Physical Demands of Elite Lead Rugby Union Referees

by

CAREL BESTER

2005013565

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Supervisor: Prof Frederik F. Coetzee

Co-Supervisor: Mr Matthew Blair

DECLARATION

I, Carel Bester, hereby declare that the work on which this assignment is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

Signature: C. Bester

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ABSTRACT

The aim of this study was threefold: to determine the physical demands on elite lead rugby union referees, to determine whether physical demands and performance of referees changed during the course of a match (first half versus second half), and to determine whether physical demands and performance were consistent across the sample of referees. Physical profile data, heart rate (HR) recordings and global positioning system (GPS) (GPSports: SPI HPU) data were collected from 17 lead elite referees during 205 national and international matches. The mean duration of a match was 97.6 min and the mean distance covered by the referees was 6,826m, the mean values for the two match halves being virtually identical, 3402.9m for the first half and 3395.3m for the second half respectively. In contrast, referees produce about 5% more metabolic power during the first half of a match (mean 6.21W/Kg) compare to the second half. On average referees spent 52.4% of the time standing still or walking, 20.3% jogging (2.3m.s^{-1} – 4.1m.s^{-1}) and 27.3% in the “work zone”(4.1m.s^{-1} – 9.6m.s^{-1}) with again virtually identical mean values for the two match halves. During a match referees spent 46.8% below 80% HRmax and 53.2% above HRmax, while spending 8% less time above 80% HRmax in the second half. The mean number of high-speed accelerations, high-speed decelerations and sprints/surges were approximately 20% lower during the second half (5.5, 9.2 & 2) than during the first match half (7, 11.1 & 2.4), although the decreases in absolute counts are small. These differences between the first and second halves of the match suggest that there is either no, or at most a slight tiring effect during the course of the match. Furthermore, referees generally performed consistently with regard to the physical performance measures studied. In conclusion, our data suggest that the elite panel referees have met the physical performance standards required for refereeing at this level

KEY WORDS: **Elite Rugby Union referee, physical profile data, GPS, physiological demands, time motion analysis, performance**

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Abbreviations

AFL: Australian Rules Football

BMI: Body Mass Index

cm: Centimetre

D: Distance

DM:	Decision Making
EE:	Energy Expenditure
GPS:	Global Positioning System
HIIE	High Intensity Intermittent Exercise
HR:	Heart Rate
IHIE:	Intermitted High Intensity Exercise
mm:	millimetre
MP:	Metabolic Power
MSPD:	Maximum Speed
NRL:	National Rugby League
s:	seconds
Sp:	Speed
TEM:	Typical Error of Measurement
TMA:	Time Motion Analysis
TMO:	Television Match Official
UEFA:	Union of European Football Associations
VO2Max:	Maximal Oxygen Uptake
WR:	World Rugby

Units of Measurement

%:	Percentage
BPM:	Beats per minute
cm:	Centimetres
kJ:	Kilo Joules
m:	Meters
mm:	Millimetres
min:	Minutes

$ml.kg^{-1}.min^{-1}$: Millilitres per kilogram per min

ms^{-1}: Metres per second

W/kg: Metabolic power

Operational definitions

Distance: Total meters covered during a match.

Heart rate zones: Is a range that defines the upper and lower limits of heart rate match intensities at which referees work.

Hi-speed running: Running at speeds <51% of MSPD

Hi-speed accelerations/decelerations: Speeds <2.4ms^{-1}

Lead rugby union referee: Individuals who are responsible for enforcing the laws of the game during a match and impose sanctions on individuals who do not follow the rules.

Metabolic power: Metabolic power can be defined as high intensity work completed considering surge (sprint), high speed running and high-speed accelerations and decelerations.

Rugby union: A field-based team sport played over two halves of 40 minutes each separated by a 10 min break. Rugby union produces a variety of physiological responses (HR) and work rate demands (e.g. repeated high intensity speed efforts and contact).

Speed zone: Is a range that defines the upper and lower limits of match speeds where referees work.

Surges (sprints): Running at speeds >80% of top-end.

Time motion analysis: TMA (Time motion analysis) involves methods such as video recording and GPS tracking. Data are analysed post-match, using various computer software programs.

CHAPTER 1

INTRODUCTION AND PROBLEM STATEMENT

1.1. Introduction

The Rugby World Cup, under the control and direction of World Rugby (WR), has established itself as one of the most important sporting events in the world following the Olympics and the FIFA World Cup (WR, 2018). The WR membership currently amounts to 101 Unions in full membership, 18 Associate Members and six Regional Members (WR, 2018).

The physiological characteristics of elite sports people and the physical demands of competing in numerous sports have been comprehensively described (Reilly *et al.,* 1990). Importantly, there is a growing body of knowledge focusing on the officials who administer the laws in these sporting activities (Martin *et al.,* 2001 & Blair *et al.,* 2018). Team sport match officials are responsible for maintaining flow and control of the game (FIBA, 2014) and ensuring fair play, both in accordance with the laws and in the spirit of the game (World Rugby, 2018). According to Mascarenhas *et al*. (2005) the performance of referees is critical, as they are responsible for maintaining a safe environment, and ensuring a fair result. Currently rugby referees combine decision making with physical work to improve their decision making (DM) in matches (Blair, 2018). This is done bi-annually at World Rugby (WR) Referee Camps. One of the many attempts to ensure that referees are accurate in their decisions is the increasing use of video replay to assist officials at the highest level. Furthermore, a variety of skills are required to referee professional sport, for example, communication (Mascarenhas *et al*., 2002a). Seneviratne (2003/04) stated that conditioning is a prerequisite for refereeing rugby at any competitive level and all referees need to be conditioned in such a manner that they meet the physiological demands of the game, and also need to apply an accurate interpretation of the laws of the game (Müniroglu, 2007). Further research in this area is recommended (Blair *et al.*, 2018). In summary, the modern rugby referees play an important role in the administration of sporting activities and need to prepare for this by combining decision making (DM) activities with physical conditioning work.

1.2 Rationale of the study

Every rugby union (hereafter referred to as rugby) match is under the control of match officials consisting of the lead referee, two assistant referees (AR's) and a television match official (TMO) at provincial, national and international level matches. According to the laws of the game (WR, 2018), the referee is the sole judge of fact and is required to apply the laws of the game in every match. As such, the decisions made by a rugby referee can be very influential on the outcome of the game and can have harsh consequences for the team, player and franchises involved with the sport (Button *et al.,* 2006). Price (2006) and Connelly (2003) noted that the referee or umpire is regularly identified as the cause of the failing of a player or team, and to be responsible for influencing the result of a game by either not enforcing the rules and/or being biased. Royal *et al*. (2006), Mascarenhas *et al*. (2009) and Lambourne and Tomporowski (2010) have also shown that physical performance, accuracy and speed of decision making of players and referees could be altered by the influence of exercise-induced fatigue.

Rugby is evolving globally as a professional sport; as such it is vital that the referees are optimally prepared for the physical demands of the sport. Sport officials are regularly placed in the media spotlight as their decisions affect the outcome of games and competitions. Therefore, the ability of the referee in rugby union to keep up with play in order to be in a good position is critical for allowing correct decisions to be made. Thus, the ability of the lead rugby referee to meet the physiological response (HR) and work rate demands (D and Sp) imposed during match play is believed to be a necessary prerequisite for optimal positioning and successful refereeing (Suarez-Arrones *et al*., 2013).

Although empirical research into sports officiating is growing, there is still a shortage of information about the demands of officiating in sport (Blair *et al*., 2018). The physiological characteristics of elite sportspeople and the physical demands of competing in numerous sports have been comprehensively described (Reilly *et al*., 1990). However, to date, very little attention has been focused on the officials who enforce the rules in these sports activities. Rugby referees have to train extremely hard to ensure that they attain, and maintain, an appropriate level of physical condition. Unfortunately, there is also little scientific support to assist the performance and development of these individuals. Button *et al*. (2006) stated that "although empirical research into sports officiating is growing, there is still a shortage of information about the demands of officiating in sport". It is important that the physical conditioning and testing of referees be based upon principles of sport specificity (Kay & Gill, 2004; Blair, 2008).

Time motion analysis (TMA) is an effective method of quantifying the demands of rugby and provides a conceptual framework for the specific physical preparation of players and referees (Morton, 1978; Treadwell, 1988; Docherty *et al.,* 1988; McLean, 1992; Menchinelli *et al*., 1992; Deutsch *et al*., 1998; Deutsch *et al*., 2002; Duthie *et al*., 2003). TMA includes methods such as video and GPS. GPS is currently the preferred method of analysis as it is more efficient when compared to video and it is becoming increasingly more accurate. Calculating the frequency, mean duration and total time spent in activities is fundamental with TMA (Canovas *et al.,* 2014). Distance covered during a game is measured using TMA. Investigators have used estimations of velocity, field markings or visual clues to measure the total distance covered in a game (McLean, 1992). Detailed information on the movements in a game provides comprehensive assessment of the demands of competition and assists in developing specific training regimes. Despite this, limited research is available with respect to the changing physical demands placed on rugby referees during matches and in the different competitions. Rugby turned professional in 1995 and since then there have been numerous changes in law, improved physical conditioning methods and match analysis techniques for the players (Quarrie & Hopkins, 2007). Quarrie & Hopkins (2007) have also stated that with professionalism, game pace and ball in play time have increased, combined with an increased level of physical contact and a reduction in the participation time per player. Therefore, It is likely that the physical demands, now placed on the referee, have also increased and further investigation is required on how this might relate to movement patterns, resulting in fatigue and DM.

1.3. Formulation of problem statement

Blair (2008) stated that although empirical research into sports officiating is growing, there is still a shortage of information in demands of rugby referees especially at elite level. Furthermore, although referees have a crucial influence on the game (Farrow & Abernethy, 2002), there is still a lack of literature investigating the performance of match officials and very little attention has focused on the officials who enforce the rules in these sports activities. It is also clear that lead rugby referees have to train extremely hard to ensure that they attain, and maintain, an appropriate level of fitness; however there is also little scientific support that can contribute to the performance and development of these individuals (Button *et al*., 2006). To conclude, high level physical conditioning of all appointed referees is crucial as they play a key role in the outcome of rugby games which they officiate.

1.4. Aim of the study

- Primary: To determine the physical demands of elite lead rugby referees by measuring the: duration of a match, total distance covered (m), % time spent in each heart rate zone (% HR), % time spent in each speed zone (% Sp), number of high speed accelerations, number of high speed decelerations, number of surges (sprints), and metabolic power (W/kg) during each game.
- Secondary: To assess whether the physical demands changed during the course of the match (first half versus second half).

1.5. Significance of the study

This is the first research project with elite-level lead rugby referees that has a very large sample of GPS match files conducted over a significant time frame. The results will also provide a valuable update on the specific physiological response and work rate demands that these officials engage in during matches. As a result, conditioning coaches will be able to use the findings of the study to develop improved and more specific lead rugby referee training programmes.

CHAPTER 2

LITRATURE OVERVIEW

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2. Introduction

2.1 Description of rugby union referees

Lead rugby match referees are responsible for enforcing the laws of the game during a match and imposing sanctions on individuals who do not follow the rules. The World Rugby (WR) International Referees Panel is a panel of elite lead rugby referees appointed by the sport's governing body, World Rugby (formerly known as the International Rugby Board) to officiate in international matches. These matches usually involve the national teams of high-performance unions from across the globe, as named by WR. The panel was established to ensure that matches between the best international teams are officiated by the best referees. World Rugby appoints a neutral four-person team (lead referee, two assistant referees, TMO) to each match in the international windows, as well as to the Six Nations, The Rugby Championship and the World Cup (http://www.sanzarrugby.com/superrugby/).

All the referees on the international panel have progressed through refereeing ranks in their domestic leagues, before developing their skills further in competitions such as the Sevens World Series panel World Rugby Under 20 competitions and multinational club competitions such as the European Rugby Champions Cup, and Super Rugby (http://www.sanzarrugby.com/superrugby/). These lead referees are employed by their home unions and have strict WR standards that they must adhere to.

2.1.1 The elite referee

Referees are responsible for maintaining flow and control of the game (FIBA, 2014); they are also tasked to ensure fair play both in accordance with the laws and the spirit of the game (WR, 2018). According to Mascarenhas *et al*. (2005) a referee's performance is critical, as they are not only responsible for maintaining a safe environment, but it is also expected from them to ensure that the game's result is fair. One of the many attempts to ensure that referees are accurate in their decisions is the increasing use of video replay to assist officials at the highest level (Mascarenhas *et al*., 2005). Furthermore, a variety of skills are required to referee professional sport (Mascarenhas *et al*., 2002a; Suarez-Arrones *et al.,* 2013) However, while governing bodies have focused on physiological assessments and physical training for their referees, structured training in fatigue induced decision making is rare (Garcia, 2003). Elite-level lead rugby referees are currently engaging in DM activities and physical work in training sessions to improve on-field performance (Matthew Blair, personal communication 17 July 2018), an area in which further research is necessary to better understand this relationship (Blair *et al.*, 2018) Even though, referees still appear to largely rely on experience to develop high level on-field performance. Research suggests that deliberate practice of a specific skill can help master an activity in the sporting environment (Helsen *et al*., 1998; Helsen *et al*., 2000; Starkes, 2000). Additionally, research by Williams and Davids (1995) suggests that mere experience will not necessarily lead to expertise. A sufficient number of challenging scenarios to develop expert performance may not be provided by refereeing itself (Means *et al*., 1993; Starkes & Lindley, 1994). This research supports the need for specific DM sessions where officials are placed under physical stress equal to and greater than what they encounter in competitive matches.

Elite lead referees need to be physically fit enough to keep up with play, able to apply the laws of the game accurately and have the personality and management skills to "sell" these resulting decisions to the players (Mascarenhas *et al.*, 2005; Kuklinski, 2007). Inaccurate decision making by elite lead rugby referees can change the course of a game, and may well even contribute to significant financial implications for the unions (Mascarenhas *et al.,* 2005). Mascarenhas *et al*. (2004) and Cochrane *et al*. (2003) stated that during a match, referees need to be in a position on the field which allows them to make the correct interpretation of the laws – hence placing demands on their fitness. Rugby turned professional in 1995 and since then there have been numerous rule and law changes, improved physical conditioning methods as well as improved match analysis which has resulted in an increased game pace, time of ball-in play and level of physical contact, combined with a reduction in the amount of participation time per player (Quarrie & Hopkins, 2007). As a result this has likely increased the physical requirements for rugby match officials (Martin *et al*., 2005). It is also well known that as a result of professional team sport, the conditioning of players improved and they are more cynical with regard to the laws of the game (Morrison, 2002; Quarrie & Hopkins, 2007). Consequently, the pressures on sports officials to produce flawless performances are increasing and with media analysts attempting to create controversy, the spotlight is often cast upon the match referees (Mascarenhas *et al.*, 2005). Undoubtedly these referees have a crucial influence on the game, and although sport science research literature holds numerous investigations into the enhancement of elite athletes (Farrow & Abernethy, 2002); there is still a lack of literature investigating the performance of match officials.

In summary, MacMillan (1996) stated that in order to become an elite referee one requires competencies based both on the experience and a thorough knowledge of the laws of the game. At this level of the hierarchy, a physical evaluation of the national referee is carried out for each action by a supervisor. At the end of the season, the sporting governing body carries out a classification of the elite referees. The majority of the elite football referees keep their qualifications but some are downgraded to the lower level whereas others lose their qualifications of elite referees, due to the age limit (MacMillan, 1996). The limiting age varies according to the discipline, however considering the growing degree of requirements of sporting competitions, careers seldom exceed the 15 years of refereeing at the highest level

(MacMillan, 1996). Macmillan (1996) also states that elite refereeing takes a considerable time, requires great availability, imposes a lot of travelling and requires true training.

2.1.2 Physical profile of lead rugby union referees

The physiology of elite sports people and the physical demands of competing in numerous sports have been comprehensively described (Reilly *et al*., 1990). However, there is a growing body of knowledge focusing on the officials who administer the rules in these sporting activities. According to Button *et al*. (2006) sports officials are regularly placed in the media spotlight as their decisions affect the outcome of games and competitions. Subsequently, not only have the physical requirements of rugby officiating been investigated, but also the DM process that related to this (Blair, 2008). Unfortunately, there is little scientific support to assist the performance and development of referee's. While empirical research into sports officiating is growing, there is still a lack of information about the demands of officiating in sport. There is a growing awareness for the need of referees to be professionally competent and to have sufficient physical fitness to meet the demands of the game.

According to Johnston and McNaughton (1994), the total distance covered in a football match, along with the intensity of the activities and the frequency with which these activities change, can provide information on the physiological response and work rate demands experienced by referees. In turn, this information can be used to develop specific training programmes to enable officials to manage the demands of the game more effectively.

It is generally accepted that the identification of the physiological response and work rate demands during games can make a significant contribution to the design of scientific conditioning programmes and the assessment of both physical strengths and weaknesses of referee's. Martin *et al*. (2001) reported that during a match, referees cover a distance of 8581m ± 668m, The distance covered during a match can be coded into six different activities i.e. standing, walking forwards, walking backwards, jogging, running and sprinting. Martin *et al*. (2001) also stated that during a match a total of 672 transitions between modes of activity were recorded. This suggests that refereeing top rugby matches is physically demanding.

On an annual basis WR provides the elite panel referees with physical monitoring guidelines. These guidelines enable a physical profile to be created for each elite-level lead rugby referee. A summary of the prescribed physical profile for elite panel referees can be seen in Table 2.1.

Table 2.1: General measures: rugby union referee criterion measures

Assessment	Male	
	Score-level (shuttle)	**Result Standard**
Yo-Yo IRL 1	≥19.01	Optimal
	18.01 to 18.08	Acceptable
	<18.01	Unacceptable
Assessment	**Male**	
	Time (s)	**Result Standard**
Stand 40m	<5.30	Optimal
	5.30 to 5.80	Acceptable
	>5.80	Unacceptable
Assessment	**Male**	
	Mean Time (s)	**Result Standard**
Mod PDT	<4.90	Optimal
	4.90 to 5.20	Acceptable
	>5.20	Unacceptable
Assessment	**Male**	
	BMI (kg/m^2)	**Result Standard**
BC&D	<18.5	Undesirable
	≥18.5 to <24	Optimal
	≥24 to <30	Acceptable
	≥30	Undesirable
Assessment	**Male**	
	Wc (cm)	**Result Standard**
BC&D	80 to <92.0	Optimal
	≥92.0 to <102.0	Acceptable
	≥102.0	Unacceptable
Assessment	**Male**	
	∑ 7SFs (mm)	**Result Standard**
BC&D	≥50.0 to <70.0	Optimal
	≥70.0 to ≤100.0	Acceptable
	>100.0 or <50.0	Unacceptable

Contextual Review of Physical Requirements of Refereeing Rugby Union at an Elite Level (Blair *et al.*, 2018)

2.2 Physical Characteristics

Blair *et al.* (2011) reported that the age and body measurement values for the officials of team sport activities are quite similar; even though there are some differences to the players they officiate. Furthermore, regardless of measurement inaccuracy contributing to the results, the authors reported that the difference in conditioning levels may be a contributing factor to the increased body mass that were reported for amateur referees.

A summary of mean (± SD) age and body dimension measures for rugby union, Australian Rules Football and rugby league research can be found in Table 2.2, where a range of sub-elite and elite-level games were investigated.

Table 2.2: Rugby union, rugby league referee and Australian rules football umpire mean (± SD) age and body dimension results.

Author(s)/Publ. Year	Subjects/Matches	Age (yrs)	Height (m)	Body Mass (kg)
Dascombe *et al*. (2003)	Regional Australian n=12, referees (15 sub-elite games 2002)	40.8 ± 9.4	1.80 ± 0.1	90.8 ±11.5
Martin *et al*. (2001)	English Premiership n=9, referees (19 games in 1998-99)	39.6 ± 5.9	1.78 ± 0.06	79.5 ± 5.0
Martin *et al*. (2005)	English Premiership n=13, referees (33 games in 1998-99)	43 ± 4	1.76 ± 0.05	78.7 ± 5.4
***Kelly et al*. (2003a)**	International (Int.) and S12 n=11, Int referees (8 Int and 23 Provincial games in 2001-01)	-	-	-
Kelly *et al*. (2003b)	International (Int.) and S12 n=10,Int. referees (5 Int and 9 provincial games in 1999-2000)	-	-	-
		37	179.5	69.2

Pyne and Ackerman (1987)	Australian Capital Territory Football League (ACT ARF) n=2, field umpires	39	172.0	59.45
Hoare (2008)	National Rugby League (NRL) n=14, referees (61 games in 2006-07)	33.5	-	81.1
Kay and Gill (2003)	National Rugby League (NRL) n=5, referees (10 games in 2000)	-	-	-
Kay and Gill (2004)	National Rugby League (NRL) n=6, referees (6 games in 2001)	35 ± 3.9	1.80 ± 0.05	81 ± 5.8

2.2.1 Age

Quarrie *et al*. (1996) reported that the mean ages of the officials ranged from mid-thirties to early forties, which is consistent with those in soccer (see Table 2.2), and older than the players they officiated. According to Hoare (2008) a notable exception to the afore mentioned mean match official age is that of National Rugby League (NRL) referees, which at 33.5 years is lower than the 35 ± 3 years reported from the NRL study by Kay and Gill (2004). An investigation by Helsen and Bultynck (2004) into Union of European Football Association (UEFA) top class referees and assistant referees during the final round of the Euro 2000 Championship (Table 2.3) serves as confirmation of this age bracket. These authors reported "that the match officials at this level of competition are on average about 15-20 years older than the professional players (p. 187)." This correlates with Castagna *et al*. (2004) who stated that all team sport officials follow the same pattern in soccer where they progress from one level to the next without any possibility of skipping a grade based on officiating skill.

Castagna *et al*. (2004) also reported a cut off age of 45 years has been imposed by some national soccer refereeing governing bodies. According to Castagna *et al*. (2005), this may be as a result of assessed physical conditioning results and how these may relate to age progression. However, Catterall *et al*. (1993) suggested that experience is a fundamental prerequisite for successful refereeing. This might explain why referees older than 45 years of age have been reported to be still active (Krustrup & Bangsbo, 2001). Mascarenhas *et al*. (2005) suggest that 10,000 hours of deliberate exercise is necessary to obtain expertise in a sporting environment. The age variables together with the physical requirements would also help to explain the similarity for officials within various team sports.

2.2.2 Height and weight

The mean (± SD) measures for height and weight of the subjects in the lead rugby referee research are very similar to those of rugby league and Australian rules football officials (Table 2.2). This is anticipated as elite lead rugby referees fulfil one specific role. According to Deutsch *et al*. (2007) this is different to the variation of positional demands in rugby union for players. Dascombe *et al*. (2003) stated one exception to this was the mean weight of the participants used in his study which was approximately 10 kilograms heavier when compared to other rugby and rugby league measures (see Table 2.2). This could be due to factors such as the reduced physical match demands and level of physical preparation (Dascombe *et al*., 2003).

According to Kay and Gill, (2004) the overall consistency between and within various groups of team sport officials for age and body dimensions, suggests that there is an age bracket and body type that is best suited to officiating team sports: an age that allows adequate officiating experience to be obtained, and a body type that can tolerate an activity that is highly intermittent, rather than highly continuous. However, some differences were reported. Bangsbo *et al.* (2004), Button and Petersen (2005) and Dascombe *et al.* (2003) stated that those population groups with higher body mass than the mean (± SD) of the investigations presented may have a lack of physical conditioning that have contributed to this. Furthermore, Dacres-Manning (1998) and Quarrie *et al*. (1996) reported that even though the age of match officials is consistently greater than the players they officiate, the reported body dimension values for rugby referees were by comparison more homogenous compared to the wide range of those reported for rugby players. This reflects the variety of positional demands placed on the players (Deutsch *et al*., 1998a), whereas the body dimension values, other than weight (Wisloff *et al*., 2004), were similar for soccer referees and the players they officiated.

Table 2.3: Soccer referee and assistant referee mean (±) age and body dimension results.

Author(s)/Publ. Year	Subjects/Matches	Age (yrs.)	Height (m)	Body Mass (kg)
Bangsbo *et al.* (2004)	Top Class Danish n=42, assistant referees (1-2 matches each)	1.) Younger 32.6 ± 0.4	1.82 ± 0.03	86.1 ± 2.2
			1.86 ± 0.03	90.0 ± 1.9

		2.) Intermediate 37.4 ± 0.3		
		3.) Older 42.4 ± 0.7	1.83 ± 0.01	87.5 ± 2.6
Button and Petersen (2005)	New Zeeland championship n=5, referees (6 matches in 2004-05)	35.4 ± 4.8	1.84 ± 0.07	87.2 ± 9.9
Button *et al*. (2006)	New Zeeland championship n=5, referees (7 matches in 2005-06)	38.2 ± 5.89	-	-
Catterall *et al*. (1993)	English 1st, 2nd, 3rd Division, Vauxhall Conference and HFS Loans n=14, referees (4,2,4,2 matches in 1991-92)	-	-	-
D'Ottavio and Castagna (2001a)	First Division Italian League (Serie A) n=18, referees (1992-1993)	37.4 ± 2.14	-	-
Helsen and Bultynck (2004)	UEFA top class officials - different European countries n=17 referees, n=17 assistant referees (31 matches in 2000)	40.2 ± 3.9	1.82 ± 0.06	79.7 ± 9.2
		41.3 ± 2.8	1.77 ± 0.08	75.3 ± 8.9
Johnston and McNaughton (1994)	Tasmanian State League Soccer Association n=10, referees (20 matches)	38.1 ± 3.8	-	-
Krustrup and Bangsbo (2001)	Danish League n=27, referees: 12 Top League, 15 2nd League (43 matches in 1997-98)	40 (29-47)	1.82 (1.69 - 1.95)	83 (69.3 - 101.6)
Krustrup *et al*. (2002)	Top Danish League n=15, assistant referees (22 matches in 1998-99 and 1999-2000)	40 (32-47)	1.81 (1.67 - 1.91)	80.5 (69.1 - 98.4)
			1.80 ± 0.07	78.5 ± 9.1

Krustrup *et al*. (2004)	Top Danish League n=21, assistant referees (22 matches)	1.) Younger 35.6 ± 2.8		
		3.) Older 44.1 ± 2.0	1.83 ± 0.07	82.7 ± 6.8
Weston *et al*. (2006)	English FA Premier League n=18, referees (6 matches each 3 Premier and 3 Football League in 2002-03 seasons	41.8 (33-47)	-	-
		-	-	-
Weston and Brewer (2002)	English FA Premier League n=8, referees (24, variety of Premier and Football League matches)	-	-	-

The physiological response and work rate demands of refereeing rugby union Super 14 games, (Blair *et al*., 2011).

2.3 Acute environmental factors

According to Weston and Brewer (2002), referee styles, environmental and match conditions need to be considered when studying physiological responses and work rate demands. Therefore, in match preparation for a rugby referee it is apparent that acute environmental factors can play a part in the level of physiological response and work rate demands that subsequently impact upon DM performance (Blair *et al.,* 2011). These factors can include: the referee's mood; sleep pattern; nutrition (both food and fluid); travel; pre-match fatigue and exercise intensity (Blair *et al.,* 2011). Since referees regularly undertake long-haul international travel, recovery from travel is important to ensure training and competition success for a referee.

