred between 0-1 m/s^2. These data likely reflect that of the many physical actions a referee has to complete; the majority of them are at a lower intensity but several higher magnitude accelerations are required in line with the short bouts of high-intensity running often required to get into key viewing positions quickly.

In order to further investigate the potential variation throughout the competitive season on the physical demands on officials, we split the season up into quarters. The physical activities of soccer officials have already been shown to vary across several matches over an 8-week period, including, high-speed running distance, total number of sprints and the number of match fouls (Weston *et al.*, 2011a). The effects of a prolonged competitive season on the physical demands of referees are not clear, however. In professional Danish players, total distance and high-intensity running distance were higher at the end of the season than at the start and middle of the season (1–3 observations within each period) with no difference in sprinting distance across the season

(Mohr *et al.*, 2003). In the present study, more accelerations and decelerations occurred in the first quarter of the season, which might be a result of the referees adjusting to officiating at the start of the season after the rest period between seasons. In addition, both Premier League and Championship officials covered less total distance during the last quarter of the season and decreased the amount of jogging and high speed running and sprinting in the last quarter of the season. In contrast, greater distance was covered walking and running in the last quarter of the season. The potential reasons for this reduction in total distance and shift of intensity from higher to lower-moderate at the end of the season are varied. The officials could have experienced a decline in physiological fitness towards the end of the season, however, with no longitudinal physiological fitness test data this is hard to determine. Similarly, the accumulation of fatigue in the officials over the course of the season could be responsible given that an official is expected to complete the same amount of games as players (sometimes more), including domestic and European competitions, over the course of a nine-month period that could mean that the official changes their physical approach to officiating to offset any chronic fatigue. Given the influence of the players physical outputs on the referee's physical demands the tactical and style of match play should be considered. At the end of the season, teams may employ different game styles and tactics, which likely would illicit different physical responses in the referee and could contribute to less physical demand compared to the three previous quarters especially if there is less competition for league positions at the end of the season. Finally, as a season progresses, a referee's technical expertise should likely improve which, as alluded to above, would improve the physical economy of moving around the pitch and thus reduce physical demand. Despite these changes in external physical loads in the last quarter of the season the present study also showed that Premier League officials had the highest average HR in the final quarter of the season. As alluded to above, the reason for these divergent changes in internal and external physical loads is not clear but may relate to several factors that can influence HR outside of exercise intensity.

The examination of top, middle and bottom ranked matches would allow for inferences to be made as to how the physiological activities undertaken by the official can change when opponents of a higher league standing face each other compared to teams of a lesser standing. Previous research has demonstrated that playing level or rank of teams is positively correlated with the high-intensity distance covered during matches (Castagna *et al.*, 2007; Weston *et al.*, 2010), thus, it is not surprising to suggest that referees may have to cover increased total distance and/or high-intensity running distance in games involving superior teams. This study found that the top ranked games in the Premier League caused increases in total distance covered, running distance and total sprinting distance when compared to middle or bottom ranked games. Using a similar methodological approach Castillo *et al*., (2018) reported that in matches involving top ten Spanish Premiere Liga teams referees covered more distance at a low walking speed but performed a higher percentage of high-intensity accelerations and decelerations than in matches involving the lowest 10 teams (Castillo *et al.*, 2018). These findings are in contrast to the current study's results, likely as a result of differences in methodologies and or playing styles between English and Spanish leagues. In agreement with the present study's findings, Castillo et al., (2018) showed that no differences in internal loading (HR, RPE) between different ranks of games. Disparity between internal and external match loading data between different ranks of teams in the present study could be attributed to the many factors that can influence HR independent of external physical loading (Castillo *et al.*, 2017).

2.5. Limitations

As with any study there are limitations, which will be considered in this section. The modern telemetry systems that were used within this study are able to accurately quantify distance covered at different speeds. However, we were unable to accurately gain the satellite coverage and determine as to what the level of coverage for each game was. The number of satellites and horizontal dilution of position (HDOP) were not collected for this study. Additionally, in some countries soccer officials at the highest of levels are employed on a full time basis. This divide exists in the Championship level of officials in England;

the ten officials in this study from the Championship were employed on a full-time, whereas some of the remaining Championship officials who were not selected were only part-time. The determination of the teams' ranking according to the final standings at the close of the season was a clear and objective approach to adopt but during the season, when the games were played, the standings were likely slightly different for some teams and as a result the interpretation of the results should take this into consideration.