2.3.1 Travel and sleep

Fowler (2015) stated that due to logistics and cost associated with methodology for travel research, few field-based studies investigating the effects of international travel on performance exist. According to Youngstedt and Connor (1999) there is evidence that air travel may have negative effects on athletic performance, however this is neither consistent, nor convincing. Bishop (2004) stated that team performance has been shown to be influenced by relatively brief air travel (across two time zones); this could be due to disturbances in daily rhythm or sleep (Worthen & Wasde, 1999). A decrease in shuttle run scores due to the effects of sleep disturbance or travel, suggested that performance may be impacted (Racinais *et al*., 2004). According to Souissi *et al*. (2003), performance may be influenced if the period of sleep disturbance is greater than 36 hours, where anaerobic performance has been proved to be affected. In contrast, sleeping patterns prior to the game might not be affected by shorter travel, as found with Australian rules football athletes (Richmond *et al*., 2004). The relationship between sleep deprivation and its effect on performance has been investigated thoroughly; despite this it is not easily explained (Pilcher *et al*., 2007). Pilcher *et al*. (2007) also investigated what the effects of acute sleep deprivation will be on a wide range of information processing (complex cognitive vs. vigilant tasks). These authors also reported that participants controlled the complex cognitive tasks more successfully when acute sleep deprivation showed no significant decrease in performance of these tasks throughout the night. In contrast, with the less interesting vigilant tasks the performance decreased significantly. A 17-hour acute period during the night was used to conduct this investigation. There are no known investigations focusing on chronic sleep deprivation or sleep disturbance with athletes such as rugby union match officials (Blair *et al*., 2011). According to Worthen and Wasde (1999) other factors may lead to athletic teams having a home advantage; crowd, learning and rule. Non-circadian mechanisms may impair athletic performance, including stress, altered diet, dehydration, thrombosis and stiffness because of restricted motion, ankle oedema and transmittal of viruses (Youngstedt & O'Connor, 1999). Despite this the authors were unaware of any athletic performance studies that had examined these alternate mechanisms. These mechanisms could affect match officials during a rugby season (Super Rugby, Heineken Cup, Six Nations, Rugby Championship and International Friendlies) where much time is spent travelling. Jaco Peyper, WR referee (Personal Communication 23 April 2014), reported that during a season on average he will complete the following return flights from South Africa: Australia and New Zealand (six round trips), Europe and United Kingdom (three round trips), Argentina (one round trip). This excludes the Trans-Tasman flights (six), domestic flights (avg. of 60) and the travelling done by train (Europe) and car (local). All this results in ± 320 hours spent on an aircraft. This is supported by Craig Joubert (2014), WR Referee (personal communication, 24 April 2014), who reported a total of approximately 400 hours spent on an aircraft during a rugby season. However, a Northern Hemisphere referee's travel time could be as little as 35% of that of a Southern Hemisphere referee (Wayne Barnes, personal communication, 25 April 2014). According to Barnes (2014), WR Referee, he will only complete one long haul round trip in June (London – Australia) and a possible round trip in September/October (London to Australia/New Zealand/South Africa or Argentina). This amounts to ± 112 hours on an aircraft, excluding local travel. Instead the Northern Hemisphere based referees complete a very large number of regional trips. There is no known research on this type of travel behaviour and its long-term effects on performance. However, some of the more experienced match officials involved in the 2014 season believe that they have adapted "reasonably well" to the constant travel due to proper planning of their trips, despite experiencing periods where they still struggle to keep their on-field performance constant.

The inconsistency in performance may, in part, be due to fatigue. Some researchers report that cognitive behaviour is facilitated by exercise, others report that it weakens mental functioning, and some suggest that it has no effect (Tomporowski & Ellis, 1986). These authors suggest that these different states are invoked by two seemingly opposite mechanisms as a result of exercise: stimulation of the central nervous system and physical fatigue of the skeletal motor system. Accordingly, the weakening effects of muscular fatigue on mental performance might be offset by an optimal level of physical fitness, resulting in a positive influence on athletic performance and DM (Blair *et al.,* 2011).

2.3.2 Nutrition

According to Shirreffs *et al*. (2004), nutritional factors also contribute to athletic performance, for example, avoiding the potential negative effects of dehydration on physiological function and subsequent exercise performance. Hydration is encouraged in the lead-up to an athletic event. Burke and Deakin (2006) reported that a major cause of fatigue is the depletion of body carbohydrate stores, where optimising carbohydrate status in the muscle and liver is a primary goal of competition preparation. It was reported that dietary carbohydrate is the key ingredient for glycogen storage (Jentjens & Jeukendrup, 2003). According to Burke *et al*. (1995), 7-10 gram (g) per kg body mass per day is sufficient for events less than 60-90 minutes in duration, "and for the athlete setting aside 24-36 hours following their last training session to stabilise fuel stores" (Burke & Deakin, 2006). Burke and Deakin (2006) also suggest that some athletes may need to rearrange their conditioning programmes to include an easier training day prior to their event. Nutrition strategies should also be in place for before, during, and in the recovery period following the event.

The effect of environmental factors on athletic performance is complex due to the lack of research in this area and the inconsistency of the available literature. However, this can be explained in some cases. Poor performance may be the result of insufficient sleep, especially if the task is less interesting (Pilcher *et al*., 2007). Physical fatigue of the skeletal motor system may have negative consequences for mental functioning, and therefore performance, although this may be offset by optimal physical condition (Tomporowski & Ellis, 1986). According to this evidence, appropriate nutrition, personalised to the event and travel, are two key factors involved with the quality of sleep, mood and level of fatigue which also have an impact on performance and decision making.

2.4 Time motion analysis on rugby referees

2.4.1 Time motion analysis (TMA)

The demands of competition have been primarily reported with the use of TMA. Motion analysis provides an objective, non-invasive method for quantifying work rate and provides information that can be used in the design of physical conditioning programmes and testing protocols (Deutsch *et al*., 1998a).

In addition to using time-motion data to improve training specificity, there is also a need to accurately quantify match demands for the purposes of designing more specific exercise protocols that allow the investigation of issues specific to rugby union (Roberts *et al*., 2008). TMA can involve recording match play using video that is analysed at a later stage by the researcher with the use of computer programme software that can track several different movement categories (Roberts *et al*., 2008). According to Roberts *et al*. (2008) video recording is optimal for the analysis of complex movement patterns, the recorded footage can be slowed down or repeated as needed. Individuals are normally filmed throughout an entire game, providing a continuous recording of the frequencies, mean and total durations in each activity. This allows for work rate and percentage game calculations.

In addition to video recording, the use of portable global positioning system (GPS) devices is another TMA that has become a popular and convenient method to quantify movement patterns and physiological demands in sport (Wisbey *et al*., 2010). According to Edgecomb and Norton (2006) a GPS is used for the accurate tracking of the displacement of an object (e.g. a player) in real time by calculating the displacement of the GPS signal gathered by the receiver which is attached to the player. The Doppler frequency calculation is used for these calculations, whereby the phase-shift difference between the satellite and an oscillator-produced signal within the receiver is measured (Edgecomb & Norton, 2006). A GPS can assist researchers in collecting data during and/or by the end of a game, hence it is not necessary to code different locomotory activities immediately (Carling *et al*., 2005), which can be regarded as an advantage over video-based TMA systems. However there are disadvantages with the use of GPS that need to be considered. Colby *et al.* (2014) reported that occasionally GPS data were deemed unreliable due to an intermittent signal where insufficient connecting satellites were detected. According to Hennessy and Jeffreys (2018) another limitation of GPS technology is that only outdoor physical activity can be tracked. For a more complete representation of overall workload, monitoring all physical activities including indoor activities is necessary (Hennessey & Jeffreys, 2018). According to Hennessey and Jeffreys (2018) a more holistic and broader understanding of the physical, technical, and tactical demands of the sport (soccer) is possibly created through the integration of GPS technology and video feedback. For such use the limitation could be a more human limitation rather than a technical limitation. This could be the result of insufficient coaching and performance knowledge, together with analytical and communication skills in deriving a meaningful interpretation from such integrated data (Hennessey & Jeffreys, 2018). According to Brown *et al.* (2016), another limitation is that GPS tracking using the metabolic power model of energy expenditure (EE) does not accurately estimate EE in field sport movements or exercise sessions consisting of different locomotory activities combined with recovery periods. Practically a key limitation with the use of any technology is how the data is organised and communicated to the players and staff at a level they can easily understand.

2.4.2 Reliability of TMA

TMA with video is a time-consuming process inherently prone to measurement error. This is due to the fact that observations are influenced by an observer's knowledge, perceived importance of competition, focus of attention, state of arousal and preparing for anticipated events (McKenzie *et al*., 1989). Although researchers TMA have favourably reported the reliability of their methods, none have reported the Typical Error of Measurement (TEM) which is a requirement in other physiological tests (Hopkins, 2000). According to Docherty *et al.* (1998) reliability is an assessment of the consistency of a measure and is usually determined by testing and then retesting individuals under the same conditions.

Lames and McGarry (2007) consider the reliability of measurements or assessments made during TMA research as vital. According to Lames and McGarry (2007), the results must be considered with caution if the reliability and validity of the testing method were not established, either within the study or in previous literature. Due to the similarities between some movement patterns during match-play, e.g. jogging and running, it is understandable that in the majority of video-based TMA studies some form of subjective judgement regarding the categorisation of each individual movement is applied (Tenga & Larsen, 2003). Thus the decision of accurately coding each movement is solely placed on the interpretation of the observers or analysers (Lames & McGarry, 2007).

Therefore, the interpretation of the defined movement activity may differ slightly, which could affect the reliability of the results. A study done on professional soccer players, O'Donoghue (2004), used 15-minute segments of ten matches to analyse the movements of 60 players. These movements were classified as high or low intensity movements and the duration of these movements was recorded. Inter-observer reliability and intra-observer reliability tests were conducted, revealing a significant systematic prejudice between observers for the percentage time spent performing high intensity activities ($p<0.01$) and between the observations of the different halves ($p<0.05$) with higher values being recorded during the first half.

Spencer *et al*. (2005) analysed reliability by analysing the movement patterns of five male hockey players during half of an international match. Test Error Measurement (TEM) values of 5.9-10.2% were reported for the frequency of movements and 5.7-9.8% for the duration of movements.

2.4.3 Movement patterns in lead rugby referees

The characteristic nature of player activity in team sports appears to be reflected by the highly intermittent nature of the activities observed for the referees. Docherty *et al*. (1988) reported that rugby players underwent an average of 788 transitions between activities during a match and that each activity bout had a mean duration of 6s. According to Reilly and Thomas (1976) association football players in the English first division changed activity 1000 times during a match and that each bout of activity had a mean duration of 5 - 6s. Correspondingly, elite Danish football players changed activity 1179 times during a match, with each activity having a mean duration of 4.5s (Bangsbo *et al*., 1991). However, the greater number of activity transitions in the study of Bangsbo *et al*. (1991) may be related to the greater number of activity categories that were included in the analysis (Martin *et al*., 2001). According to Martin *et al*. (2001) these studies indicate that the frequent changes in intensity and direction of locomotion may account for a considerable proportion of the metabolic load placed on referees during match play.

Krustrup *et al.* (2002) reported that the possibility of fatigue during the match can also be identified through a comparison of data from heart rate recordings and movement patterns during the two different halves of the match. Due to the lack of research comparing the physiological response and work rate demands placed on elite-level lead rugby referees between the two halves, the authors of the current investigation found the suggestion of Krustrup *et al.* (2002) useful as this will provide a comprehensive picture of the demands placed on rugby referees during matches.

During match play there is a variation in match official movement pattern behaviour in order to conserve energy; this has shown to alter speed-distance (Sp-D) demands (Craig *et al*., 1979; Kelly *et al*., 2003b; Castagna *et al*., 2004; Krustrup *et al*., 2004). According to Duthie *et al*. (2003) more experienced officials seem to conserve energy with their ability to anticipate play through rest (i.e. standing still, walking and jogging). Thus, more experienced officials have been shown to travel shorter total distances, therefore spending less time in the work (i.e. running and sprinting) zone. According to Blair *et al.* (2011) movement activity selection is vital in this process. For example, when compared to a novice, a more experienced Australian rules football umpire covered less distance running backwards (Craig *et al*., 1979). This combines with other limitations, which include the level of physical conditioning (Castagna & D'Ottavio, 2001), game intensity dictated by player activity, and therefore, match requirements (Bangsbo *et al*., 1991; Catterall *et al*., 1993; Duthie *et al*., 2005) and a resultant level of physical fatigue (Martin *et al*., 2001; Button & Petersen, 2005).

According to Martin *et al*. (2001), officials play a significant role in the outcome of a match, thus it is crucial to understand the demands and responses and how they relate to performance. As a result, from the substantial change in rugby union (Quarrie & Hopkins, 2007) since the launch of the professional era in August 1995 (Malcolm *et al*., 2004), it is likely that the physical requirements of the match officials have also been further increased (Martin *et al*., 2005). According to Reilly and Thomas (1986) and Tomporowski and Ellis (1986) the relationship between activity-induced fatigue and DM has become increasingly recognised, highlighting the importance of knowing the current and typical work rate demand patterns in match officials (Blair *et al.,* 2011).

Refereeing a Super 14 (Southern hemisphere premier provincial competition) rugby match involves substantial physical demand; therefore it is of utmost importance that these referees are in good physical condition (Blair *et al.* 2011). Dascombe *et al*. (2003) and Martin *et al*. (2005) reported that the physical component of match performance will probably be affected by a referee's age, anthropometrical characteristics and level of physical conditioning. Additionally, it is also expected to have an influence on their DM performance. Only a small number of previous investigations have described the personal factors of those who manage rugby union (Dascombe *et al*., 2003; Kelly *et al*., 2003a, 2003b; Martin *et al*., 2001; Martin *et al*., 2005). They suggested that more experienced referees have the ability to conserve energy. Dascombe *et al*. (2003) reported that this would result from an ability to anticipate play and could involve a reduction of functional movements that consume substantial energy, and therefore reduce the effects of fatigue (Bangsbo *et al*., 2004). According to Kelly *et al*. (2003b) distance demands have shown to be altered due to deviations in match official movement activities in order to conserve energy. Specifically, with their ability to anticipate play, more experienced officials seem to conserve energy through rest (i.e. standing still, walking and jogging) (Duthie *et al*., 2003). Subsequently, experienced officials have been shown to travel shorter distances.

3. Physical capacities of lead-rugby union referees

3.1 Physiological Response

According to (Drust *et al.,* 2000), the interest in intermittent exercise in sport has increased due to its closer resemblance to that seen in team sports. Many of the protocols used in these intermittent exercise studies are based on information from match analysis and may employ a range of work intensities and durations (Drust *et al.*, 2000). Rugby involves periods of high-intensity activity interspersed with periods of incomplete recovery and players require qualities such as endurance, speed, agility, and power (Gabbett, 2002).

The work rate demands and physiological responses of a variety of exercise IHIE athletes have been comprehensively described (Duthie *et al*., 2005; Stolen *et al*., 2005; Wisbey & Montgomery, 2005). According to Blair *et al.* (2011), a drawback of the afore mentioned research is that very little information on the forces and energetics involved with the contact between athletes during actual match play is available. However, the frequency of investigations into those officials who manage is increasing (Johnston & McNaughton, 1994; Coutts & Reaburn, 2000; Martin *et al*., 2001; Kay & Gill, 2003; Mallo *et al*., 2007). Match officials are not involved in the contact elements of intermitted high intensity exercise (IHIE) sport as players are (Castagna *et al*., 2007) thus this type of study may even work more favourably with match officials. Much can be learned from the analysis of soccer match officials as the amount of research conducted far outweighs that of rugby. Jeukendrup *et al*. (1992)

reported that, even though HR response is seen as a superior indicator of whole body metabolic stress as opposed to exercise intensity, work rate demands including speed and distance, as described by time and motion analysis techniques – have been shown to be an accurate and reliable method for tracking athlete movement (Button & Petersen, 2005). Blair *et al.* (2011) reported that although this measurement process has become more prevalent in the available literature, there are limitations that need to be recognised.

3.1.1 Maximal oxygen uptake (VO_{2max})

Maximal oxygen uptake (VO_{2max}) has been proposed as an indicator of aerobic fitness in rugby players (Reid & Williams, 1974). A high VO_{2max} facilitates the repetition of high-intensity efforts, and in soccer is positively related to the distance covered, level of work intensity, number of sprints and involvements with the ball (Helgerud *et al*., 2001).

Assuming that 200 ml of oxygen is consumed per kg of body mass per kilometre of distance covered (Di Prampero *et al*., 1993) it can be calculated that a rugby referee will expend 2826 kJ during an average match, (Martin *et al*., 2001). However, the energy cost of the activity may be underestimated by such calculations because total distance covered does not accurately reflect variations in the metabolic cost of the intermittent activities performed by a referee during match play (Martin *et al*., 2001).

Detail of an IHIE match official's HR performance is provided by the volume of oxygen consumed (VO_{2max}) measure, especially when expressed as percentage maximal oxygen consumption (% VO_{2max}) (Blair *et al.,* 2011). According to Blair *et al.* (2011), the reported values have been used to compare 'stress' responses of players and the officials who manage them. Additionally, with regards to the values for mean game % $VO_{2max,}$ further similarities between these officials from various sports may be seen. According to Weston and Brewer (2002), top class English soccer referees have a mean game % VO_{2max} estimate of 80.5 (VO_{2max}: 50.9 ± 5.7 $ml.kg^{-1}.min^{-1}$). A comparable mean game value of approximately 79 (VO_{2max}: 51.1 ± 4.7 $ml.kg^{-1}.min^{-1}$) for top class rugby referees was reported by Martin *et al*. (2005). These values are greater than that reported by Dascombe *et al*. (2003) on amateur rugby referees, which was 76 (VO_{2max}: 42.2 ± 5.9 ml.kg-1.min^{-1}). Stolen *et al*. (2005) reported a mean match oxygen consumption value of 75% VO_{2max} estimate (VO_{2max}: 45-52 $ml.kg^{-1}.min^{-1}$) for out-field soccer players. Soccer and rugby are quite similar due to the fact that both are running based sports, hence one might expect the comparable VO_{2max} value that has been reported for international rugby forwards of 51.1 (± 1.4 $ml.kg^{-1}.min^{-1}$) (Warrington *et al*., 2001).

However, Duthie *et al*. (2003) reported that these individuals possess a diverse range of physical attributes, proving that comparisons with rugby players are difficult. Blair *et al.* (2011) reported that the limitations for HR measurement (e.g. CV-drift) need to be considered when these results are interpreted. Furthermore, the similarity of 'stress' placed on match officials between various team sports are demonstrated by the values for % VO_{2max} levels reached in matches (Blair *et al.,* 2011). However, the limitations with this measure must be acknowledged as with the use of HR.

3.1.2 Percentage (%) time spent in heart rate (HR) zones

Heart rate (HR) monitoring is appropriate and non-invasive (Castagna *et al*., 2007) and has been recorded in officials from a number of IHIE team sports. However, the limitations that are involved with HR monitoring of athletes need to be acknowledged (Blair, 2008). Essentially it may not be truly representative of the stress involved (Martin *et al*., 2001). Conversely it can provide helpful information about the match officials. More specifically it can assist with the understanding of movement activities selected during a game and subsequent fatigue that may have an effect on performance (Blair, 2008). HR response of rugby referees has been described in certain published investigations (Cochrane *et al*., 2003; Dascombe *et al*., 2003; Kraak *et al.,* 2011a & Kraak *et al*., 2011b). The investigators reported the following variables: (a) mean HR (HR_{mean}); (b) HR response as a percentage of maximum HR (% HR_{max}); and (c) HR response as a relative time percentage (relative time %) working in various HR zones as a % HR_{max}. Correspondingly HR response of refereeing rugby league (Kay & Gill, 2004; Hoare 2008), and for AFL (Elsworthy & Dascombe, 2011) have been investigated by other research groups. Comparatively research studies examining the HR response of soccer officials have been much more; 13 published articles in total (Blair *et al*., 2018). Blair (2008) reported that studies from team sport officials have revealed that although the majority of the time spent and distance travelled is in the rest (i.e. represent standing still, walking and jogging) zone, average HR responses are in the work (i.e. represent HR greater than 80% of maximum game HR) zone as reported with rugby referees. According to Kay and Gill (2004) and Mallo *et al*. (2010) there is a range of extraneous factors that may influence HR, for example, anxiety and match experience. Krustrup and Bangsbo (2001) have reported the reliability of HR measurement as a method to assess physiological stress. Bangsbo *et al.* (2004) noted adjustments in movement pattern behaviour in order to conserve energy, hence explaining some of the discrepancies in reported data. Certain factors such as different level of competition and/or match official age can also contribute to these on-field physical adjustments (Blair *et al*., 2018). Mallo *et al.* (2010) states that although there is a reduced overall physical match performance from the older officials when compared to their younger counterparts, they have shown to keep up with play. This supports the findings from an investigation where contender referees spent more time in the low-intensity HR zones when compared to provincial referees, suggesting an improved game sense from older officials (Kraak *et al*., 2011a). Correspondingly, Weston *et al*. (2006) reported intensities with the higher level competitive soccer leagues. According to Blair *et al*. (2018) two key factors need consideration: the level of competition and game sense development over time by referees. One can conclude that higher levels of competition require more physical work, likely due to the increased pace of play, which in combination with game sense contributes to the work engaged in by the referee (Blair *et al*., 2018). Elsworthy *et al. (*2016) and Martin *et al.* (2005) reported largely consistent HR_{mean} values for rugby referees with an average of approximately 153–154 beats per minute (bpm), however low HR_{mean} responses (122-141 bpm) for two different levels of referees were reported during an investigation with club level matches in South Africa by Kraak *et al.* (2011b). According to Blair *et al.* (2018) the findings could be due to different factors for example: the structure and level of play (club tournament), the match play demands on the players as well as the experience and level of conditioning of the referees. Conversely, overall, similar values to those for rugby referees were reported for soccer and rugby league (Krustrup *et al.,* 2004; Hoare, 2008). A better understanding of physiological response is gained when mean HR data is converted to a percentage of maximum HR (% HR_{max}) (Blair *et al.,* 2018). The investigator observed that rugby referees work within the range of 80-90% HR_{max}, this is regarded as hard work (Table: 2.5) (Blair *et al*., 2018). However, Kraak *et al.* (2011b) reported reduced levels at 68–76% HR_{max} (Table: 2.5) from club level matches in South Africa, overall, these values suggest that high levels of aerobic fitness are required by referees.

An investigation into sub-elite rugby referees reported a mean value of 85% +/- 3.5% HR_{max} (Table: 2.5); this to date is the highest % HR_{max} recorded for rugby referees (Dascombe *et al*., 2003) the results could be due to the inferior conditioning of the officials (Blair *et al*., 2018). According to Hoare (2008) professional rugby league referees has a mean value of 81% HR_{max} when officiating. The reduced value might be due to the referees being professional and a higher level of physical conditioning. Interestingly, investigations into professional football match officials reported values ranging from 85% to 96% HR_{max} (Krustrup *et al*., 2003; Catterall *et al.,* 1993). According to Blair *et al.* (2018) the range validates how HR responses are influenced by of the different competitive levels as the investigation included a wide range of matches, from top league to junior competitions. Blair *et al.* (2018) reported that the reduced values can either be attributed to superior physical conditioning or a reduction in level of competitive play. On the contrary, the elevated values might be indicative of a more continuous style of play in football compared with other IHIE sports. The investigators stressed the importance of acknowledging the method by which HR_{max} has been calculated (direct measure versus indirect estimation) as this might be contributing to variation in reported data (Blair *et al.,* 2018). Furthermore, Blair *et al.* (2018) reported that the understanding of HR response is extended when the time spent above or below of the % HR_{max} is examined. Officiating rugby is of an anaerobic nature as most of the game HR is spent above 80% HR_{max} (work zone); this is supported by time spent at varied HR zones (Table: 2.5). In comparison, English Premiership referees spent 53% of game time in the work zone (Martin *et al*., 2005) as to the 64% of game time by Super 14 Rugby referees (Blair *et al.,* 2011). This, according to Blair *et al.* (2018), suggests that a higher level of stress were placed on the oxygen transport system during the Super 14 Rugby competition and/or there is an inferior level of hard aerobic conditioning present. The difference in playing style and increased professionalism from 2005 to 2011 might be additional contributing factors. Interestingly, it was revealed that 53% of game time was spent in the 80–90% HR_{max} zone alone during an investigation into English FA Premier League referees (Weston & Brewer, 2002). By comparison, referees officiating Super 14 Rugby only spent 42% of their time (42%) in this zone, thus providing further evidence of the contrasting physiological requirements when officiating different IHIE sports and even different competitions in different parts of the world at the highest level, and/or the nature of the game itself (Blair *et al.,* 2018).

3.2 Work Rate Demands

3.2.1 Anaerobic Power (AnP)

The ability to generate high muscular power is an important attribute of rugby, where players are required to have high muscular power to perform the tackling, lifting, pushing, and pulling tasks that occur during a match (Meir *et al*., 2001; Gabbett, 2005). However, referees need power and speed to stay with players to be in a position to make the correct decisions.

According to Cheetham *et al*. (1988), the energy contributions during the work periods in intermittent team activity are primarily anaerobic in nature. For the players, power in rugby is required in the execution of tackles, explosive acceleration, scrummaging, and forceful play during rucking and mauling (Cheetham *et al*., 1988; Quarry, 2011).

An investigation in the northern hemisphere on the activity analysis of elite-level English premiership lead rugby referees by Martin *et al*. (2001), reported the following metrics: 8581 ± 668m total distance covered and ;> 600 transitions of locomotory mode. Martin *et al*. (2001) also stated that additional metabolic demands on referees are enforced by the short-duration sprint bouts and the associated acceleration and deceleration. Furthermore, it is reported that the referee's ability to repeat and recover from these high-intensity bouts seems likely to be an important influence on their refereeing performance (Blair *et al*., 2018). Martin *et al*. (2001) reported that on average, the referees ran for 9.8 + 2.3%, and sprinted for 1.0 + 0.4% of the total playing time. No significant differences in the proportion of the playing time spent in these activities between the two halves of matches were reported. The ratio between time spent in high intensity activities (running and sprinting) to low intensity activities (standing, walking, jogging) was approximately 1:8. According to Cochrane *et al*. (2003), New Zealand Rugby Union (NZRU) referees (n = 3) spent on average 1.2% of the time at maximal sprinting, 6.7% at moderate sprinting, 15.2% on jogging, 20.5% on walking, 4.8% on moving sideways, 3.5% on turning, 32.9% on remaining stationary, 12.6% on moving backwards slowly and 2.6% on moving backwards fast. As far as physiological response of the movement patterns is concerned, Cochrane *et al*. (2003) also found that on average the rugby union referees spent 10% of a match at their maximum, 43% at supra-threshold, 36% at anaerobic threshold and 11% at sub-threshold heart rate zones. They also reported that the mean work to rest ratio was 1:5. There was no indication if the movement patterns or the work to rest ratio differed between the two halves of match-refereeing.

Match officials vary their movement pattern behaviour in order to conserve energy; this has been shown to alter Sp-D demands (Craig *et al*., 1979; Kelly *et al.,* 2003b; Castagna *et al*., 2004; Krustrup *et al*., 2004). According to Duthie *et al*. (2003), with the ability to anticipate play, more experienced officials seem to conserve energy through rest (i.e. standing still, walking and jogging). Subsequently, they have been shown to cover smaller total distances, and with this, less time in the work (i.e. running and sprinting) zone (Blair *et al.,* 2011). Movement activity selection is crucial in this process; for example, a more experienced Australian rules football umpires covers less distance running backwards when compared to a novice (Craig *et al*., 1979). When these limitations are combined with the varied methodologies used by investigators, the Sp-D discrepancies that have been reported are better understood. Despite these, the measurement of Sp-D demands can still benefit the design of physical conditioning programmes and assessment criteria that help to optimise game performance (Button & Petersen, 2005). Further, optimal benefits from these programmes are then obtained when the conditioning stimulus represents or overloads the actual response and demand that is required by the game (Dascombe *et al*., 2003; Weston *et al*., 2004).

However, the way in which motion categories are assigned as either being work versus rest has large implications for the resultant ratio that is derived. For example, an investigation into

Australian Rules Football players considered work as any running pattern greater than 2.2 ms^{-1} (Wisbey & Montgomery, 2005). This is well below the 3.6 ms^{-1} mentioned by (Blair *et al.* 2011), which was the same as that used for top-class association football referees (Mallo *et al*., 2007). Furthermore, the first half W:R (1:5.9) was similar to the second half and W:R was also similar between eight game segments throughout the match. This indicates that while the duration of Sp work and rest periods increased in the second half, the Sp demand was reasonably constant throughout the game.

Blair *et al.* (2011) reported that Sp work and rest provide some further understanding of the physical requirements of refereeing rugby Super 14 games. While the Sp response was similar throughout matches, the W:R suggests that the anaerobic metabolism plays an important role throughout match play. Furthermore, Blair *et al*. (2011) indicates that the mean game work to rest ratio during the 2007 Super 14 of 1:6.7 indicated that there was time available between passages of high intensity play to recover. While this is comparable to the work to rest ratios of 1:8 and 1:9 that have been reported for elite-level English Premiership (Martin *et al*., 2001) and international (Kelly *et al*., 2003b) rugby union referees, it seems as though the amount of time available to recover has reduced, hence less time is being spent in the rest category (Blair *et al.,* 2011). According to Blair *et al*. (2011), the results may be an indication of how the game demands have changed over the seven to eight years that have lapsed since these measures were taken.

3.2.2 Metabolic Power (MP) and Speed

The ability of a rugby referee to keep up with play to be in a good position is critical in allowing correct decisions to be made. Therefore, the ability of the rugby union referee to meet the physical and physiological demands imposed during match play is believed to be a necessary prerequisite for optimal positioning and successful refereeing (Suarez-Arrones *et al.,* 2013)

Metabolic power is defined as the product of the instantaneous velocity in running together with the corresponding energy cost per unit body mass and distance (Osgnach *et al.,* 2016). According to Gaudino *et al*. (2013) and Osgnach *et al*. (2010) the power output and energy costs of intermittent running can be estimated by the metabolic power calculations. The advances in GPS technology combined with a better understanding of the energetics of accelerations and decelerations have made it possible to estimate the duration of the instantaneous metabolic power requirements of a player in various team sports (Di Prampero *et al*., 2005). However, to date too little research is available on metabolic requirements for match officials.

Speed is used to describe how fast an object is moving, that is the distance an object will travel in a given time (Hamilton *et al*., 2008, p.278). According to Jaco Peyper (Jaco Peyper, personal communication, 22 April 2014), speed and agility is an important aspect of elite-level refereeing. This is a reasonable argument, especially to ensure that the referee is at the next breakdown early and comfortably, makes a good judgement and has possible influence on the way players act. The most significant speed related factor is most probably the continuous accelerations and decelerations demanded by the game, thus physical conditioning of this aspect is very important. Top end speed is also a good asset, but having a good quick take off and efficient stop is the key factor in phase play and more important than top end speed of 100m athlete. This is supported by Wayne Barnes (Wayne Barnes, personal communication 25 April 2014). Furthermore he adds that speed helps "when caught out of position and you need to make up a couple of metres". Craig Joubert (personal communication, 24 April 2014) believes that the ability to cover distances quickly might allow the referee to keep up with play and contribute to quality DM. More specifically, he adds that speed off the mark is very important as it contributes to optimal positioning in a dynamic environment.

3.2.3 Total distance and distances covered in each speed zone

The distance covered during a rugby union game includes walking, jogging, running, sprinting, backwards movements, sideways movements and pivoting (Martin *et al.,* 2001; Cochrane *et al*., 2003). According to Kraak *et al.* (2011a) and Mascarenhas *et al.* (2009) TMA includes the use of modern global positioning system (GPS) units and digital video, which allows for tracking of these movements in their natural environments. Kraak *et al*. (2011a) reported that modern technology has revealed a heightened ability to conserve energy and to anticipate play by experienced referees. An investigation into test level rugby referees reported that those referees at test level cover less distance running backward when compared with referees at a provincial level (Kelly *et al.,* 2003b). Various investigators (Castagna & D'Ottavio, 2001; Catterall *et al.,* 1993; Duthie *et al*., 2005; Button & Peterson 2005; Martin *et al.,* 2001) acknowledged other factors that influence the work-rest activity pattern: the level of physical conditioning; game intensity dictated by player activity, and therefore, match requirements; and the resultant level of physical fatigue. According to Blair *et al.* (2018), when combined, these factors together with the varied methodologies used by researchers, give a better understanding of the speed distance discrepancies that have been reported. These authors also reported that four published investigations and two conference proceedings focused on the work rate demands of lead rugby referees. The researcher's specifically highlighted distance traveled, and speed obtained within various movement categories. By comparison, there are five known publications into rugby league referees and three recent AF publications in which the work rate demands have been reported on (Blair *et al.,* 2018). However, similar to HR response, there have been more research studies on the work rate demands of soccer officials (Blair *et al.,* 2018).

According to Blair *et al*. (2018) the majority of time spent and distance travelled while completing the various movement patterns is within the low-intensity zone (rest zone) for lead rugby referees, where it is typically set at <3.6m/s^{-1} and involves standing still, walking, jogging and utility patterns (sideways and backwards) (Table: 2.4). An investigation involving elite level international and provincial level referees reported that referees spent up to 93% of playing time in the low-intensity zone (Kelly *et al*., 2003b) (Table: 2.4). By comparison this value is similar to those reported by Cochrane *et al.* (2003) in a study involving provincial rugby referees in New Zealand. However, these values are greater than the reported values of 77% observed in English Premiership (Martin *et al*. 2005) and Super Rugby (Blair *et al.,* 2011) (Table: 2.4), respectively. According to Mallo *et al*. (2010) soccer researchers regularly report speed over a percentage of playing distance, however, the majority (60%) of the total distance traveled is in the low-intensity zones (standing, walking, and jogging). Moreover, these low-intensity zones are characterized by frequent bouts of high-intensity activity. Cummins *et al.* (2013) reported that the inconsistencies in reported measures could be explained by a lack of standardised speed zones or definitions between sports. According to Blair *et al.* (2018) these variations in reported data could also be explained by the variations in game styles and the rules of play within and between sports. Distances of 8,518 +/- 668m were reported during a study of rugby referees officiating in the English Premiership (Martin *et al.,* 2001) (Table: 2.4). This value is greater than the reported distances of 5,139m – 6,389m for Super 14 rugby players (Austin *et al*., 2011). This value can be explained by rugby referees', as well as soccer officials', need to keep up with play at all times (Stolen *et al.,* 2005). An investigation comparing Super Rugby referees with international rugby referees reported that international rugby referees travel less distance (6,200m) (Table: 2.4), than their Super Rugby counterparts (8,000m) (Kelly *et al.,* 2003b). These lower values could be explained by the more experienced referees being extra economical when it comes to running patterns and/or the nature and pace of international versus provincial games (Blair *et al.,* 2018). It has been reported that rugby league referees travel distances (6,700m) similar to international rugby referees (Kay & Gill, 2004). Even though these two codes involve different game styles, the lengths of each game are the same (80 minutes). By comparison, distances covered by soccer and AF officials consistently exceed 11,000m (Coutts & Reaburn, 2000; Elsworthy & Dascombe, 2011; Weston *et al.,* 2011). This is primarily due to the continuous nature of play. Furthermore, additional factors such as length of play, rule changes and style of play, as well as pitch size, can also help to explain the difference in distance covered by match officials across various sports (Blair *et al.,* 2018).

Table 2.4: Rugby union referee work rate demand

Author(s)/ publication year	Subjects/matches	% Total playing time								
			Rest					**Work**		
			Stand still - limited				**Low**	**Medium**	**High**	**Maximal**
		Locomotory category Distance (m)	**Stand still**	**Walking and Sideways step**	**Walking backward**	**Turning/ pivoting**	**Jogging**	**Running**	**Sprinting**	**>Sprint**
Blair *et al*. (2011)	Super 12 Rugby n = 9,referees (12 games in 2007)	8,030 +/- 506.6	76.6 +/- 1.8			_	10.9 +/- 0.9	**8.2 +/- 0.9**	**4.3.9 +/- 1.5**	**0.1 +/- 0.1**
Kraak *et al.* (2011b)	National Club Rugby Championship (Stellenbosch, South Africa) Provincial and (Contender) n = 8, referees (16 games in 2007)	_	36.5	30.3		14.3	14	_	**4.9**	
Kraak *et al.* (2011a)	National Club Rugby Championship (Stellenbosch, South Africa) Provincial and (Contender) n = 8, referees (16 games in 2007)	_	36 (36.5)	30.7 (30.8)		14.3 (13.6)	13.05 (14)	_	**5.8 (5)**	
Cochrane *et al.* (2003)	Division 2 New Zealand National Pacific Championship n = 3, referees (3 games in 2002)	_	32.9 +/- 1.4	20.5 +/- 1.8 (walk); 4.8 +/- 0.9 (sideways)	12.6 +/- 1.0 (slow); 2.6 +/- 0.2 (fast)	3.5 +/- 0.2	15.2 +/- 1.9	**6.7 +/- 0.4**	**1.2 +/- 0.2**	
Kelly *et al.* (2003a)	Int and S12 n = 11, Int referees (8 Int. and 23 Prov games in 2000– 2001)	6,244 (Int) 7,358 (Prov)	41.6	24.3 (1.66)	11.2 (1.41)	_	18.5 (2.76)	**3.6 (4.12)**	**0.8 (6.06)**	
Martin *et al.* (2001)	English Premiership n = 13, referees (33 games in 1998 1999)	8,581 +/- 668	37 +/- 11	29.5 +/- 7.2	9.9 +/- 3.2	_	12.8 +/- 3.2 (3.81)	**9.8 +/- 2.3 (4.73)**	**1.0 +/- 0.4**	

Contextual review of physical requirements of refereeing rugby union at elite level (Blair e*t al.,* 2018).

Table 2.5: Rugby union referee physiological response

Author(s)/publication year	Subjects/Matches	Mean HR (bpm)	Mean %HRmax	%HRmax	Relative time %
Blair *et al*. (2011)	Super 12 Rugby n = 9,referees (12 games in 2007)	154 +/- 9.6	82.5 +/- 3.5%	<70 70 – 79 80 – 89 >90	10.0 26.1 41.6 22.3
Kraak *et al. (*2011b)	National Club Rugby Championship (Stellenbosch, South Africa) Provincial and (Contender) n = 8, referees (16 games in 2007)	Provincial: 141.56 +/- 60.54	Provincial: ~76	<74	48.6 (45.7)
		Contender: 122.63 +/- 21.2	(Contender): ~68	75 – 84 85 – 95 >95	27 (34.5) 17.4 (14.5) 7 (5.2)
Kraak *et al*. (2011a)	National Club Rugby Championship (Stellenbosch, South Africa) Provincial and (Contender) n = 8, referees (16 games in 2007)	_	_	<74 75 – 84 85 – 95 >95	41.5 41.3 12.12 4.9
Cochrane *et al.* (2003	Division 2 New Zealand National Pacific Championship n = 3, referees (3 games in 2002)	Highest individual: 179 +/- 5.1	_	<74 75 – 84 85 – 95 >95	11 36 43 10
Dascombe *et al.* (2003)	Regional Australian n = 12, referees (15 sub elite games 2002)	155 +/- 17	85 +/- 3.5	<70 70 – 79 80 – 89 >90	4.7 16.6 42.1 36.6
Kelly *et al.* (2003a)	Int and S12 n = 11, Int referees (8 Int. and 23 Prov games in 2000– 2001)	_	_	80.5 <70 70- 79 80 – 89 >90	 17.5 18.7 36.7 27.1
Martin *et al.* (2005)	English Premiership n = 13, referees (33 games in 1998 1999)	153 +/- 9: energy expenditure (kJ)	84 +/- 5	<70 70- 79 80 – 89 >90	5 +/- 6 42 +/- 22 24 +/- 23 29 +/- 19

Contextual review of physical requirements of refereeing rugby union at elite level (Blair e*t al.*, 2018).

CHAPTER 3

RESEARCH METHODOLOGY

3.1. Introduction

The aim of this study was to provide accurate, up-to date information on the physiological response and work rate demands placed on elite lead rugby union referees during matches. The primary aim was to determine the physical demands of elite lead rugby referees by measuring the: duration of a match (min), total distance covered (m), % time spent in each heart rate zone (% HR), % time spent in each speed zone (% Sp), number of high-speed accelerations, number of high-speed decelerations, number of surges (sprints), and metabolic power (W/Kg) during each game. And the secondary aim was to assess whether the physical demands changed during the course of the match (first half versus second half).

The primary researcher is appointed as a consultant by SA Rugby as a conditioning coach for elite South African rugby referees. This research project on retrospective World Rugby (WR) referee data will provide valuable information to governing bodies regarding the specific nature of the physical requirements placed on elite lead rugby referees during matches. The results will also provide conditioning coaches and elite lead rugby referees with valuable information that can assist with the development of physical programmes that are both individualised and specific. Furthermore, the findings of this study will also assist referees/trainers with compiling and implement recovery protocols.

This chapter elaborates on the study design and methodology used to answer the research question stated in chapter one. A detailed outline is given on the specific rugby referees included in the study and the eligibility criteria for these elite lead rugby referees. Further insight is given into the research process including the participants, data collection and analysis procedure, equipment used and the envisaged implementation of the findings from the study. In preparation for this study, literature was collected from electronic databases such as Kovsiekat, Pubmed, EbscoHost, ScienceDirect, as well as relevant academic journals and textbooks to inform methodological considerations.

3.2. Theoretical perspectives on research design and methodology

According to Peat and Barton (2005) and Prasad (2013) research is a process for acquiring new knowledge in a systematic approach involving diligent planning and interventions for discovery or interpretation of newly gained information. Clifford *et al*. (1997:56) noted that the study design can be defined as “the overall plan for deciding how information or data will be collected and analysed”. Descriptive research is a general overview of a subject through observation and description of its behaviour without any influence (Shuttleworth, 2008). Mouton (2001) concludes that research methodology describes the process that is followed by the researcher to conduct research.

Thomas *et al*. (2011) noted that the quantitative research process can be characterized by three concepts, namely that it is systematic, objective and uses numerical data from a selected sub-group in order to generalize the findings to similar populations. It also gives researchers the ability to study variables that differ in magnitude through a process of scientific and statistical analyses (Gravetter & Forzano, 2012). It must be mentioned that the research project will only commence once retrospective ethical approval and informed consent are given from the relevant professional bodies (World Rugby Referee Manager and the Home Union Referee Managers as well as the referees investigated).

3.3. Study design

A quantitative cross-sectional research design was conducted to determine the physical demands of professional rugby referees through the use of global positioning satellite (GPS) technology. This research study investigated the physiological response and work rate demands of elite lead rugby referees with the aim to deliver objective data with regards to the different variables present during refereeing a rugby match. The investigation involved analysis of GPS data gathered from World Rugby (WR) elite southern and northern hemisphere panel referees' database who officiated at an international level. The following variables was measured during a full game of rugby: duration of a match, total distance covered (m), % time spent in each heart rate zone (% HR), % time spent in each speed zone (% Sp), number of high-speed accelerations and decelerations, number of surges (sprints), and metabolic power (W/Kg).

3.4. Participants

De Vos *et al*. (2005) define the target population as a group of individuals sharing certain specified characteristics. Bowlin (2014) divided sampling into two categories, namely sampling for quantitative research and sampling for qualitative research. Both can further be separated into non-random sampling and random sampling (simple random sampling, unrestricted random sampling, cluster sampling, systematic sampling and stratified random sampling (Jones, 2015). This study made use of a non-random convenient sample. Only members of World Rugby's elite refereeing panel participated in the study. Convenient sampling is described as a cohort of subjects that happen to be in the right place at the right time (Polit & Hungler, 1993).

This study's aim was to collect data from the database of the 22 WR's elite referee panel. Participation was voluntary but was endorsed by WR. Prior to commencement of the study, referees attended an information session outlining the procedure and purpose of the research. Referees were asked to read an information sheet on the proposed research and sign a consent form. Each WR referee gave consent to WR to be monitored. Only approval from the referee to use his GPS data stored on the WR database was needed. Study participants (World Rugby's elite referee panel) had to adhere to the following inclusion criteria.

3.4.1. Inclusion criteria

1. The referee must be part of WR's elite referee panel.
2. The referee must give retrospective ethical approval and informed consent that his data can form part of the study.
3. The referee must have refereed the full game with his GPS unit.
4. The referee must be able and willing to give consent in English.

3.4.2. Exclusion criteria

1. The referee does not want to participate in the study.
2. If the data on the GPS system is faulty.

3.4.3. Withdrawal of study participants

In the case where the referee informed the researcher that he does not want his data to be used in the research project.

3.5 Equipment

GPSports SPI HPU global positioning system (GPS) units were used to gather data for this research project. The device measures 74mmx42mmx16mm with a weight of 67 g. GPS data is recorded at 15 Hz with accelerometer and gyroscope data at 100 Hz each. The device is water resistant and has a battery life of more than six hours. Accelerometers have been reported to be reliable in the measurement of biomechanical load (Boyd *et al*., 2011). Johnston *et al*. (2014) reported that 10 Hz and 15 Hz GPS units are valid and reliable measuring instruments for measuring total distance covered and are more reliable measures of movement demands than 1 Hz and 5 Hz GPS units. Despite a tendency to overestimate total distance covered, the 10 Hz GPS units provide a valid measure of total distance covered (<1% error). To conclude, this error is minimal.

3.6. Data collection

The data collection involved seventeen (17) WR elite panel referees (five referees did not give consent) from both the southern and northern hemispheres, refereeing at international level. The data was collected over a period of two years (2015 & 2016) in the following tournaments and matches: Rugby World Cup, Six Nations, Rugby Championship, Super Rugby Tournament, European Challenge Tournament, June International Test Window and November International Test Window. Information from each game was exported from the TeamAMS software (GPSportsTM, Canberra, Australia) spread sheet (Microsoft Excel) and then uploaded to the SPSS 15.0 statistical programme for further analysis. Firstly, a descriptive analysis of the data was done. Secondly, a discriminant analysis was done. Coefficients (SC) greater than or equal to |.30| were considered relevant for the interpretation of the linear vectors. All of the statistical analyses were done with a level of significance of $p \leq 0.05$.

Each referee was equipped with a (GPS). The referee wore the GPS unit in a specially designed GPS vest underneath the jersey between his left and right scapula in the upper thoracic spine area. The vest is designed to be comfortable and prevent unwanted movement of the GPS unit, but will not hinder performance.

The referee himself was responsible for the positioning of the GPS in the vest prior to the game. The GPS unit is fitted and switched on ten minutes before warm-up starting approximately 30 minutes before kick-off. Warm-up data was also collected but was separated from match play data during analysis. GPS units were switched off directly after the match by the referee. After the match, data was downloaded to a personal computer and then sent to WR database. World Rugby oversaw reliability of the data of the referees, before data was sent to the researcher. The reliability of the analysis was determined by the re-analysis method (test-retest reliability) for inter-rater reliability (James *et al*., 2013). This method entailed that the researcher did a re-analysis of the GPS data after the original analysis by WR. Further analysis was carried out using TeamAMS Software.

Firstly, the primary researcher scrutinized the data files of every rugby referee to make sure that no faulty data collection took place. This primary research extracted and analyzed the following variables: duration of a match (min), total distance covered (m), % time spent in each heart rate zone (% HR), % time spent in each speed zone (% Sp), number of high-speed accelerations and decelerations, number of surges (sprints), and metabolic power (W/Kg).

The current study made use of the following heart rate zones for elite lead rugby referees – Heart Zones 1 – 2 (≤80% HRmax) = 0 – 144bpm and Heart Rate Zones 3 - 6 (≥80% HRmax)

= 144 – 216bpm; this is a combination of the different zones as stipulated by Blair *et al*. (2011). Blair *et al*. (2011) divided the heart rate zones into four categories: light stress (<70% HRmax), moderate stress (70 – 79% HRmax), threshold stress (80 – 89% HRmax) and maximum aerobic stress (>90% HRmax), where zone 1 and 2 are the rest zone and zone 3 and 4 are seen as the work zone. However, previous research by Kraak *et al.* (2011b) and Cochrane *et al.* (2003) made use of the four heart rate zones as stipulated by Deutsch *et al.* (1998): sub-threshold (>74% HRmax), anaerobic threshold (75 – 84% HRmax), supra threshold (85 – 95% HRmax) and maximal (>95% HRmax).

Furthermore, the study made use of the following speed zones for elite lead rugby referees: speed zone 1 – 2 (standing still and walking) < 2.3m.s^{-1}, speed zone 3 (jogging) = 2.3 - 4.1m.s^{-1} and speed zone 4 – 6 (work zone) = 4.1 – 9.6m.s^{-1}. Blair *et al*. (2011) divided the speed zones into two categories, the rest zone (≥3.6m.s^{-1}) and work zone (≤3.6m.s^{-1}). High speed accelerations and high-speed decelerations where defined as speeds ranging between 2.4 – 4.8ms^{-1} (Cummins *et al.,* 2013).

3.7. Pilot study

A pilot study involves a small-scale research study which is conducted before the intended study to investigate if crucial components such as the planning and execution of the testing procedures will be suitable for the main-study (Cocks *et al.,* 2013). According to Burnham *et al.* (2008), pilot studies enable the researcher to:

- Test the accuracy of the sampling frame.
- Alert the researcher to unforeseen difficulties.

A pilot study was done on two referees' GPS data to further identify possible errors and to ensure that the recorded GPS data was understandable, recorded effectively, and could be analysed. The effectiveness of the data sheets, equipment, and protocols was established.

3.8. Statistical analysis

Descriptive statistics: Referee characteristics

Descriptive statistics (mean, standard deviation, min, Q1, median, Q3, max) for the mass, age, height, maximum HR, and maximum speed of the 17 referees are provided. Furthermore, the number of games refereed by each referee, as well as the percentage of all games in the data base, is provided.

Descriptive statistics: Quantitative performance indicators

Descriptive statistics (mean, min, Q1, median, Q3, max) for the following quantitative performance indicators are provided, separately for each half of the game, and for the total game:

- duration of a match (min)
- total distance covered by the referee (m)
- time spent in each speed zone (%)
- time spent in each heart rate zone (%)
- number of high-speed accelerations and decelerations
- number of surges (sprints)
- metabolic power (W/Kg).

Since the data for different games, but for the same referee, correlates, the standard deviation was not calculated. The speed zones were grouped as follows: Zone 1-2; Zone 3, Zone 4-6. Similarly, the HR zones were grouped as: Zone 1-2; Zone 3-6.

Descriptive statistics: Count performance indicators

Descriptive statistics (mean, min, q1, median, q3, max) for the following count performance indicators are provided, separately for each half of the game, and for the total game:

- Number of high-speed accelerations
- Number of high-speed decelerations
- Number of sprints/surges

Comparison of game halves: Quantitative performance indicators

The two halves of each game were compared with respect to the quantitative performance indicators using a mixed model for repeated measures (MMRM), where the repeated measurements for each performance indicator were the two data points recorded in each half of the game. An unstructured (UN) covariance structure was fitted for those two repeated measurements. Furthermore, the factor “half” (first half versus second half) was fitted as a fixed effect, and the factors “referee”, and the “referee x half” interaction term, were fitted as random effects. The random effects were fitted to allow for correlation between the data measured for the same referee (in different games). Based on this mixed model, estimates of the mean values of the performance indicator in question for each half of the game were calculated. An estimate for the “second half – first half” mean difference, the 95% confidence interval (CI) for the mean difference, and the associated P-value (testing the null-hypothesis of zero mean difference) were calculated. Lastly, box plots of the individual "second half – first half" differences for each performance indicator are provided, grouped by referee.

Comparison of game halves: Count performance indicators

The two halves of each game were compared with respect to the count performance indicators using a generalised linear mixed model (GLIMM), where the repeated measurements for each performance indicator were the two data points recorded in each half of the game. An unstructured (UN) covariance structure was fitted for those two repeated measurements. Furthermore, the factors "referee" and "half" (first half versus second half) were fitted as fixed effects. Based on this GLIMM, estimates of the mean values of the performance indicator in question for each half of the game were calculated (that is, the mean rate of occurrence per half of a game); an estimate for the "second half / first half" rate ratio, the 95% confidence interval (CI) for the rate ratio, and the associated P-value (testing the null-hypothesis of a rate ratio of 1) were also calculated. Lastly, box plots of the individual "second half – first half" differences for each performance indicator are provided, grouped by referee.

Comparison of referees: Quantitative performance indicators

Referees were compared with respect to the quantitative performance indicators with respect to the data for the whole game as follows:

- duration of a match (min)
- total distance covered by the referee (m)
- time spent in each speed zone (%)
- time spent in each heart rate zone (%)
- number of high-speed accelerations and decelerations
- number of surges (sprints)
- metabolic power (W/Kg).

Referees were compared with respect to the quantitative performance indicators (sum or average values for the whole game, as indicated above) using a linear mixed with no fixed effect, and "referee" as random effect. The variance component due to referee and the residual variance were calculated. Based on these estimates, the intra-class correlation coefficient was calculated as the ratio of the variance component due to referee, and the sum of the referee and the residual variance components. A p-value for the "referee" variance component (testing the null-hypothesis that the variance component is zero), is reported. Box plots of the individual values for each performance indicator (sum or average values for the whole game, as indicated above) are provided, grouped by referee.

Comparison of referees: Count performance indicators

Referees were compared with respect to the count performance indicators with respect to the data for the whole game as follows:

- Number of high-speed accelerations: Total (sum of data for two halves)
- Number of high-speed decelerations: Total (sum of data for two halves)
- Number of sprints/surges: Total (sum of data for two halves)

Referees were compared with respect to the square root of the above count performance indicators (sum of the values for the whole game, as indicated above) using a linear mixed with no fixed effect, and "referee" as random effect. (The data was transformed using the square root since this transformation stabilises the variance for Poisson distributed data.) The variance component due to referee and the residual variance were calculated. Based on these estimates, the intra-class correlation coefficient was calculated as the ratio of the variance component due to referee, and the sum of the referee and the residual variance components. Based on these estimates, the intra-class correlation was calculated as the ratio of the variance component due to referee, and the sum of the sum of the referee and the residual variance components. A p-value for the "referee" variance component (testing the null-hypothesis that the variance component is zero), is reported. Box plots of the individual values for each performance indicator (sum of the values for the whole game, as indicated above) are provided, grouped by referee.

3.9 Methodological errors

Systematic methodological errors were minimized by using the same equipment (GPSportsTM SPI HPU GPS units) supplied by WR. All the previous-mentioned equipment was calibrated as per manufacturer's specifications, and all the referees were monitored according to the WR protocol. Random methodological errors that may have occurred include changes in weather on the different days that the matches were played. Rain or cloudy weather may have interfered with the GPS signal of the GPS sport system. The data may also have been influenced by external factors that may lead to early fatigue by referees such as games refereed in extremely hot conditions and the number of games refereed in the last month. Furthermore, game plans may also differ from one match to the other and could have an effect on the results of the referee's physical demand.

3.10 Implementation of findings

This research project will provide valuable information to governing bodies (WR) regarding the specific nature of the physical requirements placed on elite lead rugby referees during matches. The results will also provide conditioning coaches and referees with valuable information that can assist with the development of physical programmes that are both individualised and specific.

3.11. Ethical aspects

The study did not involve any physical contact with the referees, as data were collected via World Rugby using the global positioning system (GPS – GPSportsTM: SPI HPU) that they wore in each officiating game.

The project only commenced after ethical approval and informed consent was given from the following professional bodies:

- Health Sciences ethics committee of the University of the Free State (HSREC 151/2017 (UFS-HSD2017/1426);
- The Department of Exercise and Sport Sciences at the University of the Free State
- World Rugby Referee Manager
- Referees giving informed consent that their match GPS, weight, height and BMI data can be used in the study
- Home Union Referee Managers

The research proposal was submitted to the Ethics Committee of the Faculty of Health Sciences prior to commencement of the study.

Each referee signed an informed consent before the study commenced. The study was voluntary and referees did not receive any financial compensation for their participation. Referees will be informed beforehand that the results of the study will be published in relevant scientific journals. Personal information was kept confidential at all times and under all circumstances.

CHAPTER 4

RESULTS

4.1 Introduction

The primary aim of this study was to profile the physical characteristics of elite lead rugby referees and to determine the physical demands placed on those referees during rugby matches using an accelerometer (GPS – GPSportsTM: SPI HPU). GPS data provided the following match and performance characteristics:

- duration of a match (min)
- total distance covered by the referee (m)
- time spent in each speed zone (%)
- time spent in each heart rate zone (%)
- number of high-speed accelerations and decelerations
- number of surges (sprints)
- metabolic power (W/Kg).