2.6. Implications

Due to the elite nature level of participants used here, this study can aid better prescription of physical training, which could accurately reflect the match demands of officials at each respective level. The high standards of both physical fitness and perceptual-cognitive functioning are demanded of the elite level referees in order for the referee to successfully officiate over the most elite level games. The data do indicate that the physical demands of referees at the Premier League level are slightly higher than at the Championship level. Therefore, appropriate training interventions should be made for referees who are promoted to the Premier League to ensure they can meet the increased physical demands. A similar increase in physical demands was evident in both Premier League and Championship matches of top ranked teams which would impact the periodization of training for referees that are scheduled to officiate such games during the season.

This study has given a broad view of some of the demands that are placed on officials at the highest level of soccer match play. Using this data in a practical setting moving forward, sports science and coaching staff could prescribe different training regimes dependent on the level (Premier League vs. Championship) of the match an official might be taking control of and, also, the ranking of the team (from the previous season). Although using the data from the season prior to judge a team's ranking may not be 100% accurate and representative of the loading, it could be used as an indicator for some of the training stressors for the official to be subjected to in the training sessions before the match (MD-3 to MD-1). For example, higher sprinting exposure, longer jogging capacity, rate of change of play, i.e., more accelerations and decelerations during Championship matches and greater exposure to higher HR max zone running at the Championship level.

Working on the physiological capacity of the official in the training week leading up to a game is just as important as being able to help the official to recover from each game. Sports science staff are tasked with using data that new advancements in technology have provided to ensure the availability of players and their officiating counterparts alike. Taking this data as a view to what the season can demand of an official can potentially be used to determine the recovery needs of the official. MD+1 can be more significant than MD-1 in ensuring the official is able to complete another elite level match. Being able to structure the training week by taking into account the level of game, ranking of teams and the quarter of the season could allow for more time spent recovering, by changing of the scheduled pitch based training sessions and indoor gym sessions or allocating more time to recover from the games that could be predetermined as being particularly physiological demanding.

2.7. Future research

Future research should look towards the prescription of the fitness testing consistently used by national and international official governing bodies to develop the validity of certain aspects of these tests to make sure the tests can accurately determine whether an official is able to successfully officiate over the highest ranked games. Perceptual-cognitive demands within the game are still yet to be quantified at the elite level. The high volume of match decisions needed to be made during a 90minute match, combined with extraneous variables that can greatly influence the official's decision making capabilities are not fully understood. A better understanding of how these can be trained/acquired will help to develop the official's decision-making skills, that can then run hand in hand with a more accurately developed training program.

Taking into account the work already performed with AFL officials on their perceptual-cognitive decision-making performances (Larkin et al., 2014a, Larkin et al., 2014b, Larkin et al., 2016 Larkin et al., 2017, Kittle, Elsworthy & Spittle, 2018). As a review into the virtual assistant referee VAR has already shown to be able to improve the on field decision making from 92.1% to 98.3% (Spitz et al., 2020) the use of the new breaks in play, due to the use of the VAR, could potentially allow for more detailed physiological measures to be taken. Previously, internal physiological markers were not able to be taken via blood sampling and thus the internal indicators of how demanding the game can be on an official are not truly understood. Using the gaps in play due to VAR, the official is now able to have a 30 second to 1 minute rest. Within this time frame there could be an opportunity to collect a blood sample and/or temperature readings. Finally, within this study, data was taken out for official cup competitions; FA Cup, EFL Cup, UEFA Champions League and UEFA Europa League matches were all disregarded, one part of these matches that has not been taken into account is the effect that extra time can have on an official. Soccer teams are allowed to use substitutions, whereas unless injured, officials are required to officiate the full 120 minutes. With the possibility of another 90 minute match being less than 72 hours away in their schedule, and their body not having enough time to recover. Could the technological advancements give the PGMOL sports science staff the information needed to make an informed decision on the official’s readiness to participate in such a situation.

2.8. Conclusion

This study has given an insight into the demands of Premier League and Championship soccer on the match official by allowing a more in depth look at physical profiles, game demands and movement characteristics of referees. This is the first study to systematically quantify competitive match play loads of Premier League and Championship officials over the course of a full season using objectively collected GPS and HR monitoring data. The main findings were that the top ranked Premier League games have the greatest effect on the physiological loading of the official with increased total distance covered, running and sprinting. Despite a lower HR throughout the season, Championship officials spend more time in the higher HR max zones. Championship officials are also subjected to more acceleration and deceleration actions compared to the Premier League officials.

CHAPTER 3

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