A secondary aim of the study was to assess changes in the physical demands and performance of referees during the course of the match (first half versus second half). A third aim was to assess whether physical demands and performance of referees were consistent across the sample of referees.

This chapter will present the results from the study. In Section 4.2 the demographic information and physical profile of the participating referees are presented, while Sections 4.3 and 4.4 present the GPS data (match and performance characteristics) and their analysis. The match and performance characteristics collected from each referee and match, listed above, were analysed as follows:

- Firstly, in Section 4.3, the individual differences between the first and second halves of each match with respect to these variables were considered; this analysis was done to assess if physical demands and performance of referees changed during the course of the match to see, for example, whether any tiring effect could be observed by comparing first and second half match data.
- Secondly, in Section 4.4, the total values of the GPS variables for the match were considered; this analysis was done to assess if physical demands and performance of referees were consistent across the sample of referees.

4.2 Demographic information of participants

4.2.1 Number of referees and number of games analysed

Data were collected for seventeen (17) World Rugby (WR) elite lead panel referees from eight countries located in both the southern and northern hemispheres, over a period of two years (2015 – 2016) in the following professional tournaments and matches: Rugby World Cup, Six Nations, Rugby Championship, Super Rugby Tournament, European Challenge Tournament, June International Test Window and November International Test Window. A total of two hundred and five (n=205) matches officiated by the 17 participating referees were analysed. Only matches where a single referee officiated during the whole match (both halves) were included in the data base for this study. Because of the different experience levels of the referees, the nationality of the teams involved in the matches, and the availability of GPS reception in the stadium the numbers of matches officiated by the various referees differ and are presented in Table 4.1.

Table 4.1: Data base: Number of games officiated per referee

Referee No	Frequency	Percent %
1	2	1.0
2	22	10.7
3	9	4.4
4	28	13.7
5	9	4.4
6	12	5.9
7	32	15.6
8	8	3.9
9	5	2.4
10	3	1.5
11	12	5.9
12	15	7.3
13	18	8.8
14	14	6.8
15	6	2.9
16	2	1.0
17	8	3.9
Total	**205**	**100**

Note: To maintain confidentiality, the referees were arbitrarily allocated a number from 1 to 17.

4.2.2 Physical profile of the referees

Descriptive statistics for the physical measurements of participating referees (body weight, age; height and BMI) are presented in Table 4.2 below.

Table 4.2: Physical profile of elite Rugby Union referees: Descriptive statistics

Statistic	Variable					
	Age (yrs)	Weight (kg)	Height (m)	BMI	Max HR (b/min)	Max Speed (m/sec)
N	17	17	16	16	17	17
Mean	38.1	83.4	1.812	25.45	186.5	8.37
SD	4.91	5.15	0.04	1.94	6.56	0.40
Min	29	75	1.74	22.6	170	8.0
Q1	35	79	1.79	24.3	185	8.0
Median	38	82	1.80	24.8	185	8.5
Q3	42	88	1.83	26.8	190	8.5
Max	46	92	1.90	29.4	200	9.0

Notes: N: Number of players; SD: Standard Deviation; Q1: First quartile; Q3: Third quartile

4.3 Match and performance characteristics: Differences between first and second halves of match play

4.3.1 Match duration, distance covered and metabolic power

Descriptive statistics for match duration, distance covered by the referee during the match, and metabolic power are presented in Tables 4.3 and 4.4 respectively. Statistics are provided for each half of the match and for the total match.

Table 4.3: Match duration, distance covered and metabolic power: Descriptive statistics

Variable	Statistic	First Half	Second Half	Total
Match Duration (min)	N	205	205	205
	Mean	47.78	49.77	97.55
	Min	40.8	42.5	87.2
	Q1	45.5	47.7	94.5
	Median	47.3	49.5	97
	Q3	49.0	51.4	100.4
	Max	66.1	63.4	115.2

Distance Covered (m)	N	205	205	205
	Mean	3423.91	3402.00	6825.90
	Min	2379.9	2129.8	4836.8
	Q1	3166.9	3100.6	6368.4
	Median	3415.8	3397.1	6811.9
	Q3	3697.4	3679.4	7314.8
	Max	4530.5	4660.7	8774.4
Metabolic Power (W/Kg)	N	205	205	205
	Mean	6.21	5.88	12.09
	Min	4.2	3.2	7.4
	Q1	5.6	5.3	11.2
	Median	6.2	5.9	12.2
	Q3	6.8	6.4	13.2
	Max	8.6	8.2	15.9

Notes: N: Number of players; SD: Standard Deviation; Q1: First quartile; Q3: Third quartile

Results of the statistical comparison of the data for the second and first halves of the matches are presented in Table 4.4 for the three variables match duration, distance covered and metabolic power.

Table 4.4: Match duration, distance covered and metabolic power: Statistical comparison of second and first match halves

Performance indicator	Mean		Comparison "Second – First Half"		
	First Half	Second Half	Mean Difference	95% CI for mean difference	P-value
Duration (min)	47.90	49.89	1.98	1.34 to 2.63	<0.0001 *
Distance (m)	3402.91	3395.30	-7.61	-114.94 to 99.72	0.8739
Metabolic Power (W/Kg)	6.16	5.85	-0.31	-0.52 to -0.11	0.0064*

Notes: Mean difference: Difference between means (Second half – First half) of the metric in question. **95% CI:** 95% confidence interval for mean difference from mixed model for repeated measures (MMRM) fit. **P-value** from MMRM fit, testing the null-hypothesis that the mean difference in question is 0; * indicates statistical significance (P<0.05).

In the subsections below, the variables match duration, distance covered and metabolic power are discussed individually. For each of these variables, side-by-side box plots display the distributions of the individual differences between the second and first halves of each match officiated by the 17 referees (Figures 4.1 to 4.3).

The box plots illustrate the range between the first to the third quartile of the data. In other words the box displays the central 50% of the data. The difference between the third and the first quartile is referred to as the inter-quartile range (IQR). The horizontal line in the box indicates the median of the data, while the diamond indicates the mean. The whiskers drawn from the box display the most extreme point that is less than or equal to 1.5 times the IQR. Values higher or lower than the 1.5 times the IQR are displayed by a "+" or a "o" sign.

<u>Match duration</u>

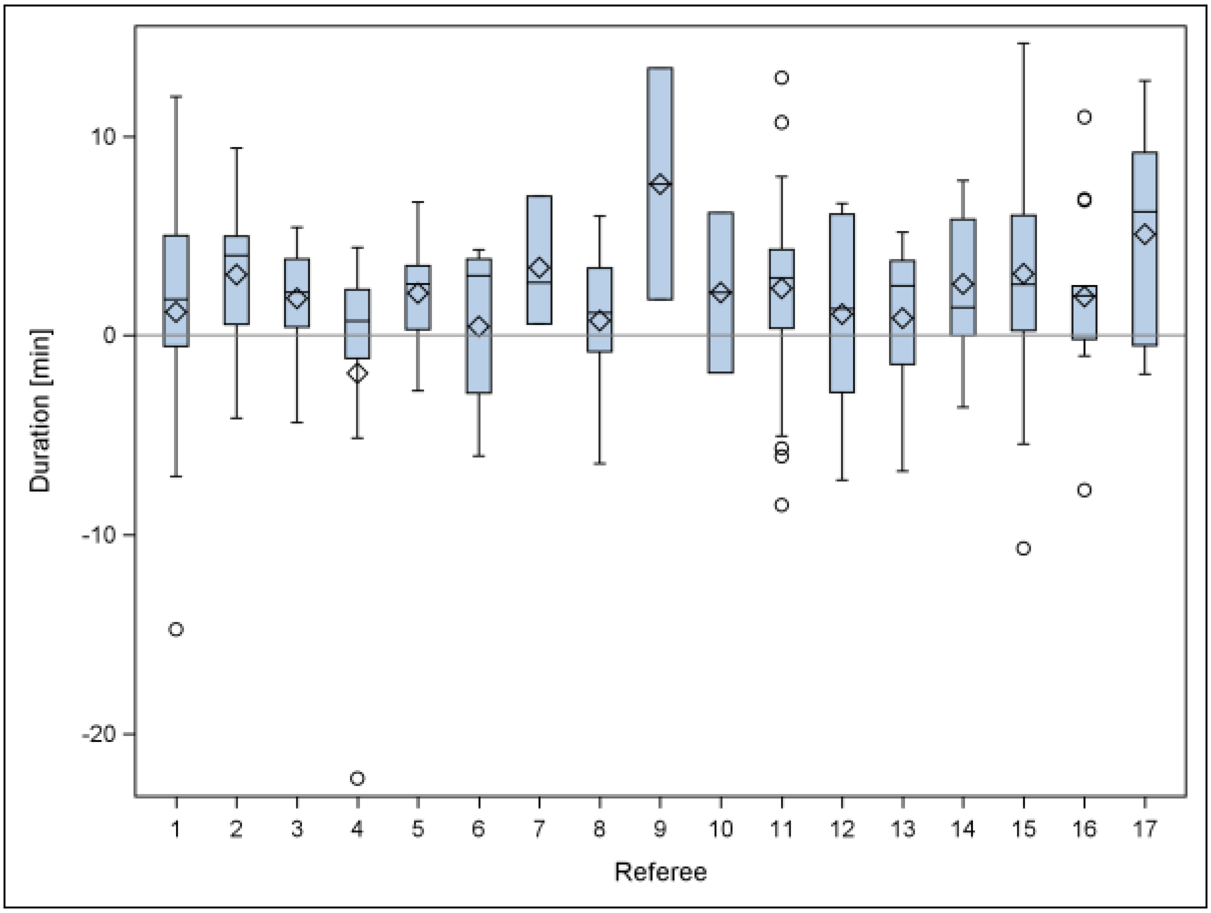

Figure 4.1: Box plot: Difference in match duration between second and first half (17 referees; n=205 matches)

The mean match duration for the 205 matches was 97.55 min. The mean duration of the second match half was 49.89 min (range 42.5 min to 63.4 min), and the mean duration of the first half 47.90 min (range 40.8 min to 66.1 min).

The box plots of the differences in match duration between the second and first half of each match show that for all referees the median differences are above the zero line, and all means but one (no 4) are above the zero line. Similarly, the first quartiles are above the zero line for most referees.

Table 4.4 shows that the mean durations of the two halves differ by about 2 min (95% CI 1.3 min to 2.6 min); thus, while the durations of the first and second half differ statistically significantly ($p<0.0001$), the mean difference is negligible in practical terms.

Distance covered

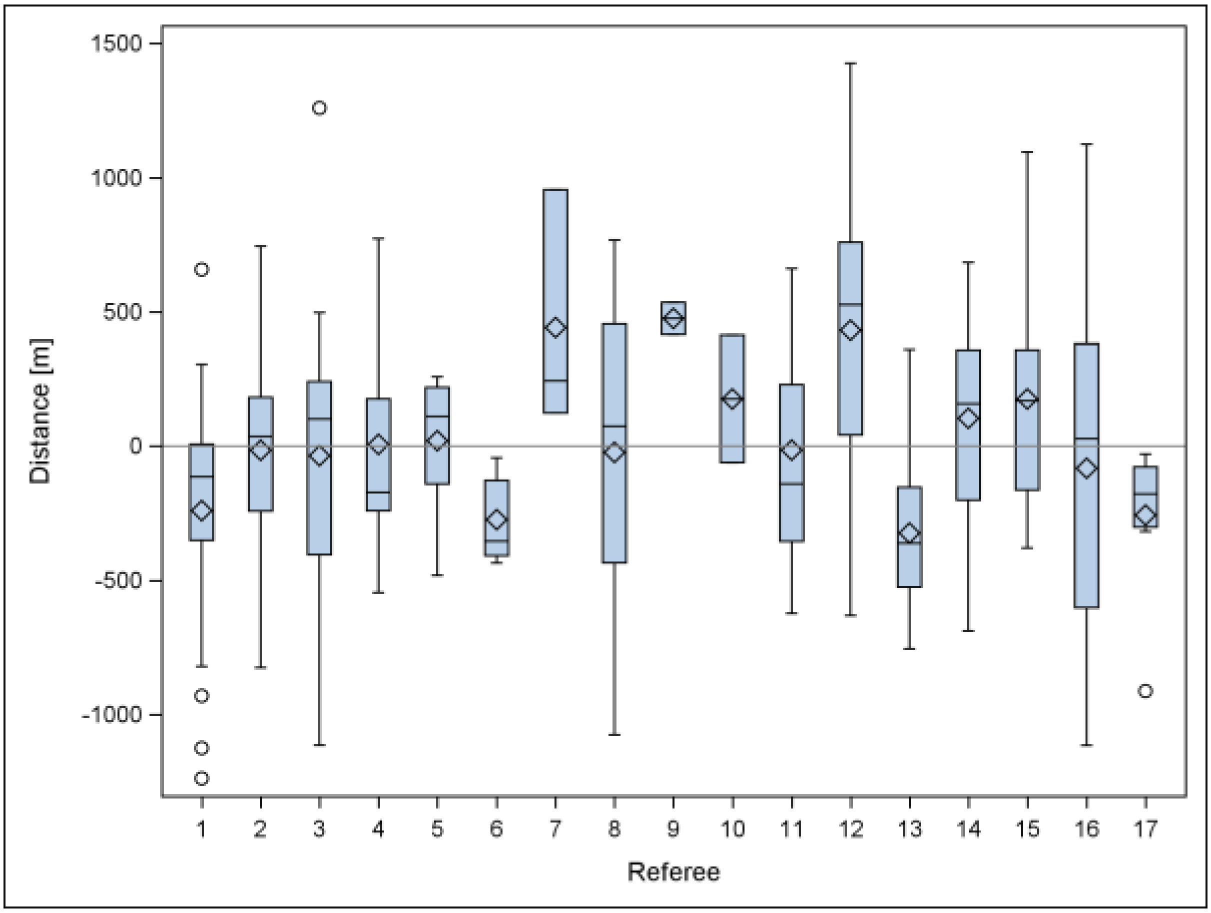

Figure 4.2: Box plot: Difference in distance covered between second and first half (17 referees; n=205 matches)

The mean distance covered for the 205 matches was 6825.90m. The mean distance covered for the second match half was 3402m (range 2129.8m to 4660.7m), and the mean duration of the first half 3423.91m (range 2379.9m to 4530.5m).

The box plots of the differences in distance covered between second and first half of each match show that there is approximately an even distribution of medians above (9) and beneath (6) the zero line, with two medians (no 2 and no 16) on or just above the zero line. The same can be said with regard to the distribution of the means above (6) and beneath (5) the zero line, with six (no 2, 3, 4, 5, 8 and

11) means on or just above/beneath the zero line. Most of the third quartiles are above the zero line, while most first quartiles are below zero.

The mean distances covered by the referees during the second and first halves differ by only about 8m (95% CI -115m to 100m), which is negligible in practical terms and not statistically significant ($p<0.8739$) (Table 4.4).

Metabolic power

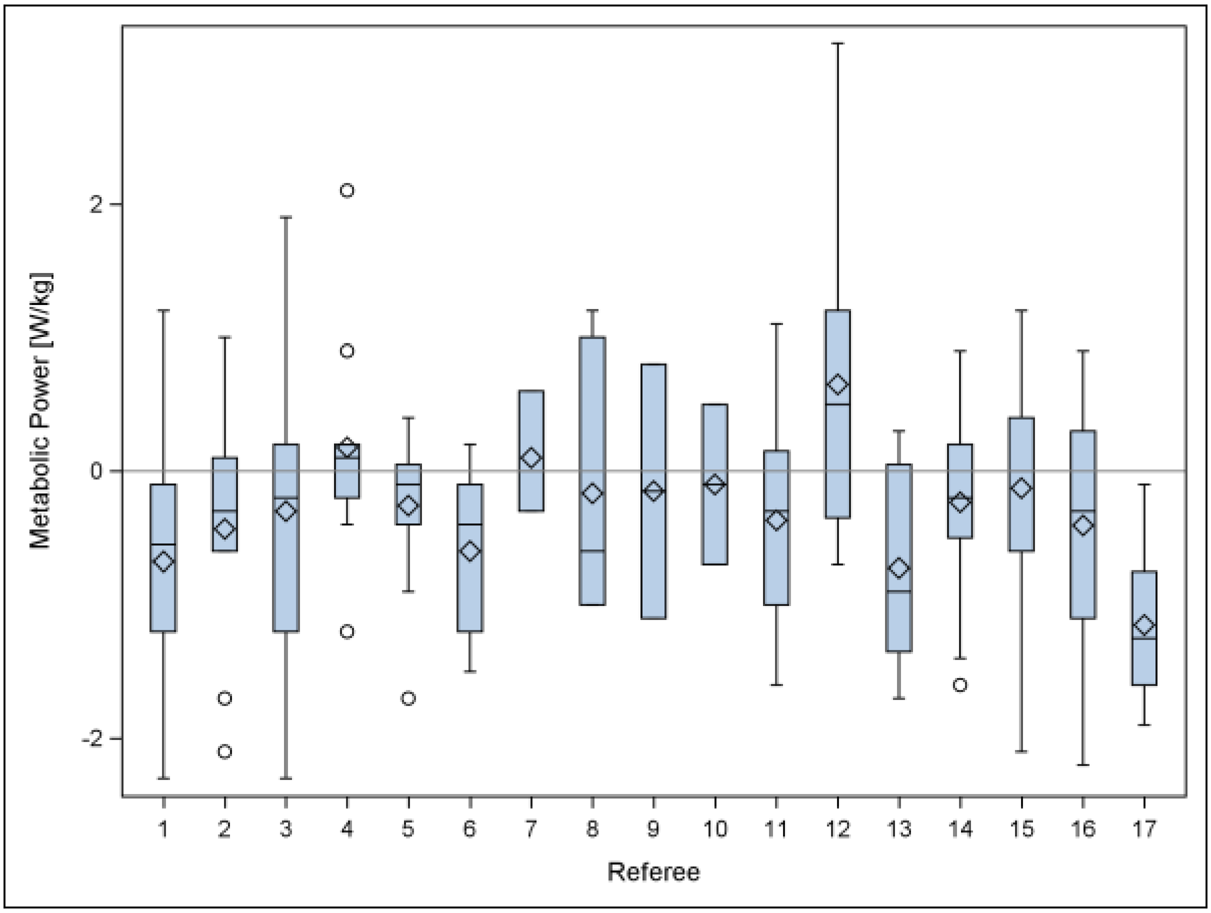

Figure 4.3: Box plot: Difference in metabolic power between second and first half (17 referees; n=205 matches)

The mean metabolic power produced by referees for the 205 matches was 12.09 W/kg. The mean metabolic power produced for the second match half was 5.88 W/kg (range 3.2 W/kg to 8.2 W/kg), and the mean metabolic power produced during the first half was 6.21 W/kg (range 4.2 W/kg to 8.6 W/kg).

The box plots of the differences in metabolic power between the second and first half of each match suggest that all but three medians (no 4, 7 and 12) are below the zero line, and all but three means (no 4, 7 and 12) are below the zero line. The same can be said for most of the first quartiles that are below the zero line.

Table 4.4 shows that the mean metabolic power of the second half is significantly (p=0.0064) lower than the mean metabolic power of the first half; the mean difference is -0.31 W/kg (95% CI -0.52 W/KG to -0.11 W/kg).

4.3.2 Speed zones

Tables 4.5 and 4.6 present descriptive statistics for the difference in % time spent in the various speed zones. Statistics are provided for each half of the match, and for the total match.

Table 4.5: Difference in % time spent in different speed zones between the second and first half of matches officiated: Descriptive statistics

Variable	Statistic	First Half	Second Half	Total Match
Time Spent in Speed Zones 1 – 2 (%)	N	204	204	203
	Mean	52.38	52.46	52.44
	Min	40.9	32.2	39.4
	Q1	48.4	48.6	49.0
	Median	52.2	52.6	53.0
	Q3	55.8	56.3	55.7
	Max	66.9	66.1	65.0
Time Spent in Speed Zone 3 (%)	N	204	204	203
	Mean	19.97	20.56	20.25
	Min	14.40	14.20	15.60
	Q1	18.20	18.80	18.50
	Median	19.80	20.40	20.20
	Q3	21.60	22.50	21.70
	Max	26.90	28.10	27.50
Time Spent in Speed Zones 4 – 6 (%)	N	204	204	203
	Mean	27.66	26.98	27.31
	Min	15.30	17.10	18.00
	Q1	25.00	24.30	24.90
	Median	27.80	26.90	27.20
	Q3	30.30	29.60	29.70
	Max	40.20	42.30	37.10

Notes: N: Number of players; SD: Standard Deviation; Q1: First quartile; Q3: Third quartile

Results of the statistical comparison of the data for the second and first halves of the matches are presented in Table 4.6 for the different speed zones.

Table 4.6: % Time spent in speed zones 1 - 6: Mean differences between second and first halves

Performance indicator	Mean		Comparison "Second – First Half"		
	First Half	Second Half	Mean Difference	95% CI for mean difference	P-value
Time Spent in Speed Zones 1 – 2 (%)	52.06	52.01	-0.06	-1.42 to 1.32	0.93
Time Spent in Speed Zone 3 (%)	20.25	20.85	0.60	0.12 to 1.07	0.02*
Time Spent in Speed Zones 4 – 6 (%)	27.70	27.12	-0.58	-1.58 to 0.42	0.22

Notes: Mean difference: Difference between means (Second half – First half) of the metric in question. **95% CI:** 95% confidence interval for mean difference from mixed model for repeated measures (MMRM) fit. **P-value** from MMRM fit, testing the null-hypothesis that the mean difference in question is 0; * indicates statistical significance (P<0.05).

In the subsections below the % time spent in the different speed zones is discussed individually. For each of these speed zones, side-by-side box plots display the distributions of the individual differences between the second and first halves of each match officiated by the 17 referees (Figures 4.4 to 4.6).

Time spent [%] in speed zones 1 – 2 (0 – 29% MSPD)

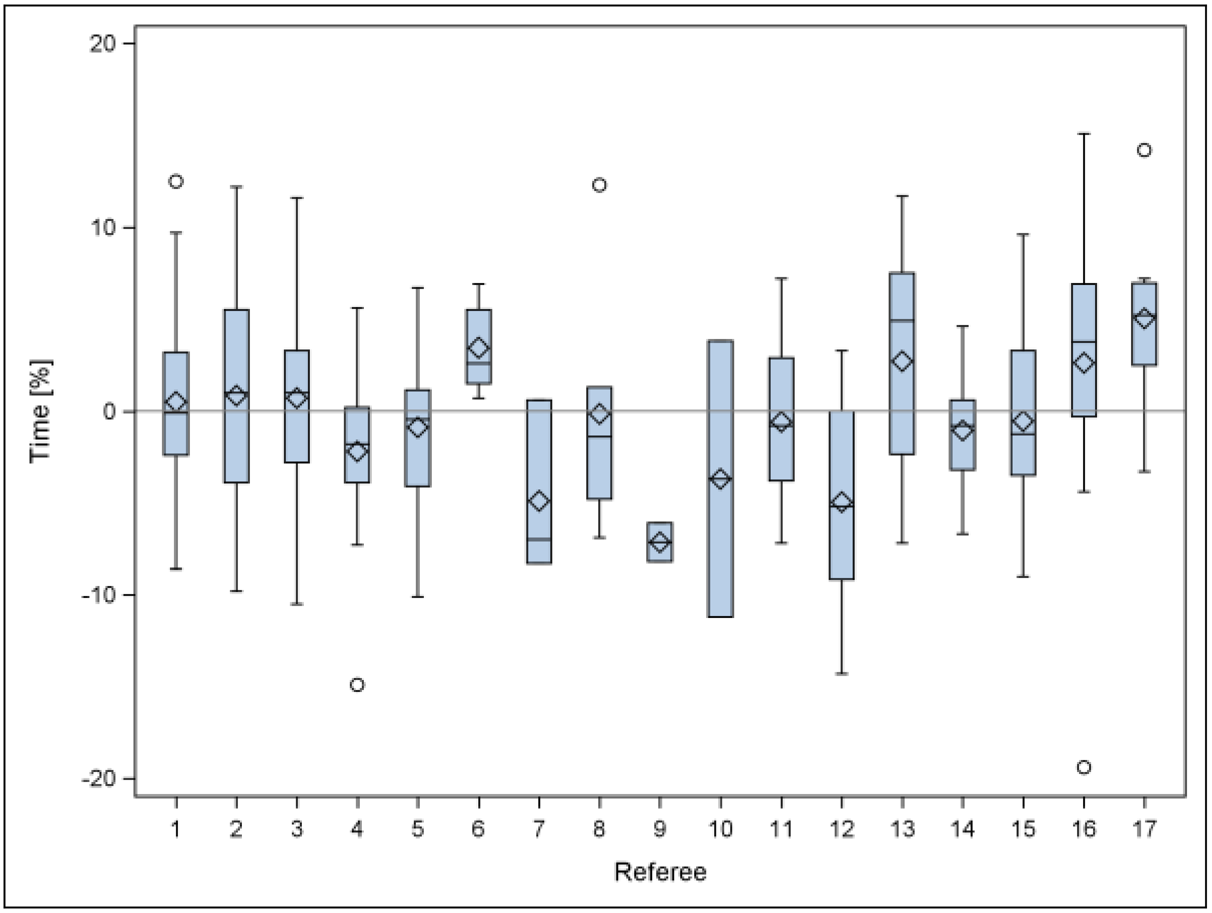

Figure 4.4: Box plot: Difference in % time spent in speed zones 1 – 2 between second and first half (17 referees; n=203 matches)

The mean % time referees spent in speed zones 1 - 2 for the 203 matches was 52.44%. The mean % time referees spent in speed zones 1 – 2 during the second match half (N=204) was 52.46% (range 32.2% to 66.1%), and the mean % time referees spent in speed zones 1 – 2 during the first half was 52.38% (range 40.9% to 66.0%).

The box plots of the difference in % time spent in speed zones 1 – 2 between the second and first half of each match suggest that there is approximately an even distribution of medians above (7) and below (10) the zero line. The same can be said with regard to the distribution of the means above (7) and below (10) the zero line as well as the distribution of the first quartiles.

The mean % time spent in speed zones 1 - 2 between the second and first halves differ by only about -0.06% (95%CI -1.42% to 1.32%), which is negligible in practical terms and not statistically significant (p=0.93) (Table 4.6).

Time spent [%] in speed zone 3 (29 – 51% MSPD)

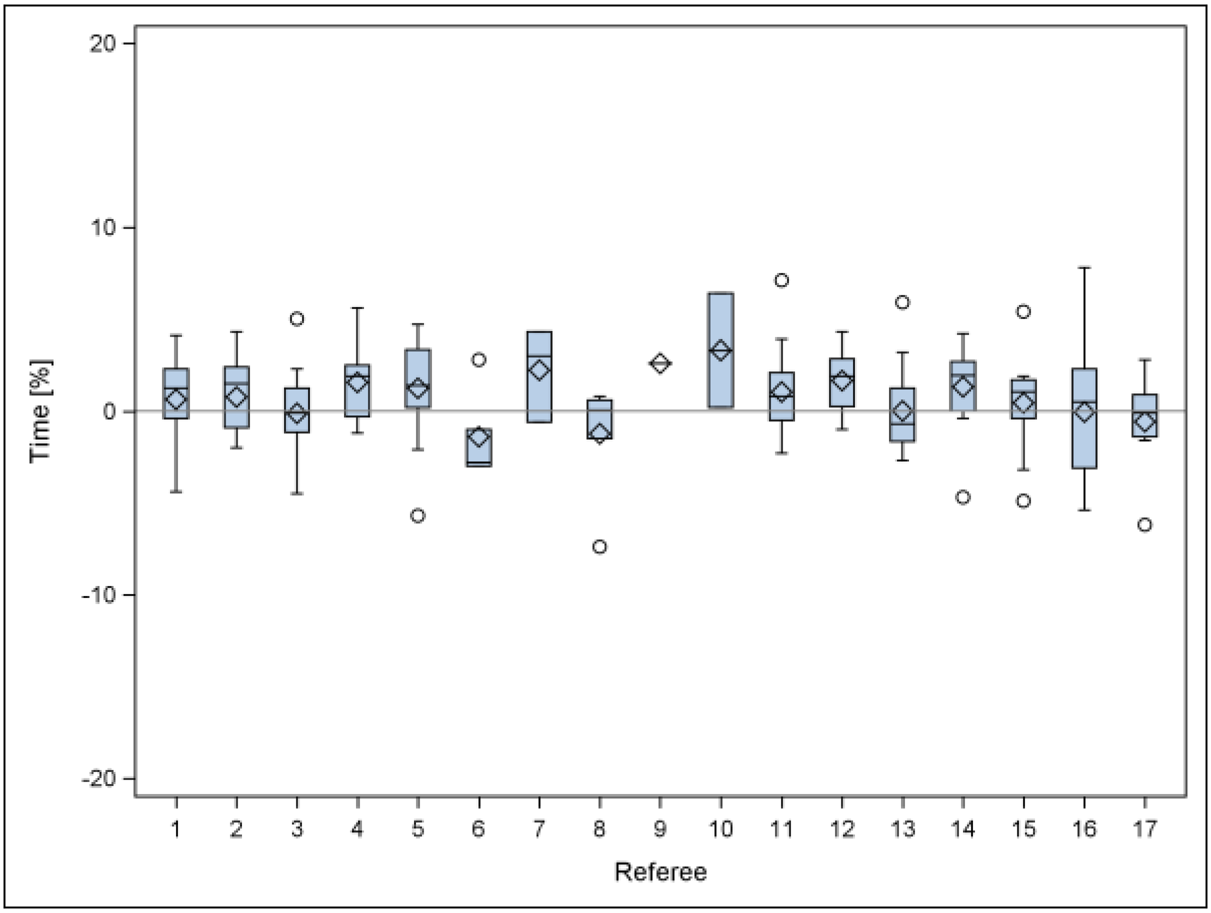

Figure 4.5, Box plot: **Difference in % time spent in speed zone 3 between second and first half (17 referees; n=203 matches)**

The mean % time referees spent in speed zone 3 for the 203 matches was 20.25%. The mean % time referees spent in speed zone 3 during the second match half was 20.56% (range 14.20% to 28.10%), and the mean % time referees spent in speed zone 3 during the first half was 19.97% (range 14.40% to 26.90%).

The box plots of the difference in % time spent in speed zone 3 between the second and first half of each match suggest that all but four medians (no 6, 8, 13 &17) are above the zero line, and all but four means (no 6, 8, 13 & 17) are above the zero line. The same can be said for most of the first quartiles that are above the zero line.

Table 4.6 shows that the mean % time spent in speed zone 3 during the second half is significantly higher (p=0.02) than the mean % time spent in speed zone 3 during the first half, the mean difference is 0.60% (95% CI 0.12% to 1.07%).

<u>Time spent [%] in speed zones 4 – 6 (≤ 51% MSPD)</u>

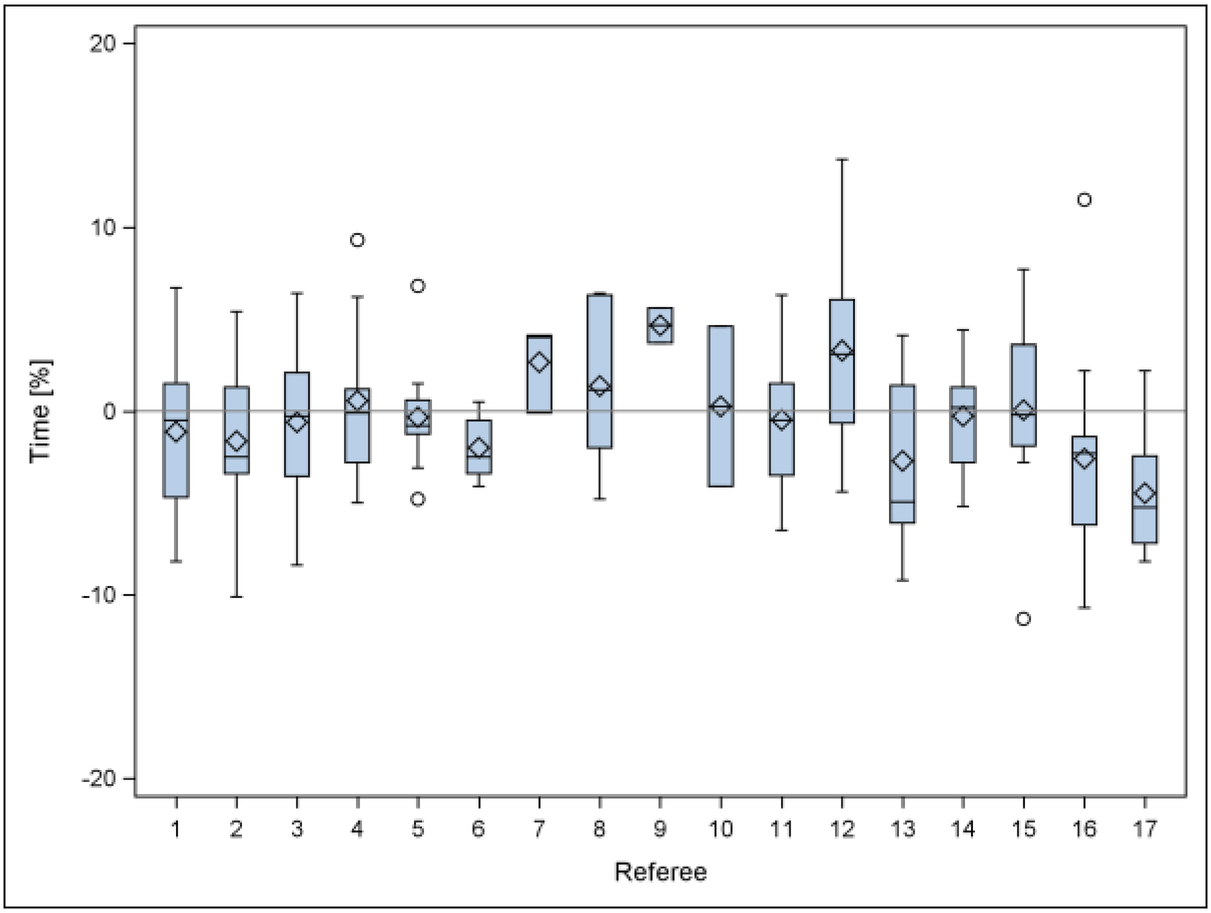

Figure 4.6, Box plot: **Difference in % time spent in speed zones 4 - 6 between second and first half (17 referees; n=205 matches)**

The mean % time referees spent in speed zones 4 - 6 for the 203 matches was 27.31%. The mean % time referees spent in speed zones 4 - 6 during the second match half (N=204) was 26.98% (range 17.10% to 42.30%), and the mean % time referees spent in speed zones 4 - 6 during the first half was 27.66% (range 15.30% to 40.20%).

The box plots of the difference in % time spent in speed zones 4 - 6 between the second and first half of each match suggest that only six medians are above the zero line (no 4, 7, 8, 9, 10 and 12), with eight medians below the zero line and three medians (no 3, 14 and 15) are on or just above/below the zero line, and all but five means (no 4, 7, 8, 9 and 12) are below the zero line. The same can be said for most of the first quartiles of the referees that are below the zero line.

The mean % time spent in speed zones 4 - 6 between the second and first halves differ by only about -0.58% (95%CI -1.58% to 0.42%), which is negligible in practical terms and not statistically significant (p=0.22) (Table 4.6).

4.3.3 Heart rate zones

Descriptive statistics for the difference in % time spent in the different heart rate zones are presented in Tables 4.7 and 4.8, respectively. Statistics are provided for each half of the match, and for the total match.

Table 4.7: Difference in % time spent in heart rate zones 1 - 6 between the second and first half of matches officiated: Descriptive statistics

Variable	Statistic	First Half	Second Half	Total Match
Time Spent in Heart Rate Zones 1 – 2 (%)	N	205	205	205
	Mean	42.50	51.18	46.84
	Min	0.00	0.30	0.20
	Q1	26.10	34.00	31.30
	Median	44.20	53.50	49.30
	Q3	60.30	69.60	64.40
	Max	90.00	97.90	89.40
Time Spent in Heart Rate Zones 3 – 6 (%)	N	205	205	205
	Mean	57.51	48.83	53.17
	Min	10.10	2.10	10.70
	Q1	39.70	30.40	35.70
	Median	55.80	46.60	50.80
	Q3	73.90	66.00	68.70
	Max	100.1	99.70	99.90

Notes: N: Number of players; SD: Standard Deviation; Q1: First quartile; Q3: Third quartile

Results of the statistical comparison of the data for the second and first halves of the matches are presented in Table 4.8 for the different heart rate zones. Note that the fraction (%) of time spent in heart rate zones 1 – 2 is statistically compared between the first and second halves of each match. The time (%) spent in heart rate zone 3 – 6 is simply the complement of the % time spent in heart rate zone 1 – 2, so that the results given below in Table 4.8 for heart rate zone 3 – 6 do not constitute an independent statistical analysis.

Table 4.8: % Time spent in heart rate zones 1 - 6: Mean differences between second and first halves

Performance indicator	Mean		Comparison "Second – First Half"		
	First Half	Second Half	Mean Difference	95% CI for mean difference	P-value
Time Spent Heart Rate Zones 1 – 2 (%)	38.95	47.03	8.08	4.62 to 11.54	0.0002*
Time Spent Heart Rate Zones 3 – 6 (%)	61.05	52.97	– 8.08	– 11.54 to 4.62	0.0002*

Notes: Mean difference: Difference between means (Second half – First half) of the metric in question. **95% CI:** 95% confidence interval for mean difference from mixed model for repeated measures (MMRM) fit. **P-value** from MMRM fit, testing the null-hypothesis that the mean difference in question is 0; * indicates statistical significance (P<0.05).

In the subsections below, the variable; difference in % time spent in the different heart rate zones is discussed individually. For each of these heart rate zones, side-by-side box plots display the distributions of the individual differences between the second and first halves of each match officiated by the 17 referees (Figures 4.7 to 4.8).

Time spent [%] in heart rate zones 1 – 2

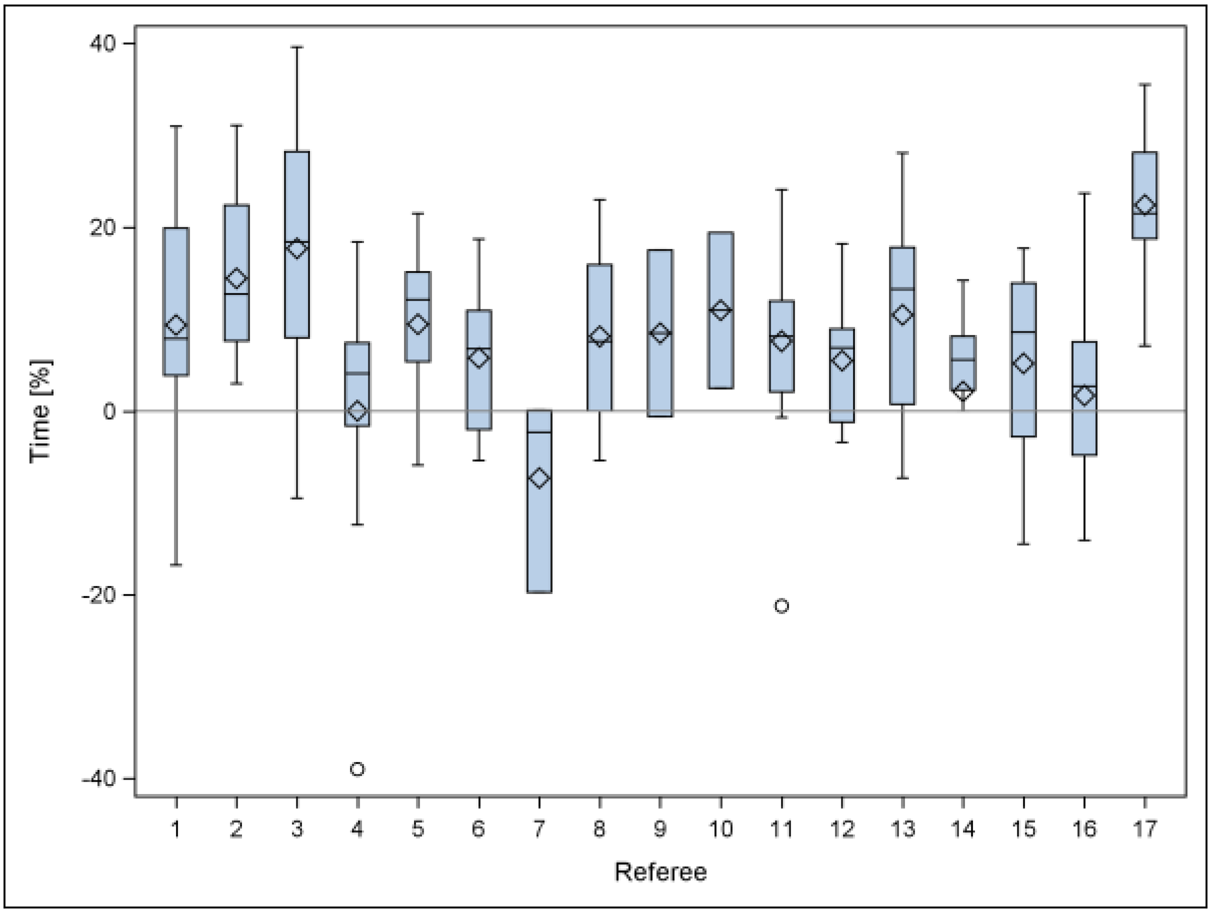

Figure 4.7: Box plot: Difference in % time spent in heart rate zones 1 -2 between second and first half (17 referees; n=205 matches)

The mean % time referees spent in heart rate zones 1 - 2 for the 205 matches was 46.84%. The mean % time referees spent in heart rate zones 1 – 2 during the second match half was 51.18% (range 0.30% to 97.90%), and the mean % time referees spent in heart rate zones 1 – 2 during the first half was 42.50% (range 0% to 90.0%).

The box plots of the difference in % time spent in heart rate zones 1 – 2 between the second and first half of each match suggest that all but one median (no 7) are above the zero line, and all but one mean (no 7) are above the zero line. The same can be said for most of the first quartiles of the referees that are above the zero line.

Table 4.8 shows the mean % time spent in heart rate zones 1 - 2 of the two halves differ by about 8.08% (95% CI 4.62 % to 11.54 %) with the % time spent during the second half being significantly (p=0.0002) higher than the mean % time spent in heart rate zones 1 - 2 during the first half.

Time spent [%] in heart rate zones 3 – 6

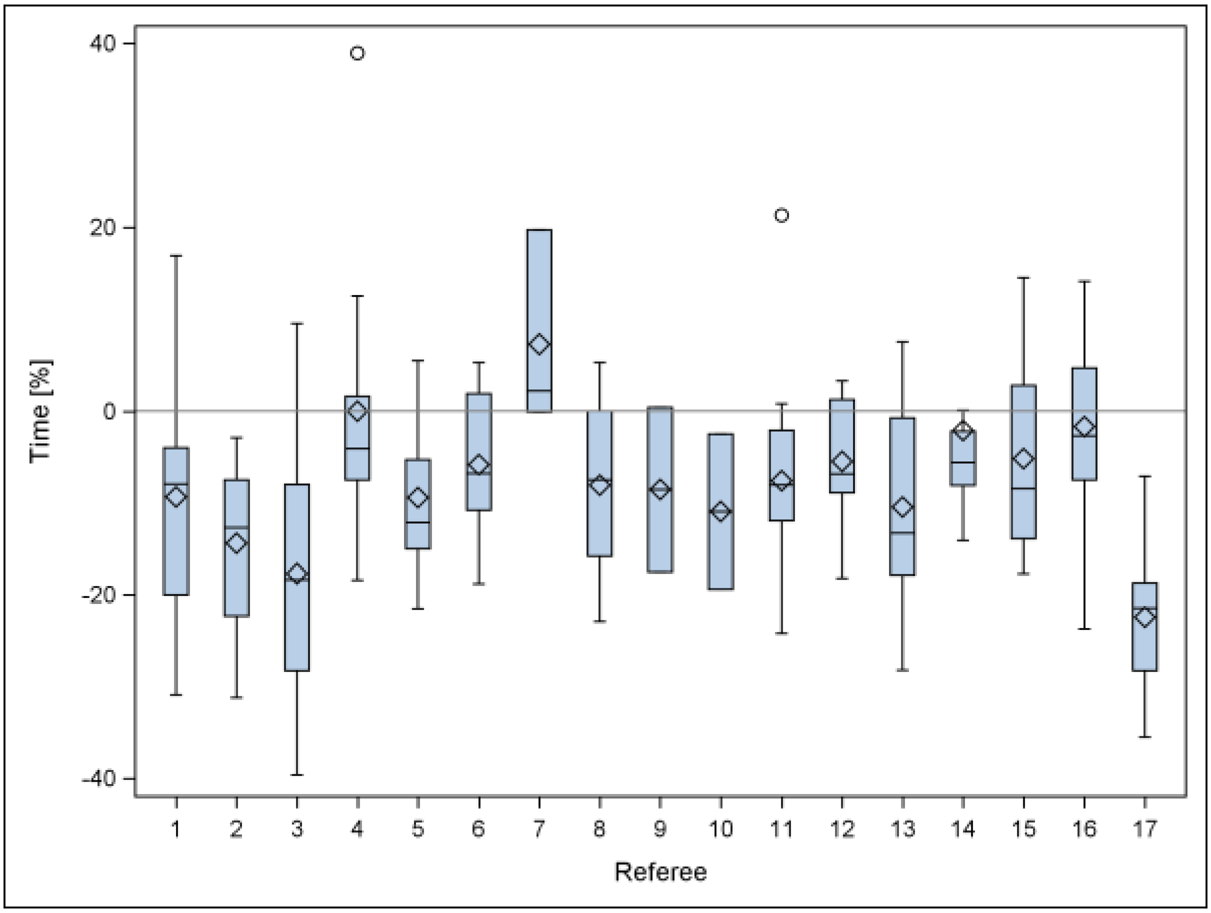

Figure 4.8, Box plot: ***Difference in % time spent in heart rate zones 3 - 6 between second and first half (17 referees; n=205 matches)***

The mean % time referees spent in heart rate zones 3 - 6 for the 205 matches was 53.17%. The mean % time referees spent in heart rate zones 3 - 6 during the second match half was 48.83% (range 2.10% to 99.70%), and the mean % time referees spent in heart rate zones 3 – 6 during the first half was 57.51% (range 10% to 100.1%).

The box plots of the difference in % time spent in heart rate zones 3 - 6 between the second and first half of each match suggest that all but one median (no 7) are below the zero line, and all but one mean (no 7) are below the zero line. The same can be said for most of the first quartiles that are below the zero line.

The mean % time spent in heart rate zones 3 - 6 of the two halves differ by about -8.08% (95% CI -11.54% to 4.62%) with the % time spent during the second half being significantly (p=0.0002) higher than the mean % time spent in heart rate zones 3 - 6 during the first half.

4.3.4 High-speed accelerations, high-speed decelerations and sprints/surges

Tables 4.9 and 4.10 present descriptive statistics for the total number of high speed accelerations, high speed decelerations and sprints/surges are presented in, respectively. Statistics are provided for each half of the match, and for the total match.

Table 4.9: Difference in number of high-speed accelerations, high-speed decelerations and sprints/surges between the second and first half of matches officiated: Descriptive statistics

Variable	Statistic	First Half	Second Half	Total Match
High Speed Accelerations	N	205	205	205
	Mean	7.0	5.5	12.5
	Min	0	0	0
	Q1	3	1	5
	Median	6	4	11
	Q3	10	9	19
	Max	24	18	40
High Speed Decelerations	N	205	205	205
	Mean	11.1	9.2	20.4
	Min	0	0	0
	Q1	5	3	10
	Median	9	7	16
	Q3	17	14	30
	Max	36	32	66
Sprints/Surges	N	205	205	205
	Mean	2.4	2.0	4.4
	Min	0	0	0
	Q1	0	0	1
	Median	2	1	3
	Q3	4	3	6
	Max	12	11	23

Notes: N: Number of players; SD: Standard Deviation; Q1: First quartile; Q3: Third quartile

Results of the statistical comparison of the data for the second and first halves of the matches are presented for the three variables match high speed accelerations, high speed decelerations and sprints/surges (Table 4.10).

Table 4.10: High-speed accelerations, High-Speed Decelerations and Sprints/Surges: rate ratio between second and first half

Performance indicator	Rate [\game half]		Comparison "Second / First Half"		
	First Half	Second Half	Rate ratio	95% CI for rate ratio	P-value
High speed accelerations	6.01	4.70	0.782	0.719 to 0.851	<0.0001*
High speed decelerations	8.86	7.40	0.830	0.762 to 0.904	<0.0001*
Sprints / Surges	1.75	1.41	0.803	0.703 to 0.916	0.0012*

Notes: Rate ratio: Ratio of incidence rates [/game half] of the metric in question. **95% CI:** 95% confidence interval for rate ratio from generalized linear mixed model fit. **P-value** from generalized linear mixed model fit, testing the null-hypothesis that the rate ratio in question is 1. * indicates statistical significance (P<0.05).

In the subsections below, the variables high speed accelerations, high speed decelerations and sprints/surges are discussed individually. For each of these variables, side-by-side box plots display the distributions of the individual differences between the second and first halves of each match officiated by the 17 referees (Figures 4.9 to 4.11).

High-speed accelerations

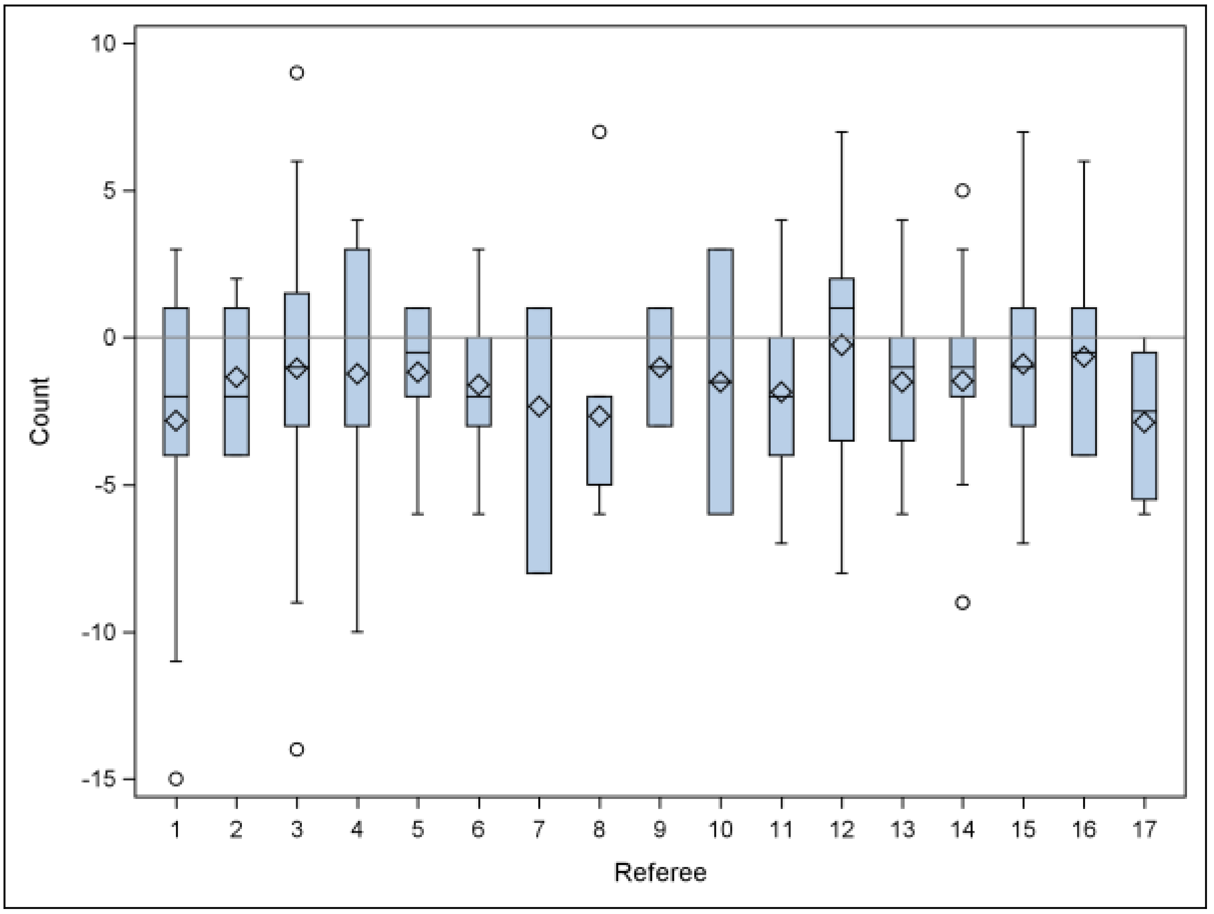

Figure 4.9, Box plot: Difference in high-speed accelerations between second and first half (17 referees; n=205 matches)

The mean number of high speed accelerations for the 205 matches was 12.5. The mean number of high speed accelerations during the second match half was 5.5 (range 0 to 18), and the mean number of high speed accelerations during the first half was 7 (range 0 to 24).

The box plots of the differences in high speed accelerations between second and first half of each match suggest that all but one median (no 12) are below the zero line, and all of the means are below the zero line. The same can be said for most of the first quartiles that are below the zero line.

The rate ratio of high speed accelerations during the second half is significantly ($p<0.0001$) lower than the rate ratio of high speed accelerations during the first half, the rate ratio is 0.782 (95% CI .719 to 0.851) (Table 4.10).

High-speed decelerations

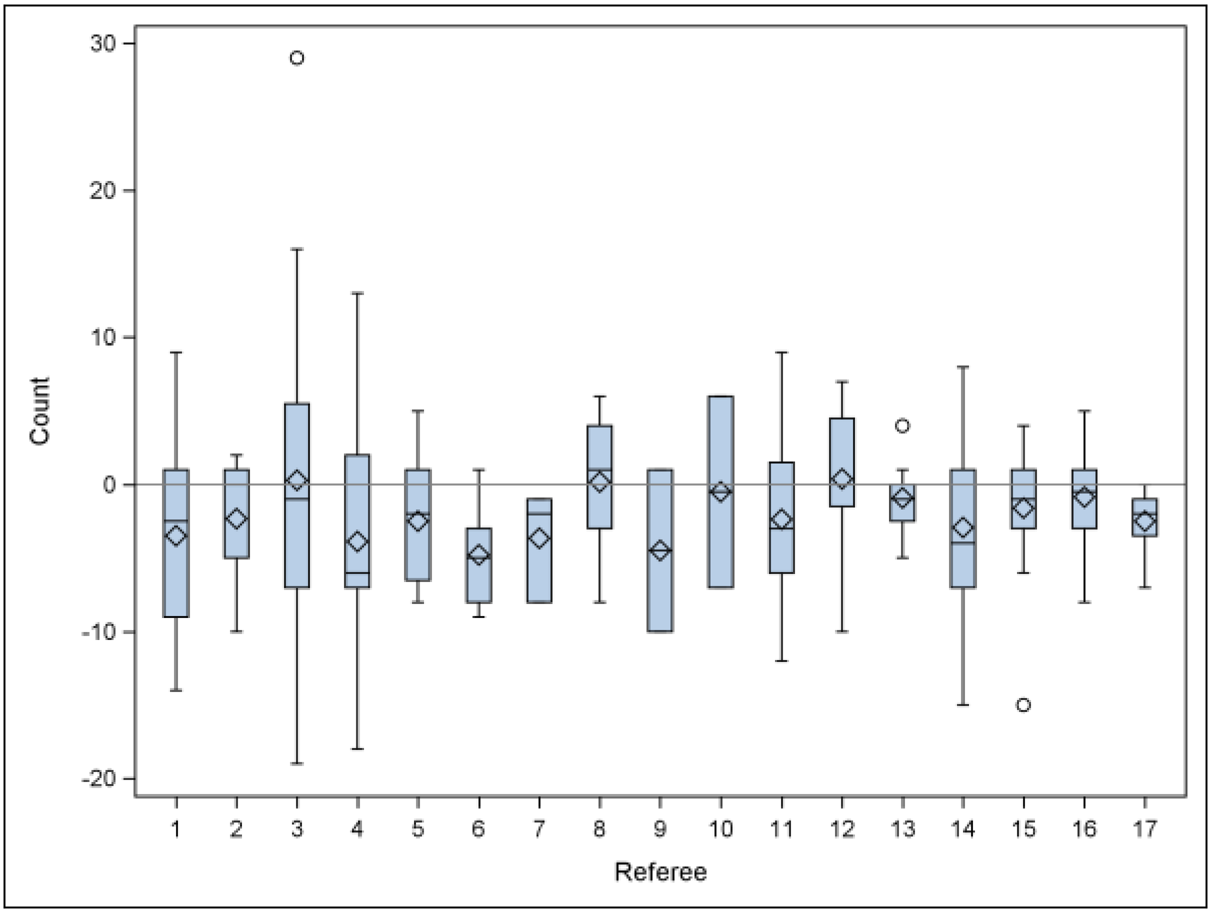

Figure 4.10, Box plot: Difference in high-speed decelerations between second and first halves (17 referees; n=205 matches)

The mean number of high speed decelerations for the 205 matches was 20.4. The mean number of high speed decelerations during the second match half was 9.2 (range 0 to 32), and the mean number of high speed decelerations during the first half was 11.1 (range 0 to 36).

The box plots of the differences in high speed decelerations between second and first half of each match suggest that for all the matches, all but one median (no 8) are below the zero line, and all but three means (no 3, 8 and 12) are on or below the zero line. The same can be said for most of the first quartiles that are below the zero line.

Table 4.10 shows the rate ratio of high speed decelerations during the second half is significantly ($p<0.0001$) lower than the rate ratio of high speed decelerations during the first half, the rate ratio is 0.830 (95% CI 0.762 to 0.904).

Sprints/surges

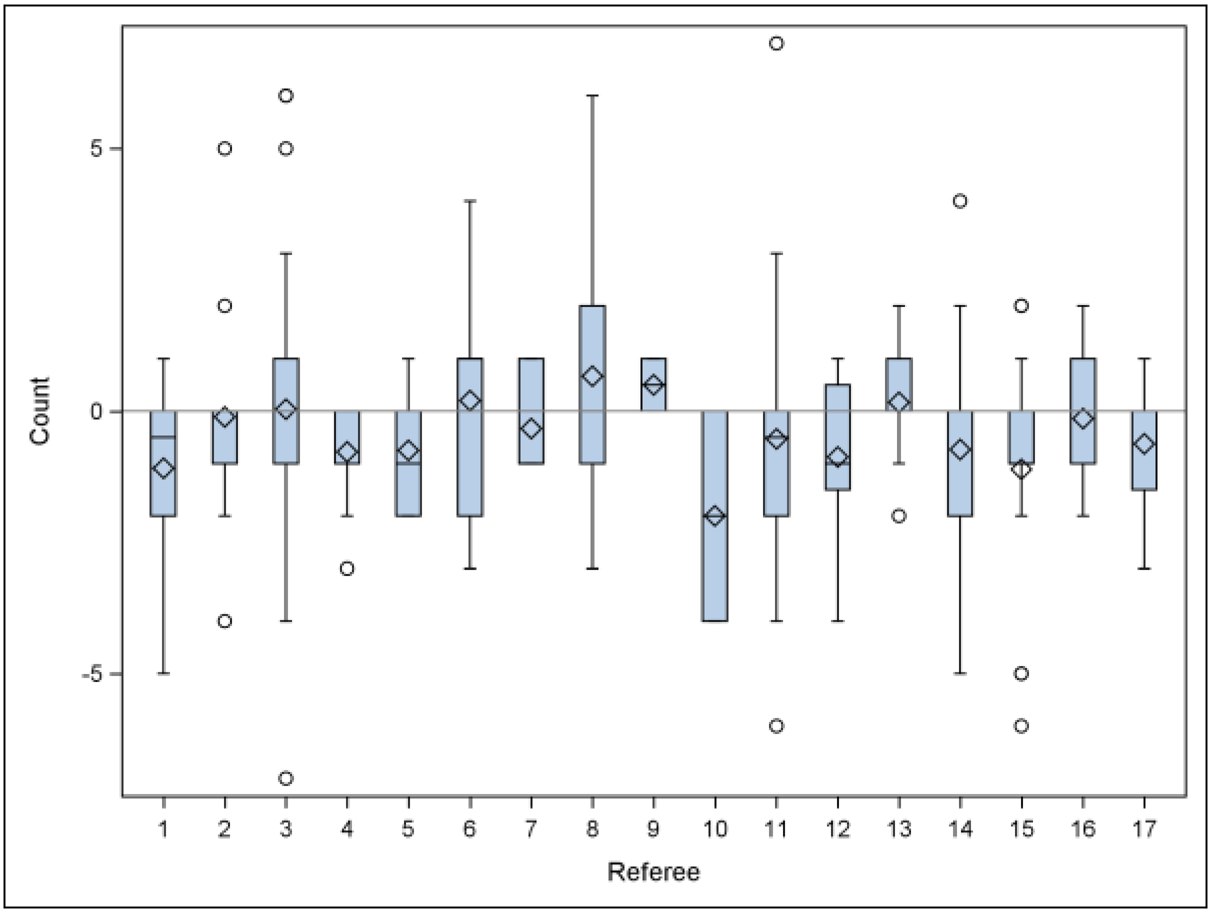

Figure 4.11, Box plot: Difference in sprints/surges between second and first halves (17 referees; n=205 matches)

The mean number of sprints/surges for the 205 matches was 4.4. The mean number of sprints/surges during the second match half was 2 (range 0 to 11), and the mean number of sprints/surges during the first half was 2.4 (range 0 to 12).

The box plots of the differences in the number of sprints/surges between second and first half of each match suggest that for all the matches, all but four medians (no 6, 8, 9 and 13) are on or below the zero line, and all but four means (no 6, 8, 9 and 13) are on or below the zero line. Similarly most of the first quartiles are below the zero line.

The rate ratio of sprints/surges during the second half is significantly (p=0.0012) lower than the rate ratio of sprints/surges during the first half, the rate ratio is 0.803 (95% CI 0.703 to 0.916) (Table 4.10).

4.4 Match and performance characteristics: Consistency of referee performance (match totals)

In this section the total values of the performance characteristics for the match are considered. As stated before, this analysis was done in order to assess whether physical demands and performance of referees were consistent across the sample of referees. Consistency of total values of match and performance characteristics across referees was characterized by the intra-class correlation coefficient (ICC), which is the ratio of the variance component due to referee, over the sum of the referee and residual variance components. The data is consistent across referees when the ICC is small, that is, when the variance component due to referee (relative to the sum of the referee and residual variance components) is small.

The ICCs for the match totals of the various performance indicators are presented in Table 4.11 below.

Table 4.11: Totals of match performance characteristics: Intra-class correlation coefficient

Consistency of referees

Performance indicator	Variance component		Intra-class correlation coefficient	P-value
	Referee	Residual		
Duration	3.88	20.12	0.16	0.0403*
Distance	64114	423298	0.13	0.0579
Metabolic Power	0.25	2.17	0.10	0.0650
Speed Zone 1 - 2	10.97	11.35	0.49	0.0052*
Speed Zone 3	1.53	3.32	0.32	0.0085*
Heart Rate Zone 1 - 2	285.30	164.42	0.63	0.0037*
High-Speed Accelerations	0.60	1.48	0.29	0.0146*
High-Speed Decelerations	1.49	1.58	0.49	0.0066*
Sprints/Surges	0.31	0.98	0.23	0.0169*

P < 0.05 * significant

P < 0.01 ** highly significant

Notes: Variance component: Estimate of variance component from mixed linear model fit. **Intra-class correlation coefficient:** Ratio of (referee variance component) / (sum of referee and residual variance component). **P-value** from mixed linear model fit, testing the null-hypothesis that the referee variance component is 0.

4.4.1 Match duration, distance covered and metabolic power

Below, side-by-side box plots display the distributions of the match totals for match duration, distance covered, and metabolic power of matches officiated by the 17 referees (Figures 4.12 to 4.14).

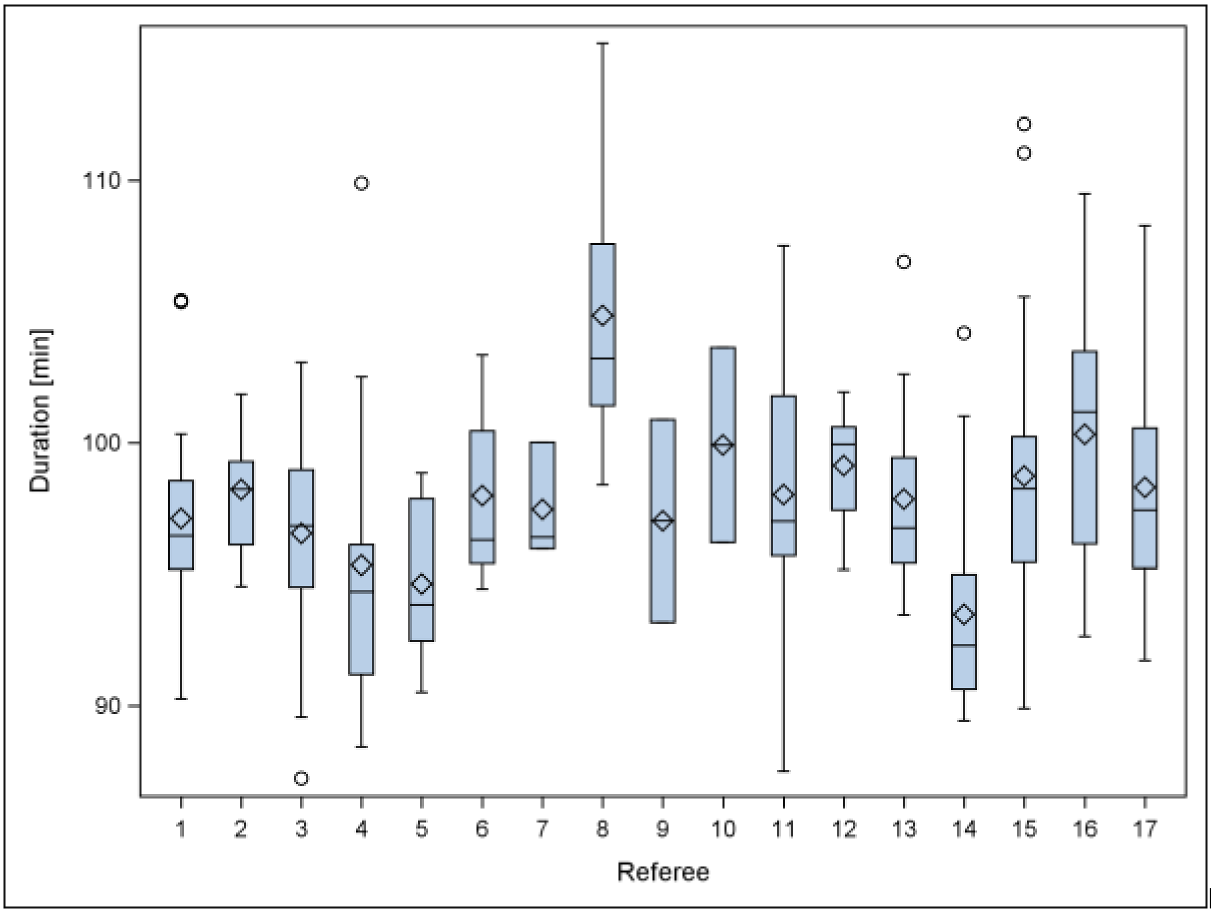

Figure 4.12, Box plot: Total match duration (17 referees; n=205 matches)

The box plot for match duration suggests that the distributions of the data for the various referees are quite tightly grouped together in the sense that both the range of distributions (minimum to maximum value) and the interquartile range (Q1 to Q3; the boxes) largely overlap. Furthermore, the ICC, although statistically significant, is very small (0.16), which confirms the visual impression.

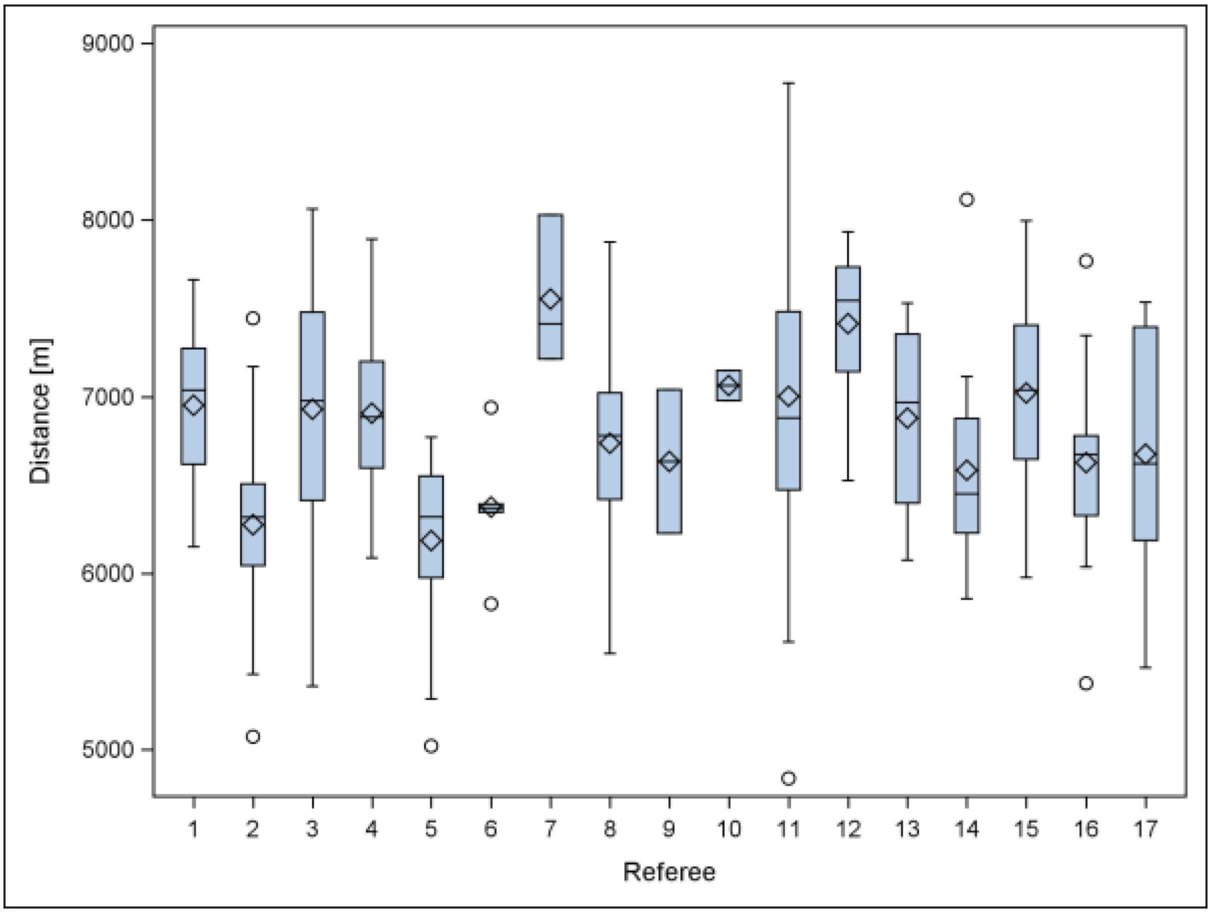

Figure 4.13, Box plot: Total distance covered (17 referees; n=205 matches)

The box plot for distance covered suggests that the distributions of the data for the various referees are quite tightly grouped together in the sense that both the range of distributions (minimum to maximum value) and the interquartile range (Q1 to Q3; the boxes) largely overlap. Furthermore, the ICC is not statistically significant and very small (0.13), which confirms the visual impression.

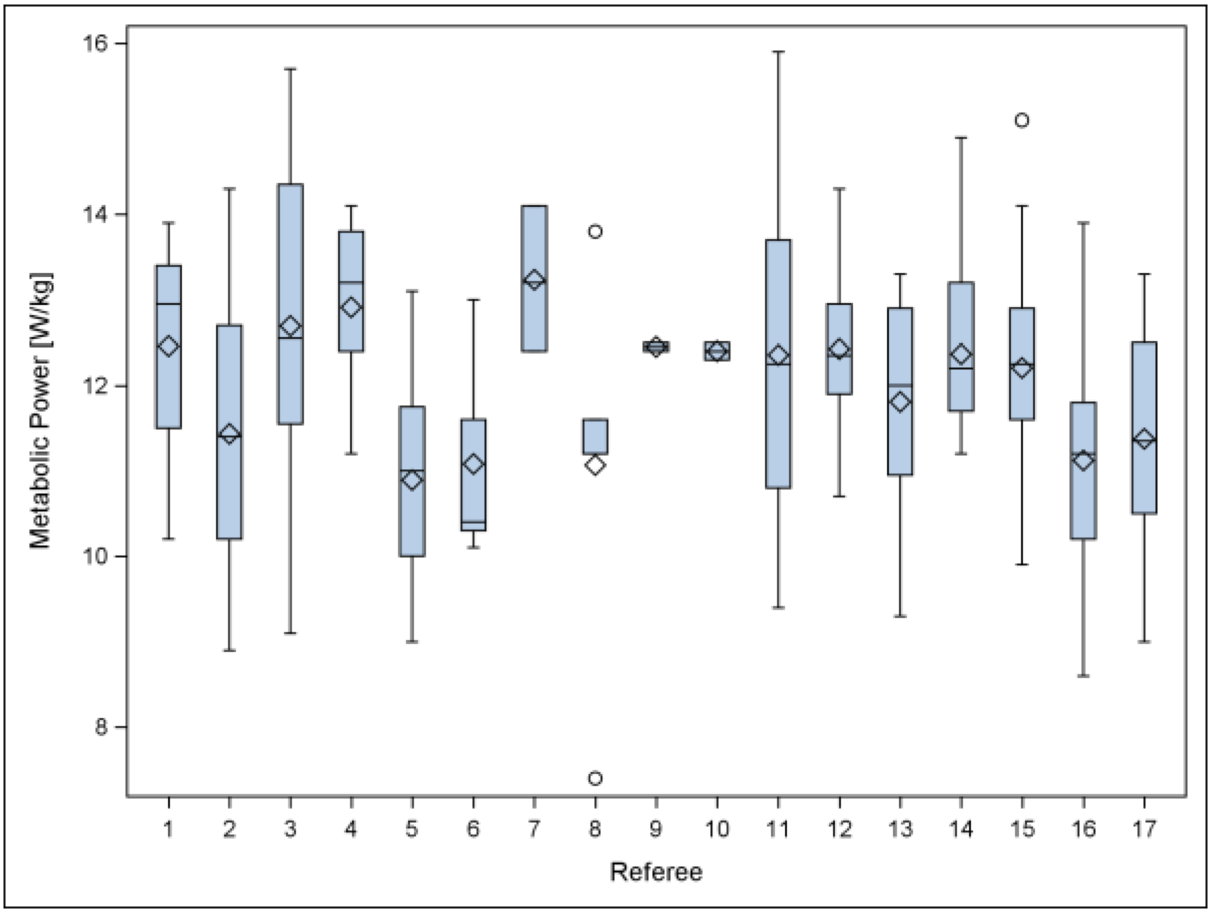

Figure 4.14, Box plot: Total metabolic power (17 referees; n=205 matches)

The box plot for metabolic power suggests that the distributions of the data for the various referees are quite tightly grouped together in the sense that both the range of distributions (minimum to maximum value) and the interquartile range (Q1 to Q3; the boxes) largely overlap. Furthermore, the ICC is not statistically significant and very small (0.10), which confirms the visual impression.

4.4.2 Speed zones

Below, side-by-side box plots display the distributions of the match totals for the % time spent in the different speed zones of matches officiated by the 17 referees (Figures 4.15 to 4.17).

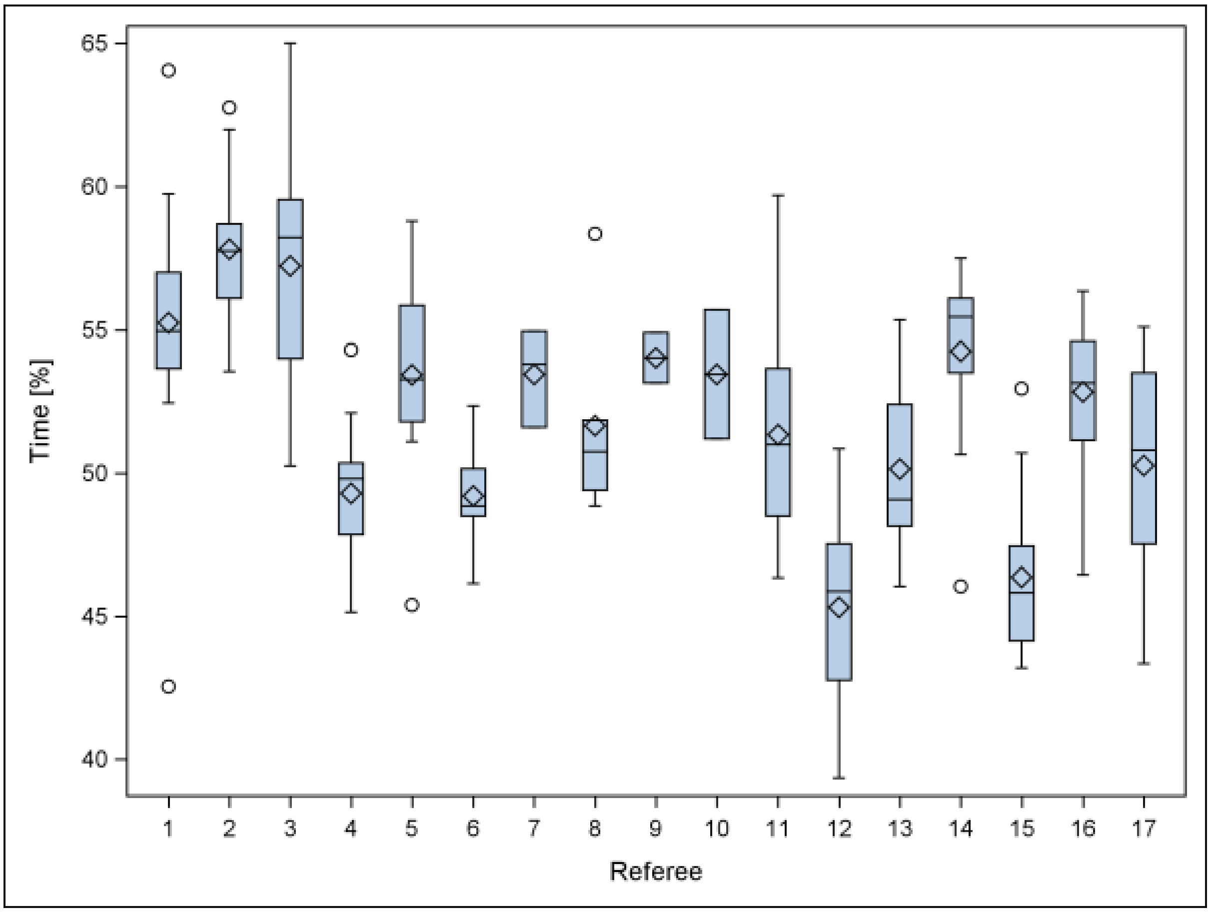

Figure 4.15, Box plot: **Total time spent [%] in speed zones 1 – 2 (17 referees; n=205 matches)**

The box plot for speed zones 1 – 2 suggests that the distributions of the data are quite widely spread. Furthermore, the ICC for speed zone 1 – 2 is moderately large (ICC=0.49) and statistically insignificant (P=0.0052), which confirms the visual impression.

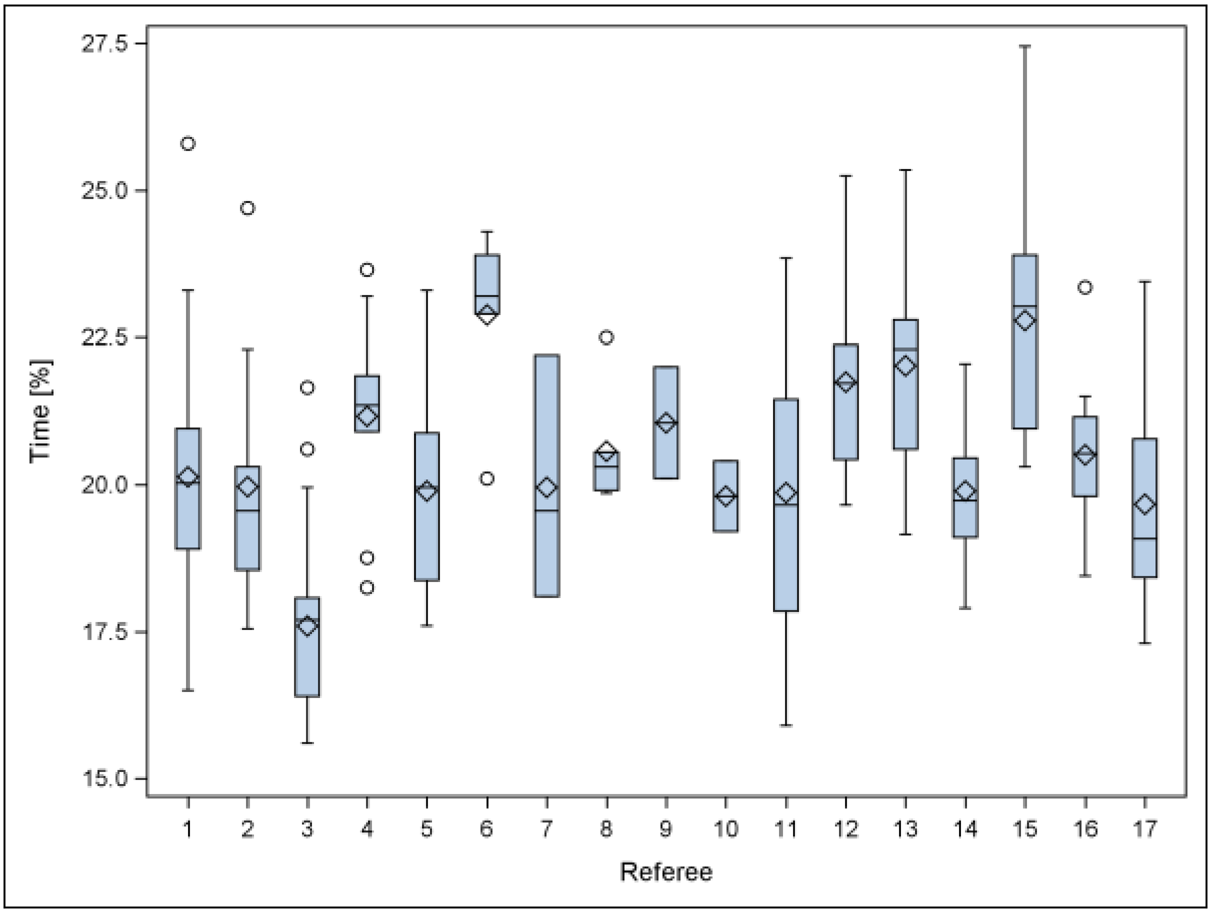

Figure 4.16, Box plot: Total time spent [%] in speed zone 3 (17 referees; n=205 matches)

The box plot for speed zone 3 suggests that the distributions of the data of the various referees are relatively consistent. Furthermore, the ICC for speed zone 3 is moderately small (ICC=0.32) although it is statistically significant (P=0.0085). This confirms the visual impression.

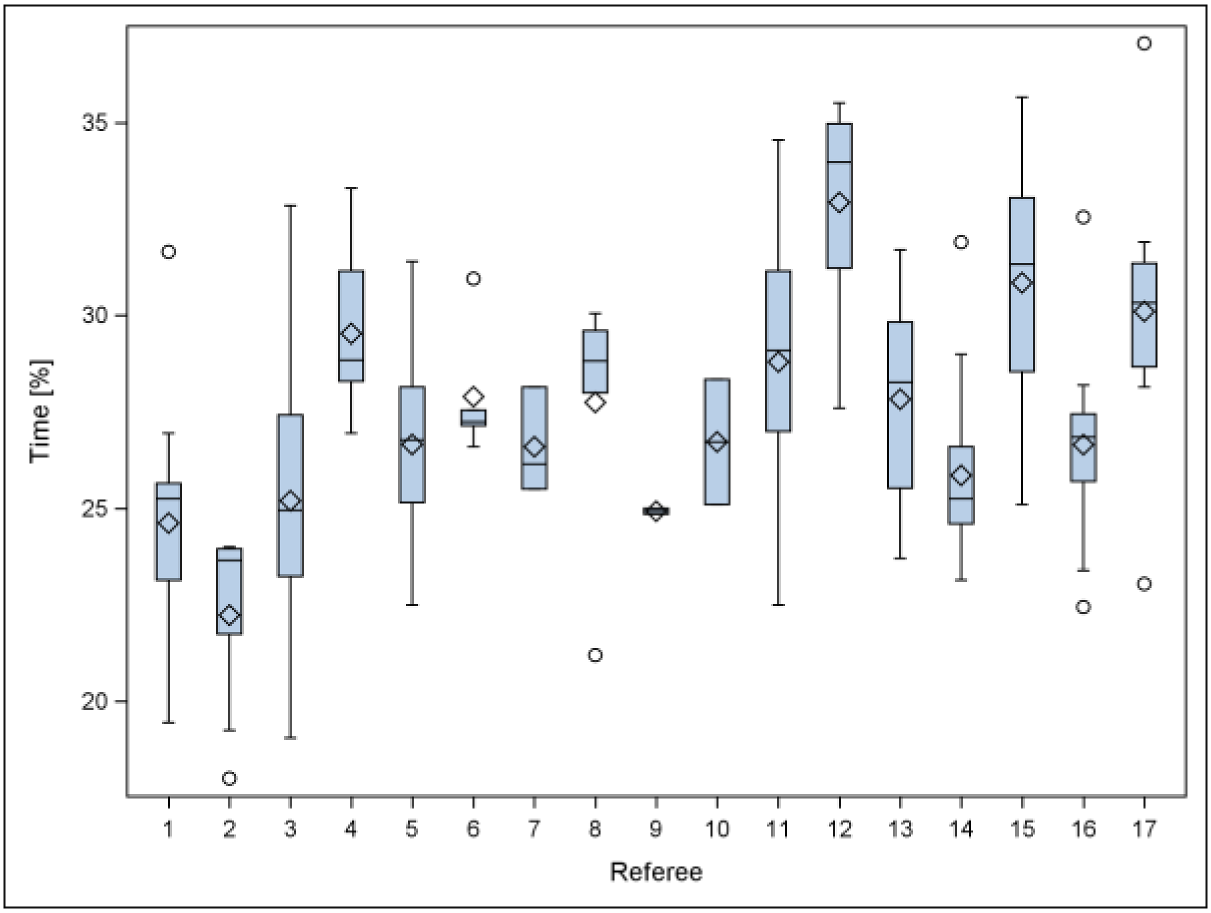

Figure 4.17, Box plot: **Total time spent [%] in speed zones 4 - 6 (17 referees; n=205 matches)**

The box plot for speed zones 4 – 6 suggests that the distributions of the data are widely spread.

4.4.3 Heart rate zones

Below, side-by-side box plots display the distributions of the match totals for the % time spent in the different heart rate zones of matches officiated by the 17 referees (Figures 4.18 & 4.19).

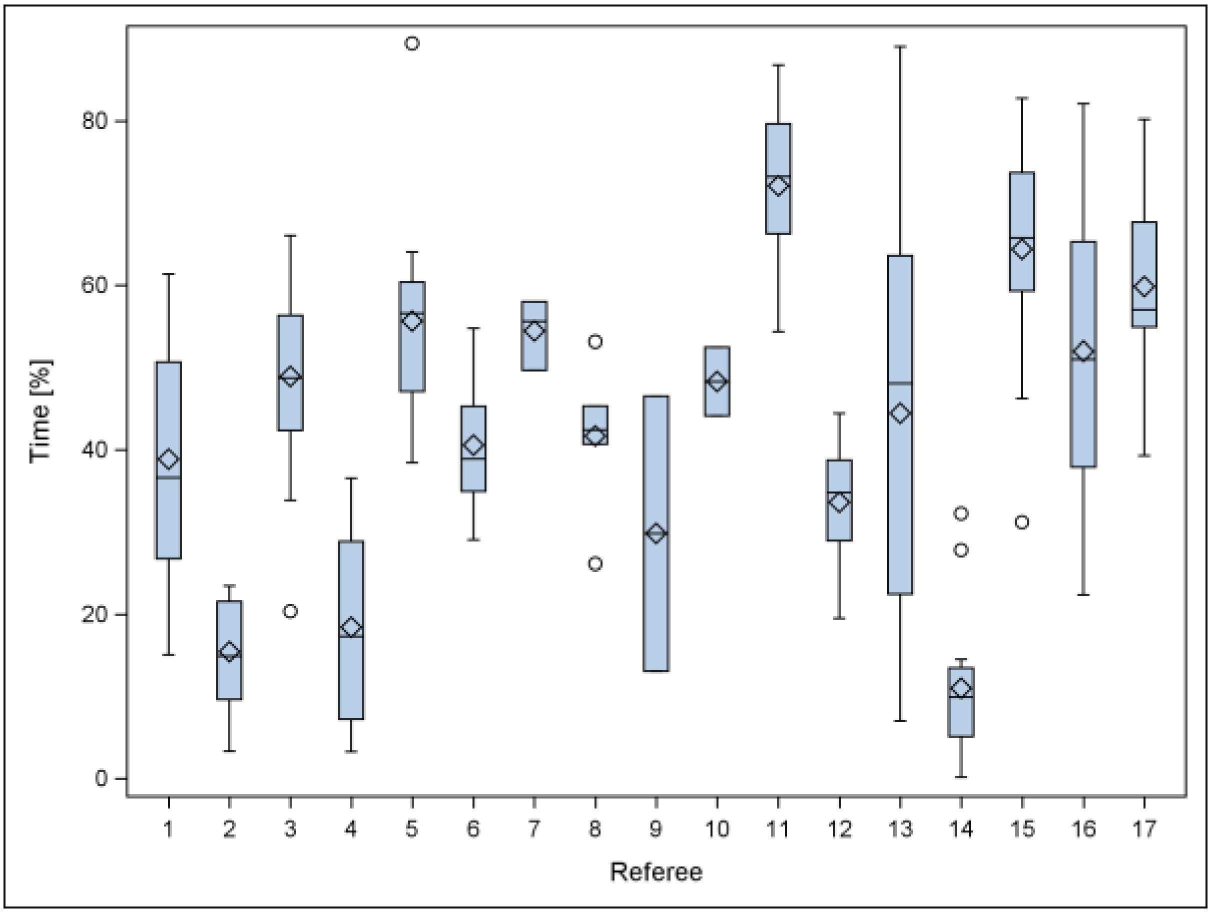

Figure 4.18, Box plot: Total time spent [%] in heart rate zones 1 - 2 (17 referees; n=205 matches)

The box plot for heart rate zones 1 – 2, suggests that distributions of the data for this heart rate zones show great variation between referees. In keeping with this observation, the ICC for heart rate zone 1 - 2 is statistically significant (P=0.0037), and moderately large (ICC=0.63).

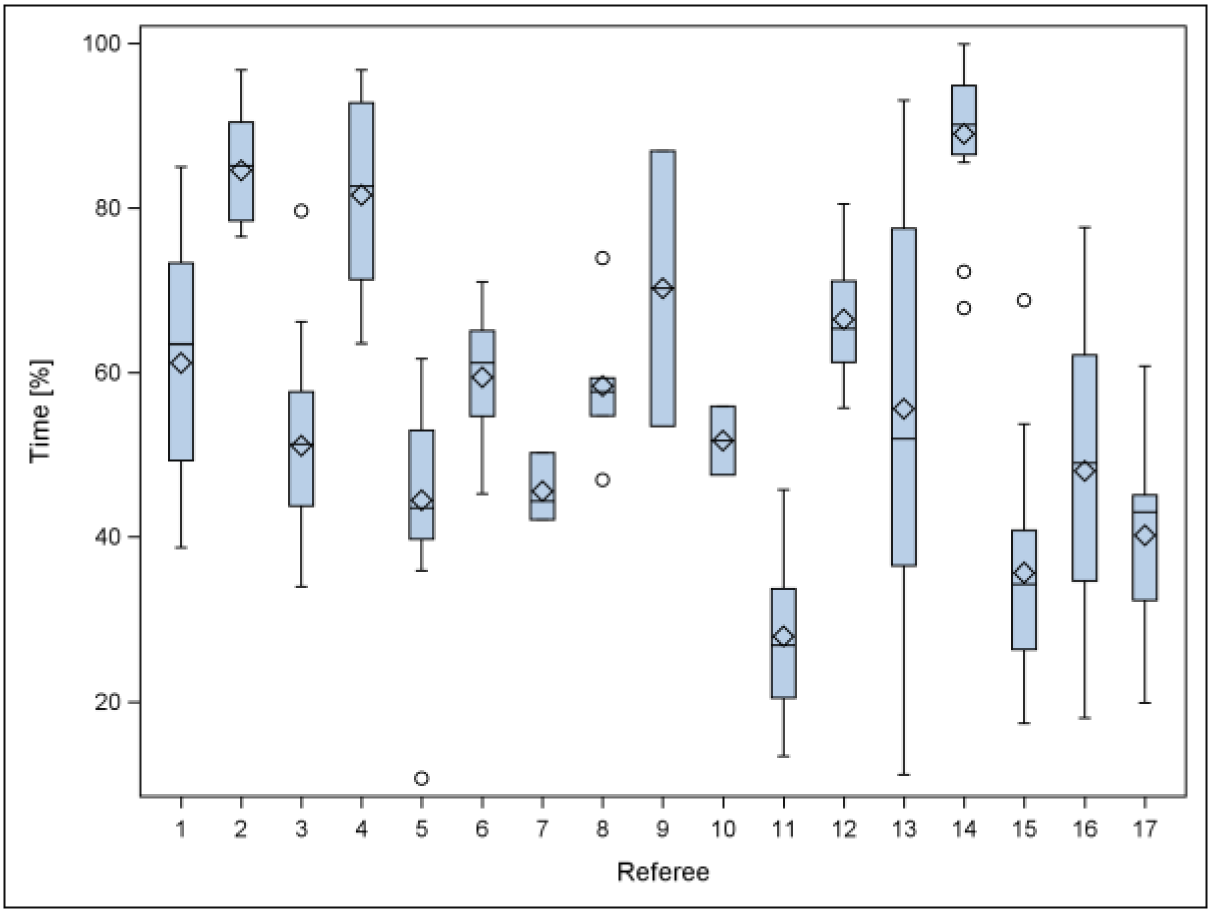

Figure 4.19, Box plot: ***Total time spent [%] in heart rate zones 3 - 6 (17 referees; n=205 matches)***

The box plot for heart rate zones 3 - 6, suggests that distributions of the data for this heart rate zones show great variation between referees.

4.4.4 High speed accelerations, high speed decelerations and sprints/surges

Below, side-by-side box plots display the distributions of the match totals for high speed accelerations, high speed decelerations and sprints/surges of each match officiated by the 17 referees (Figures 4.20 to 4.22).

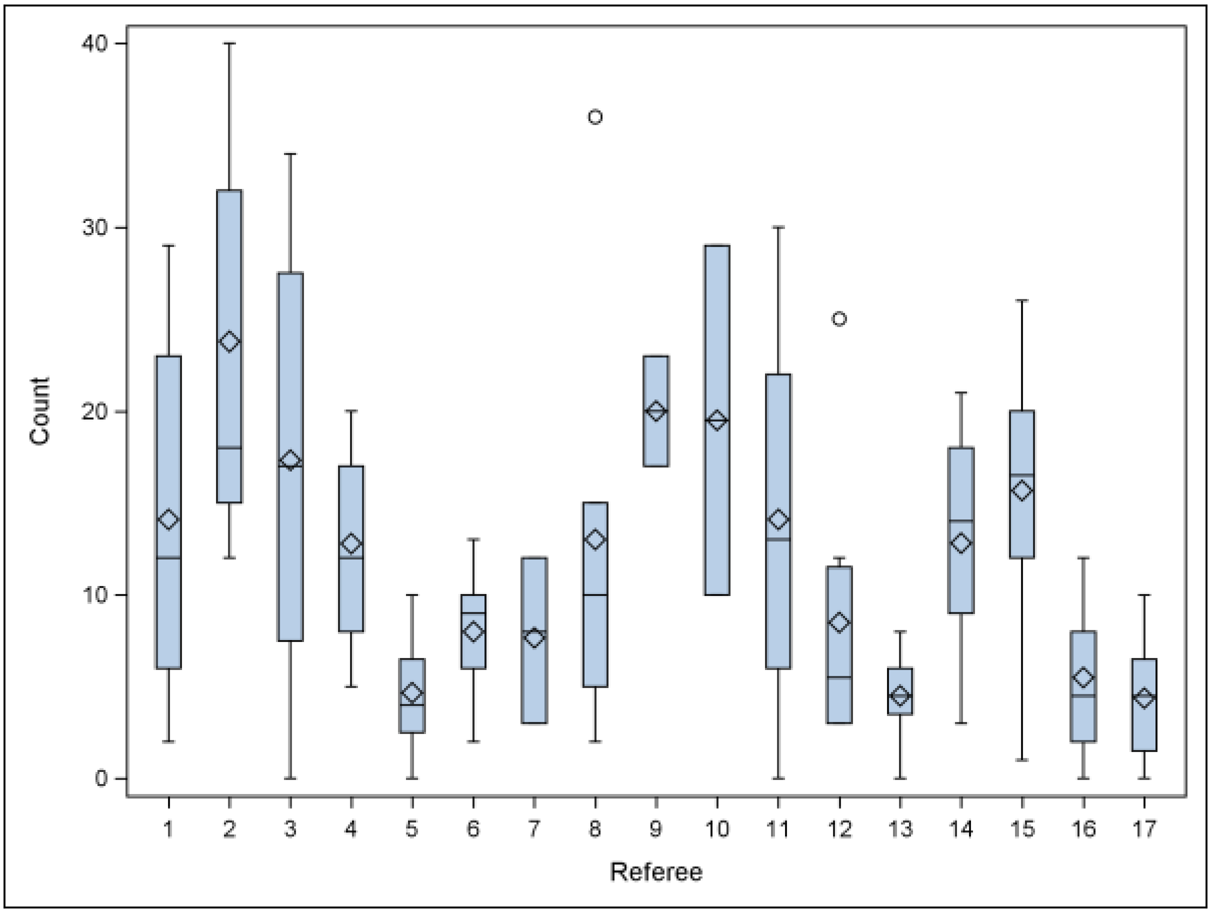

Figure 4.20, Box plot: ***Total number of high-speed accelerations (17 referees; n=205 matches)***

The box plot for high speed accelerations suggests that the distributions of the data for high speed accelerations of the various referees are reasonably tightly grouped together. Furthermore, the ICC for high speed accelerations, although statistically significant, is small (ICC = 0.29), which confirms the visual impression.

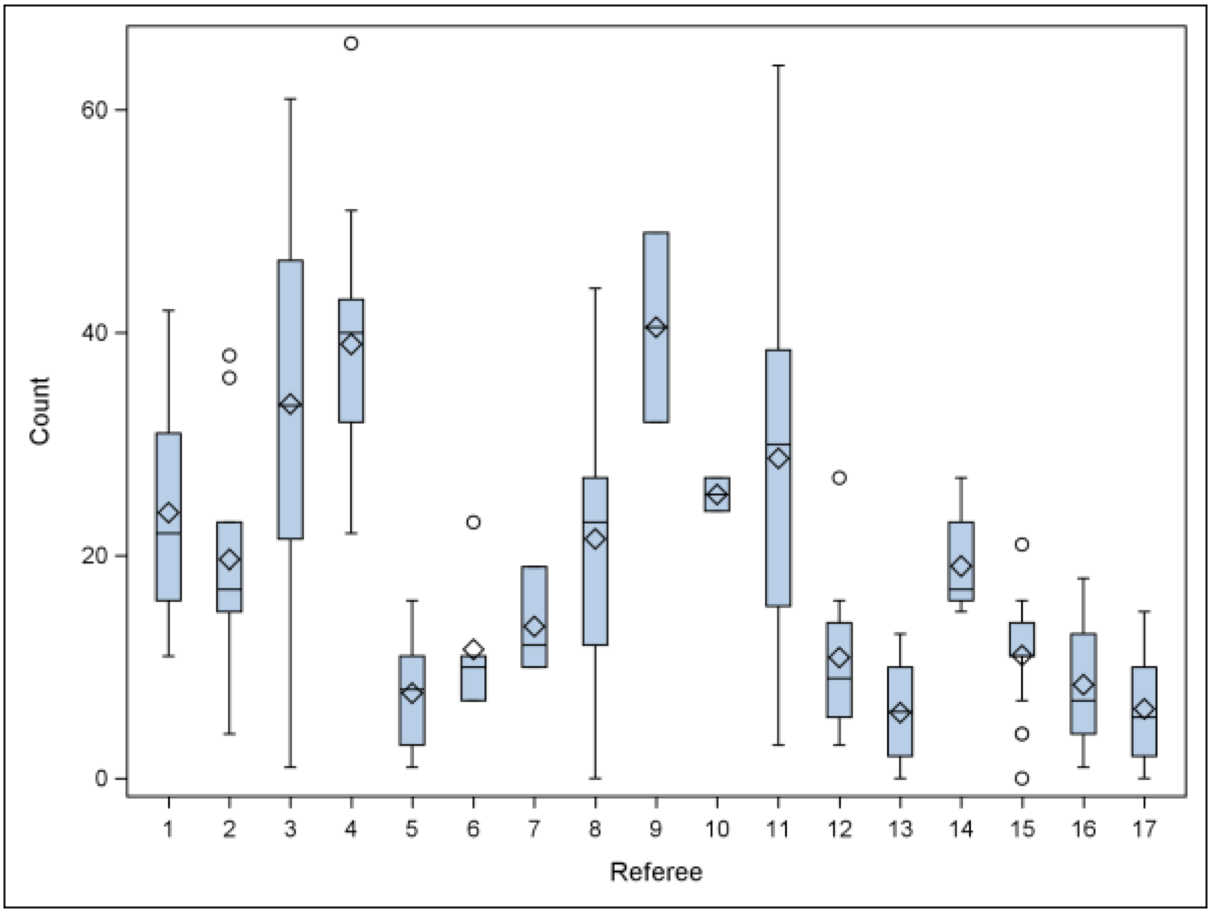

Figure 4.21, Box plot: ***Total number of high-speed decelerations (17 referees; n=205 matches)***

The box plots for high speed decelerations suggest that the distributions of the data for high speed decelerations of the various referees are widely spread. Furthermore, the ICC for high speed decelerations is statistically significant and moderately large (ICC=0.49), which confirms the visual impression.

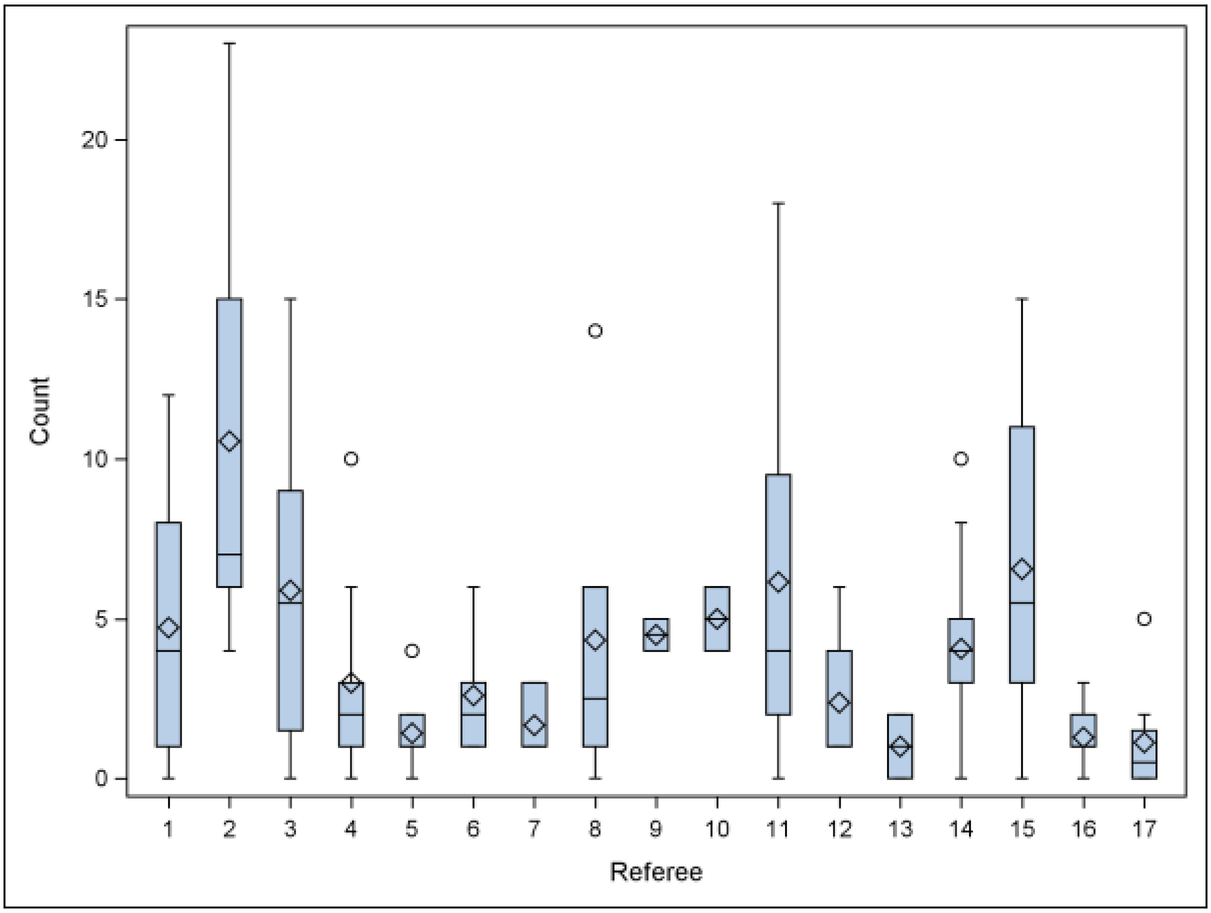

Figure 4.22, Box plot: Total number of sprints/surges (17 referees; n=205 matches)

The box plot for sprints/surges suggests that the distributions of the data for sprints/surges of the various referees are reasonably tightly grouped together. Furthermore, the ICC for sprints/surges, although statistically significant, are small (ICC = 0.23), which confirms the visual impression.

CHAPTER 5

DICUSSION OF THE RESULTS

5.1 Introduction

To date only a few studies that have used time and motion analysis (TMA) to investigate elite lead rugby referees (Blair *et al.,* 2018; Blair *et al.,* 2011; Kraak *et al.,* 2011b; Kraak *et al.,* 2011a; Cochrane *et al.,* 2003; Kelly *et al*., 2003a; Martin *et al.,*2001). This has identified the need to investigate this unique cohort of referee's. With the introduction of professional rugby in 1995, the game became faster so it is very likely that the physical demands on the referee have increased. Understanding these demands can help with the physical preparation with regard to the physical characteristics, e.g. body mass index (BMI), physiological response and work rate demands is more clearly understood. Such knowledge will help in the optimal preparation of referees for competition. Tables 4.1 and 4.2 provides evidence of previous TMA research on rugby referees focussed on provincial games with most of these studies having a small sample size. In contrast, the current study had 17 participants officiating provincial as well as international matches. For these 17 participants a total of 205 (n=205 for GPS data) GPS game files were recorded for analysis between 2015 and 2016. Only matches where the participants completed both halves of the game were included in the study.

5.2 Physical profile

As previously mentioned, there is insufficient data on the physical profile of elite lead rugby referees. However, three published studies have reported age, height and body weight of rugby referees (Dascombe *et al.,* 2003; Martin *et al.,* 2001; Martin *et al.,* 2005). The current study reported the age, height, body weight, BMI, Max HR - Sp Speed of 17 participants. The physical profile data suggests that the elite rugby referees in this group have a reasonably wide age range, narrow range of body weight, but a wide range of BMI values. Anthropometric characteristics are recognized as being important for referees, because somatotyping indirectly affects, for example, agility, speed of movement, reaction time, and endurance ability during a game of rugby refereeing (Martin *et al*., 2001).

5.2.1 Age

In the current study the mean (SD) age of elite lead rugby referees (n=17) was 38.1 (SD 4.91) years (Table 4.2). This is similar to previous research (Martin *et al*., 2001) that reported a mean age of 39.6 (SD 5.9) years for English Premiership referees. Furthermore, Dascombe *et al.* (2003) reported a similar mean age of 40.8 (SD 9.4) years (Regional Australian Referees). However, Martin *et al.* (2005) reported a somewhat higher mean age of 43 (SD 4) years, namely about five years older than in the current study.

It is expected that, given the increasing pace of the game and higher physical demands placed on rugby players, that elite referee pools will become younger. However, keep in mind that with an increase in age referees acquire more experience and learn to anticipate play better with increased economy of movement (Blair *et al*., 2011).

5.2.2 Body weight and height

The mean body weight of elite lead rugby referees in this study is 83.4 (SD 5.15) kg (Table 4.2) and mean height = 1.81 (SD 0.04) m (Table 4.2). These values are similar to previous research (Martin *et al.,* 2005) that reported a mean body weight of 78.7 kg for rugby referees. Although insignificant, the mean height reported by Martin *et al.* (2001) is 5 cm less than in the current study. Additionally, Martin *et al.* (2001) reported a similar mean body weight of 79.5 kg, with a mean height of 1.78 m. Dascombe *et al.* (2003) reported a much higher mean body weight of 90.8 kg, but these referees had a mean height of 1.80 (SD 0.1) m. Kay and Gill (2004) found National Rugby League (NRL) referees to have a mean body weight of 81kg (mean height 1.80m), with Hoare (2008) reporting a similar mean body weight of 81.1kg for NRL referees.

Elite lead rugby referees in the present study have an increased body mass in comparison to the work reported by, Martin *et al.* (2005) and Dascombe *et al.* (2003) on elite lead rugby referees with similar heights. This could be due to a more professional approach towards strength and conditioning in the modern game. Although research suggests that the mean height of elite lead rugby referees is approximately similar, it is interesting to note that the population of referees officiating in the English Premiership competition (Northern hemisphere) is shorter than the other referees in the different sporting codes.

5.2.3 BMI

In the current study the mean BMI of elite lead rugby referees is 25.45kg/m^2 (Table 4.2). This is similar to previous research (Blair *et al*., 2011) that reported a mean BMI of 26.9 (SD 1.9) kg/m^2. However, the BMI of the current study is greater than the mean BMI of 23 kg/m^2 for football referees, reported by Krustrup *et al.* (2009).

However, the BMI for elite lead rugby referees in the present study range between 22.6 kg/m^2 & 29.4 kg/m^2. The difference in BMI values could be due to various contributing factors. Firstly, the genetic compilation of the referee (white muscle fibre vs red muscle fibre) could be a determining factor in the BMI result. This could help explain why some referees have a higher BMI than others. Furthermore, the referee's daily nutritional intake together with their training regime could also be contributing factors, especially when they do long haul travelling. Importantly referees need to be disciplined with regards to their diet and training sessions when travelling, as a lack of discipline could have an influence on the BMI value.

5.3 Match and performance characteristics

5.3.1 Match duration

The concept of pacing behaviour, the distribution of energy resources that optimise running performance, is well known in continuous sports such as running (Millet, 2011) and cycling (Skorski & Abbiss, 2017), but has also become increasingly important in intermittent team sports such as soccer and rugby (Waldron & Highton, 2014; Gabbett *et al*., 2015; Ferraz *et al*., 2017). Between competing rugby teams of comparable physical capacities, the ability to manage effort during exercise and its resulting DM aspect might be decisive for team performance and the result of the game (Smits *et al*., 2014). According to Ferraz *et al*. (2017) coaches might use prior knowledge of exercise duration (here, the duration of the match) together with information about current match status (losing or winning) to determine the pacing behaviour of a team during the game. For example, a team might use delaying tactics either to try to "close out" the game when in a winning position, or to compensate for declining fitness or a reduced number of players on the field due to bookings. Therefore, rugby referees must be aware that players might try to control and manipulate match duration using such tactics.

It is also interesting to note that total match duration has increased over the years. This could be explained by the amount of substitutions made during a match, the time TMO decisions take, and as mentioned, by the fact that a team's game plan might be to "close" the game in the second half. In the current study the mean match duration (total) (n=205) was 97.6 min (Table 4.3) with a median of 97 min. To the researcher's knowledge there is only one published study that has reported match durations: Martin *et al*. (2001) reported a much lower mean match duration of about 85 min than the present study. No research could be found where the duration of the two halves for rugby union officiating was compared.

The ICC for match duration, although statistically significant, is very small (ICC=0.16; p=0.04; Table 4.11), which confirms that overall match duration was consistent between referees. However, comparing the data of Martin *et al*. (2001) with ours, it is interesting to note that the average match duration have increased by more than 10 min over the years. This could be due to modern television technology playing a bigger role in rugby (TMO decisions) than previously, longer stoppages for injuries as player welfare is important, as well as due to changes to the laws of the game that allow for more stoppages.

The average difference in duration between match halves found in the present study is very small; the very slightly longer second halves could be explained by more substitutions being made during the second half, the fact that TMO decisions may take a little longer in the last minutes of the game which are often decisive for the match outcome and lastly that a team's game plan might be to "close" the game.

5.3.2 Distance covered

The results of the current study suggest that the mean total distance covered by elite lead rugby referees is 6 825.90m (median= 6 811.9m) (Table 4.3). This is similar to previous research (Kelly *et al.,* 2003a) that reported a mean distance covered of 6 244m for elite lead rugby referees (International). However, Blair *et al.* (2011) reported a much higher mean distance covered of 8 030 (SD 506.6) m. This is similar to Martin *et al.* (2001) who reported mean distance of 8 581 (SD 668) m.

This study found that the difference in mean distance covered between the first (3402.9m) and second (3395.3m) halves are negligibly small (± 20 m). This is similar to the study of Blair *et al*. (2011) which mentioned that there was no significant difference in distance covered between the first and second halves. However, no other research could be found where the difference in distance covered between the first and second half was investigated. The similarity of distances covered between the two halves suggest that there is little to no tiring.

The ICC for distance covered is not statistically significant ($p<0.8739$) and very small (ICC = 0.13; $p = 0.05$; Table 4.11), which confirms that referees performed consistently with regard to distance covered. However, comparing the data of Blair *et al*. (2011) with the present study, it is interesting to note that, although the duration of matches increased over the years, it is evident that the distance covered by referees has decreased. This can be explained by more efficient referee coaching, experienced referees that are more economical with running patterns and the nature and pace of the game that evolved over the years. Additional factors that contribute to the difference in distance covered could be style of play and law changes (Blair *et al.,* 2011). However, both our and published data suggest that an elite rugby union referee should be able to cover distances of 9 km in match conditions.

5.3.3 Metabolic power

No research could be found where the calculation of metabolic power for elite lead rugby referees was investigated. The results of this study suggest that the mean metabolic power (total) produced by elite lead rugby referees during a match (n=205) is 12.09 W/Kg (median 11.2 W/kg) (Table 4.3). Additionally, the study found that referees produced slightly more metabolic power (mean = 6.21 W/Kg) during the first half than during the second half (mean = 5.88 W/Kg). Although this reduction (0.33 W/Kg) from the first to the second half is notable, it is not large, suggesting at most a small tiring effect during the match. If there is such an effect, even small, the question arises if this reduction in metabolic power in the second half is due to player fatigue and/or referee fatigue or both.

The maximum metabolic power produced during a match by a referee (15.9 W/Kg) suggests that occasionally referees face situations where the match demands significantly more physical work than during the average match, and indicates that referees do less work in the second half of a match. However, the lower metabolic power observed during the second half of a match may suggest an increase in the level of referee fatigue and a selective use of power-related activities and/or highlight the slowing of the game as players become more physically exhausted and tire. We might expect the power used by players to increase during the second half as the current laws allow for all eight reserve players to be used as substitutes. Further research that also measures key GPS metrics of the players would provide meaningful measures to enable accurate comparisons to lead referees.

Overall, the MP produced by the group of referees were consistent (ICC = 0.10; p = 0.06; Table 4.11). This could be the result of, increased referee fatigue, player fatigue or match sense (referee). Furthermore, a combination of the mentioned factors could also result in a reduction in MP.

The results from Table 4.3 revealed that the most metabolic power produced during a match by a referee was 15.9 W/Kg; this is 3 W/Kg more than the mean metabolic power produced, suggesting that sometimes referees will be in situations where some matches demand more physical work than others.

5.4 Speed zones (% Time spent)

The results of the current study show that the mean % time spent (total) in speed zones 1 – 2 (0 – 29% MSPD) by elite lead rugby referees (n=203) to be 52.44% (Table 4.5). Other investigators reported values of ~77 % (Cochrane *et al*., 2003; Kelly *et al.,* 2003a; Martin *et al*., 2005; *Blair et al.,* 2011). This is similar to the higher values of an investigation into South African Provincial and Contender referees of ~81% (Kraak *et al.,* 2011a). The lower value reported by the current investigation could be due to an increase in game demands, resulting in referees being required to work at higher speeds to keep up with play. There is almost no difference in the % time spent in speed zones 1 – 2 (n=204) between the second half (52.46%) and the first half (52.38%). This is supported by Blair *et al.* (2011) who reported no significant difference between the second half (88.0 SD 3.9)% and the first half (86.9 SD 3.5)%. The reported similarity between the two halves suggests that there could be little change in game demands or referees adapt their behavioural patterns with regard to changing physical demands. However, Kraak *et al*. (2011a) reported significant differences in mean duration between the two halves for standing still (d=2.05) and lateral movements (d=0.76), but no significant difference (d=0.33) for walking. It should be noted that a part of speed zone 3 from this current study is included in the rest zone reported by Blair *et al.* (2011), hence a higher value could be expected. The results from table 4.5 reveal that some referees spend up to 65% of the time in this zone where other referees only spend 40% in this zone.

The ICC for % time spent in speed zone 1 – 2 is moderately large and statistically insignificant (ICC=0.49; P=0.0052; Table 11), which confirms that overall % time spent in speed zone 1 – 2 was inconsistent between referees.

The mean % time spent in speed zone 3 (29 – 51% MSPD) by elite lead rugby referees (n=203) was 20.25% (Table 4.3). This is similar to previous research by Kelly *et al.* (2003a) that reported a mean % time spent of 18.5%. However, Blair *et al.* (2011) reported a much lower value of 10.9 (SD 0.9) % time spent in speed zone 3. This correlates with Cochrane *et al*. (2003), Martin *et al*. (2005) and Kraak *et al.* (2011a) who reported mean % time spent of 15.2 (SD 1.9)%, 12.8 (SD 3.2)% and 13.05% (provincial) and 14% (contender), respectively. The results are evident of an increase in game pace over time. This increase requires referees to work at higher speeds over longer periods of time in order to keep up with play.

There is a statistically significant (p=0.0085) difference in mean % time spent in speed zone 3 between the first and second halves (0.60%). This finding could be explained by a change in game demands or a change in the behavioural patterns of the lead referees. However, Kraak *et al*. (2011a) mentioned that there was no significant difference in mean duration for jogging between the first and second halves (d=0.16). It is important to note that some referees only spend 15% of a game in this zone where other referees spend up to 27% of the game in speed zone 3 (Table 4.5). The ICC for % time spent in speed zone 3, although statistically significant, is moderately small (ICC=0.32; P=0.0085; Table 4.11), which confirms that overall % time spent in speed zone 3 was consistent between referees.

The results from the current study suggest the mean % time spent in speed zones 4 – 6 (≤51% MSPD) by elite lead rugby referees (n=203) to be 27.31% (Table 4.5). This is much higher than the 12.6% reported by Blair *et al.* (2011), which correlates with Kraak *et al.* (2011a), Cochrane *et al*. (2003), Kelly *et al.* (2003a) and Martin *et al.* (2005) who reported percentages of 5.8%, 7.9%, 4.4% and 10.8%, respectively. This finding could be explained by an increased pace of play over time and that referees are physically able to adapt to the changing game demands. Furthermore, there is no significant difference (p=0.22) in % time spent in speed zone 4 – 6 between the second and first halves (-0.58%) for elite lead rugby referees. This is supported by Blair *et al.* (2011) who reported no significant difference in % time spent between the second half (12.0 SD 2.4%) and the first half (12.5 SD 2.8%). However, Kraak *et al.* (2011a) reported significant differences in mean duration for sprinting (d=0.77), additionally it should be noted that the range for sprinting as reported by Blair *et al.* (2011) is 5 – 7m.s^{-1}, hence it can be expected that the value could be higher as the current study's range for the work zone (zones 4 – 6) is 4.1 – 9.6m.s^{-1}. The results from table 4.5 reveal that although the mean duration for time spent in speed zones 4 – 6 is 27.31%, some referees spend much more time in this zone during a game (37.10%). However, in some instances referees only spend 18% of the total game time in this zone, which is much lower than the mean. Overall, for % time spent in speed zone 4 – 6, the performance between the referees was inconsistent.

In summary, the average time spent in speed zones 1 – 2 decreased over the years with an increase in average time spent in speed zone 3 and 4 – 6. This can be explained by an increase in game pace over the years due to more specialised conditioning of players, evolving playing styles and law changes. Interestingly, speed zones 1 – 2 and 4 – 6 had no significant differences in average % time spent between the second and first halves by elite lead rugby referees; this could be explained by more efficient conditioning for elite lead rugby referees. Although statistically insignificant (p=0.22), the small difference between the second and first half for % time spent in speed zones 4 – 6 can be explained by a change in game demands during the second half, referees adapting their running patterns or referees are tiring during the second half. The significant differences between the second and first halves (p=0.0085) for % time spent in speed zone 3 can be explained by a change in game demands or a change in the behavioural patterns of the referees. The results serve as is evidence that the physical demands with regard to speed that are placed on referees during the game is more or less the same for both halves. However, the significant differences reported between the two halves for provincial and contender panel referees can be explained by a lack of specific conditioning for the referees and the playing styles of the teams that may be at a lower level.

5.5 Heart rate zones (% Time spent)

The mean % time spent by elite lead rugby referees in the present study in the rest zone (HR zone 1 – 2) is 46.8 % (Table 4.7). This value is similar to the research of Cochrane *et al.* (2003) and Martin *et al.* (2005) who reported a mean % time spent in the rest zone of about 47%. In contrast, Blair *et al*.

(2011) reported a lower mean value of 36.1% for time spent in the rest zone, while Dascombe *et al*. (2003) and Kelly *et al.* (2003a) reported mean values of 21.3% and 26.2%, respectively. Kraak *et al*. (2011b) reported much higher mean % time spent of 75.6% for provincial referees and 80.2% for contender panel referees. The results suggest that referees adapted well to the evolving physical game demands as they are spending more time in the resting zone. This suggests that referees level of hard aerobic (aerobic power) condition has improved.

In the present study elite lead rugby referees spent about 8% more time in HR Zone 1 – 2 during the second half than during the first half. Blair *et al*. (2011) also reported a higher % time spent in the rest zone in the second half (42.6%) than in the first half (32.8%). Kraak *et al*. (2011b) also reported significant differences between the two halves in % time spent in the rest zone, indicating that referees spend more time the sub-threshold (d=7.90) and anaerobic threshold (d=0.92) during the first than during the second half. Therefore, both the current data and the literature suggest that the time spent in HR zones 1 – 2 increases in the second half compared to the first half, with a commensurate decrease in the complementary zones HR 3 – 6. The ICC for % time spent in HR 1 – 2 is moderately large (0.63), so that referees do not perform consistently with respect to this variable. This may be due to biological variation in HR profile between the different referees.

The mean % time spent in the work zone (HR zone 3 - 6) for elite lead rugby referees (n=205) is 53.17%. This is similar to previous research: Cochrane *et al.* (2003) and Martin *et al.* (2005) reported a mean % time spent in the work zone of 53% and ± 53%, respectively. However, Blair *et al.* (2011) reported a much higher mean value of 63.9% for time spent in the work zone. This is similar to the work of Kelly *et al*. (2003a) who reported mean % time spent of 63.8%. Dascombe *et al.* (2003) reported an even higher mean % time spent in the work zone of 78.7%. This suggests that physical conditioning for referees improved over the years and that referees are able to handle the changing physical demands of the game more effectively. Additionally, Kraak *et al.* (2011b) reported much lower mean values for provincial (24.4%) and contender referees (19.7%), respectively. This could be due to games that are not physically very demanding and were in a weekly tournament format. There is a statistically significant difference in mean % time spent in HR zone 3 - 6 between the first and second halves (~8%). However, Blair *et al.* (2011) reported no significant difference in % time spent in the work zone between the second half (66.7 SD 17.5%) and the first half (67.2 SD 15.3%). This correlates with Kraak *et al.* (2011b) who reported no significant difference (d=0.34) in mean % time spent in the supra-threshold between the two halves. The results suggest that the lower % time spent in the specific HR zone could be due to a decrease in game pace. However, it could be the result of the decrease in the referee's physical effort due to cumulative match fatigue or behavioural patterns. This is evident and consistent with most of the referees. Although the mean % time spent in HR zone 3 - 6 is 53.17%, some referees only spend 10.7% of a game in the work zone. However, table 4.11 reveals that some referees can spend as much as 99.90% of a game in this particular zone. Overall, for % time spent in heart rate zone 4 – 6, the performance between the referees was inconsistent.

To summarize, the average time referees spend in the rest zone increased over the years with a decrease in average time spend in the work zone during a game. This can be explained by better physical conditioning of referees and more economical work ethic by referees. The difference between the two halves is evident of the lower physical demands placed on referees during the second half due to more and longer rest periods that might be the result of stoppages. For example, injuries or substitutions made more regularly during the second half. However, it could also be the result of the decrease in the referee's physical effort due to cumulative match fatigue or behavioural patterns and/or referees needing to work less as players tire.

5.6 High speed accelerations and high speed decelerations (frequency)

According to the research team's knowledge this is the first study to investigate the frequency of sprints/surges for elite lead rugby referees. Previous studies only investigated % time in the 'sprint' speed zone.

For this study a range of 2.4 – 4.8^{ms-1} was used to classify high speed accelerations and high speed decelerations. In our study both mean high speed accelerations, mean high speed decelerations and mean sprints/surges decreased by about 20% during the second half compared to the first half, suggesting a certain tiring effect during the match (although the absolute decreases in the numbers of these events are quite small). Furthermore, while on average referees accelerate 12.5 times (Table 4.9) during a game, some referees have up to 40 accelerations per game, while others do not accelerate at all (Table 4.11). This correlates with the frequency of decelerations, where some referees decelerate 66 times during a match and others don't decelerate once.

Nevertheless, the ICC for high-speed accelerations, although statistically significant, is small (ICC = 0.29; P= 0.01; Table 14.11) which confirms that overall high-speed accelerations were consistent between referees. The ICC for high speed-decelerations is statistically significant (P=0.006) and moderately large (ICC=0.49), which confirms that overall high-speed decelerations were inconsistent between the referees. The frequency of accelerations and decelerations decreased significantly during the second half of the game. This might be due to the reduced physical demands placed on the lead referees during the second half. For example, increased rest periods from stoppages in match play due to injuries and substitutions. Further explanations could include increased cumulative player or lead referee fatigue.

5.7 Sprints/surges (frequency)

This is the first study to investigate the frequency of sprints/surges for elite lead rugby referees. Previous studies only investigated % time in the 'sprint' speed zone. The mean frequency (total) sprints/surges for elite lead rugby referees (n=205) was 4.4 (SD 5). This is in support of previous research, Kraak *et al.* (2011b) that reported a mean frequency of 5.8% sprints (total) per game. This correlates with Blair *et al.* (2011) who reported % time spent sprinting during a match to be 4.4%. However, Cochrane *et al.* (2003), Kelly *et al.* (2003b) and Martin *et al.* (2005) reported much lower values of 1.2 (SD 0.2)%, 0.8% and 1.0 (SD 0.4)%, respectively.

This study found that on average a referee sprints 2.4 times during the first half, which is slightly more than the 2 times referees sprint during the second half. Kraak *et al.* (2011b), reported a significant difference (d=0.77) between the second (2) and first half (4) of a match. The results are consistent and overall for most referees. An explanation for the reduction in the sprint/surges frequency during the second half is a change in the behavioural patterns of the referees. However, changing game demands during the second half, decreased number of high intensity bouts and the reduction in the referee's physical effort due to cumulative match fatigue, could be additional reasons for the reduction in sprints/surges during the second half. Further explanations for the reduction in sprint/surges frequency during the second half could be the result of lower physical demands placed on referees during the second half due to more and longer rest periods that might be the result of stoppages. For example, injuries or substitutions made more regularly during the second half. Further explanations could include cumulative player fatigue as well as match sense (referee).

Table 4.11 shows that referees only sprint 4 times during a match, in some instances referees had to sprint 23 times during a match, whereas some matches did not involve one sprint. The results revealed that referees sometimes even need to sprint 12 and 11 times during the first and second half, respectively.

The ICC for sprints/surges, although statistically significant, is small (ICC = 0.23; P=0.01; Table 4.11). This suggest that the, overall sprints/surges were consistent between the referees. The amount of times a referee needs to sprint during a match increased over the years. This is explained by the change in physical demands for players, increased game pace and playing styles. It is interesting to note that the difference in the frequency of sprints during the second and first half is not big. A possible explanation for this is that although the pace of the game seems to be a little slower during the second half, referees still need to be able to reach high speeds of running to keep up with play as substitutions are more likely to be made in the second half.

CHAPTER 6

Conclusion and Future Research

6.1 Introduction

In order to optimize rugby referee performance it is critical to have an understanding of the physiological response and work rate demands of the specific sport to ensure sport specific physical conditioning programmes. Blair *et al.* (2018) highlighted the importance of sport specific training programmes for optimal referee performance. As can be seen from Chapter 2, various researchers previously investigated the nature of elite lead rugby referees and the physical requirements engaged by these referees throughout match play (Cochrane *et al.*, 2003; Dascombe *et al., 2003*; Kelly *et al.,* 2003a; Martin *et al.,* 2005; Kraak *et al.,* 2011a; Kraak *et al.,* 2011b; Blair *et al.,* 2011; Blair *et al.,* 2018). These studies focused mainly on distance, HR and speed demand measures. Some of these studies did investigate the difference between the two halves. Additionally, these investigations had relatively small sample sizes and limited availability of modern sport technology such as GPS, which limited the number of metrics investigated. This created a gap in the literature and a real need to investigate the physiological response and work rate demands placed on referees throughout a match at an elite level. The current study was focussed on elite-level lead rugby union referees and investigated the match totals and physical differences between the two halves.

6.2 Conclusion

Our comparison of the two match halves with regard to the various performance characteristics indicated either virtually identical values for the two match halves (match duration, distance covered and percentage time in various speed zones) or at most small differences (metabolic power; percentage time in HR zones; numbers of high-speed accelerations, decelerations and sprints/surges). These results highlight overall consistency between halves with some difference in power measures. This difference might be due to variables such as referee experience and increased rate of substitutions. Furthermore, the size of the between-individual variation in physical performance measures relative to the within-individual variation was generally small to moderate, which might indicate that physical performance of referees across the sample was reasonably consistent. Therefore, our data will be helpful in the development of lead rugby referee-specific conditioning programs.

~~It is important to note, that although this study focused on the physical demands of elite lead rugby referees, it can also help "aspiring referees" to understand the physical demands of refereeing during match-play at the top level. Furthermore, it will also help top referees and strength and conditioning coaches to develop individualized conditioning programs based on their physical profile.~~

Measures relating to the primary aim of this investigation suggest that elite lead rugby referees have a reasonably wide range of age, body weight, and height (BMI). However, it is well reported that anthropometric measures are recognized as being important for referees, because somatotyping indirectly affects for example: agility, speed of movement, reaction time, and endurance ability during a game of rugby refereeing.

It is interesting to note that the mean match duration has increased over the years. This could be explained by the amount of substitutions that is made during a match, the time TMO decisions take and lastly that a team's game plan might be to "close" the game in the second halve. Although the duration of matches increased over the years, it is evident that the total distance covered by referees has decreased. This can be explained by more efficient referee coaching, experienced referees that are more economical with running patterns and the nature and pace of the game that evolved over the years. Additional factors that contribute to the difference in distance covered could be style of play and law changes.

The amount of metabolic power referee's produce during a match varies and is match dependent. This could be the result of, increased referee fatigue, player fatigue or match sense (referee). Furthermore, a combination of the mentioned factors could also result in a reduction in metabolic power and high-speed accelerations/ decelerations from 1H to 2H.

The average time spent in speed zones 1 – 2 decreased over the years with an increase in average time spent in speed zone 3 and 4 – 6. This can be explained by an increase in game pace over the years due to more specialised conditioning of players, evolving playing styles and law changes. The average time referees spend in the rest zone increased over the years with a decrease in average time spend in the work zone during a game. This can be explained by better physical conditioning of referees and more economical work ethic by referees.

The results from our investigation revealed that although on average referees tend to accelerate only a few times during a game, however in some instances referees get up to high amounts of accelerations per game. Furthermore, in some instances referees don't even accelerate once during a match. This correlates with the high frequency of decelerations by referees during a match and others don't decelerate once. This suggests that in some instances the physical demands of the game do not require the referee to accelerate or decelerate at a high-speed. According to the research team's knowledge this is the first study to investigate the frequency of sprints/surges for elite lead rugby referees. Previous studies only investigated % time in the 'sprint' speed zone. The amount of times a referee needs to sprint during a match increased over the years. This can be explained by the change in physical demands for players, increased game pace and playing styles.

The secondary aim of this study, in comparing the two halves of rugby match refereeing, firstly notes that no practical significant difference was found for the mean duration of a match halves and the mean distance covered during a match. It would seem that the aerobic standards of rugby referees is acceptable and elite referees have the capacity to repeatedly perform and recover from intense activity for the full duration of a rugby match.

Secondly, the metabolic power produced by referees during the second half of a match is significantly lower than the first half. This is due to a large practical significant difference for mean number of high-speed accelerations, mean number of high-speed decelerations, and the mean number of sprints/surges when comparing the two halves of match refereeing. These results indicate that referees tend to accelerate, decelerate and sprint less during the second half of a match than during the first half. The question arises if this reduced metabolic power in the second half is due to player fatigue and/or referee fatigue or both. A factor like substitutions of players is more relevant in the second half which will also influence the game. However, it is well known that rugby refereeing is a HIIE; therefore the development of aerobic and anaerobic power is critical for referees. Conditioning coaches can prescribe maximum aerobic speed sessions to develop aerobic power, and repeated sprints and sprints to develop anaerobic capacity and anaerobic power respectively for referees. To conclude, the development and the use of highly intermittent training are critical for referees.

Thirdly, the study revealed that there is no practical significant difference for % time in speed zones 1 – 2 (0 – 29% MSPD) during the first and second half of a match. However, a large practical significant difference was found for % spent in speed zone 3 (29 – 51% MSPD), revealing that referees spent more time in the mentioned speed zone during the second half of a match. This indicates that most probably referees have to use more energy to keep up with general play in the game (while power work is trimmed with only essential activity maintained). On average, the % time spent in speed zones 4 – 6 (≤ 51% MSPD) by referees during the second half (26.98%) is less than during the first half (27.66%), which will able the referee to keep up with the general play. As stated previously, more substitutes takes place in the second halve which may contribute to differences between the two halves. However, strength and conditioning coaches should consider these speed zone guidelines for designing programs for referees to keep up with the demands of the game.

Lastly, in comparing the two halves of rugby match refereeing, a large practical significant difference was found for % time spent in HR zones 1 – 2 (≥ 80% MHR). Referees spent 51% of the second half in this HR zone, this is far greater than the 42.5% spent in this zone during the first half. Furthermore, a large practical significant difference was found for % time spent in HR zones 3 – 6 (≤80% MHR). On average referees spent 57.5% of the first half in HR Zones 4 – 6 (≤ 80% MHR) and only 48.8% during the second half. Additionally, this study revealed that on average referees spent 46.8% of the match below 80% MHR and 53% of the game above 80% MHR. Again, this needs further research because

~~factors like substitution of players and more injuries in the second half as well as game plan strategy may play a significant role in these reported differences.~~

~~To conclude the specific measures from GPS in-match physical achievements provides the locomotion of referees in rugby matches, and movement profiles that also contribute to program design for individual referees.~~

6.3 Limitations, future research and practical implications

Certain limitations regarding this study can be indicated:

- No low speed accelerations and decelerations were reported.
- Splitting the match into four quarters might reveal further meaningful detail.

In order to optimize referee performance and to construct appropriate conditioning programs it is critical to have an understanding of the physiological demands placed on referees during a match. The findings of the current study show some differences in physical performance between referees, but at most slight differences between the second and first half of a match (suggesting at most a slight tiring effect). Strength and conditioning coaches can use these findings to in developing conditioning programs. For example, conditioning programmes for referees should focus on developing the whole spectrum of speed, accommodating frequent accelerations, decelerations, top-end speed, sprints etc. Referees certainly should have high levels of anaerobic performance to accommodate the short recovery periods between high-intensity activities. In order for referees to perform at a high intensity throughout the duration of the match, referees also need to have high aerobic as well as anaerobic endurance achieved by high-intensity training modalities. Our data suggest that the elite panel referees studied here generally meet those performance standards.

Future studies could research whether the physiological demands placed on referees during a match have an impact on their decision making abilities. Furthermore, future studies could compare different competitions e.g. Super Rugby, Pro 14, Aviva Premiership and the French Top 14, to determine whether different competitions impose different physiological demands on referees.

CHAPTER 7

Reflection on the Research Process

7.1 Introduction

Research alone can be a very intimidating, frustrating and time-consuming process. However, just the thought of doing research on a topic that few before you have done, creates a curiosity within you that drives you to go the extra mile. Research provides us with opportunities to ask an in-depth question of which the answer improves our knowledge and skills to excel in our field of practice. Without constant research, many professionals stagnate and therefore fail to improve themselves in their field of practice.

Like Albert Einstein said: *"Curiosity has its own reason for existing."*

That was the driven force behind this project, the curiosity and pure desire to know more about the physiological demands placed on elite rugby union referees and how I, as a sport scientist and sport conditioning specialist, can use the information from this project to further develop rugby referees to excel in their sport.

7.2 Reflecting on the research process

Four years ago I got this crazy idea of changing the refereeing industry, so I decided to take on this mammoth task. However, like many other students I was unsure of where to start the process. By browsing the internet I came across this simple six-step plan on how to do research:

Step 1: Find the right supervisor
Step 2: Don't be shy, ASK!
Step 3: Choose the correct topic
Step 4: Keep your plan realistic
Step 5: Prepare a project timeline
Step 6: Write, write and write

Step one: Find the right supervisor

Finding the right supervisor to guide me through the research process was relatively easy. I already knew what I wanted to achieve and the research question was already formulated in my mind, or so I thought. This is how the relationship between Prof F.F Coetzee and I started. Deciding that Prof Coetzee will be my senior supervisor was an obvious choice, considering that he was part of the of the Springbok team between 2004 and 2007 – winning the world cup in 2007 – and he formed part of the Springbok conditioning team for the 2011 world cup. His extensive experience as a conditioning coach and his interpersonal relationships, convinced me that he was the right person to guide me through this process.

I also needed someone who is an expert when it comes to the physical conditioning of referees and in time motion analysis. I approached Mr M.R Blair and as we already had a working relationship, asked him to be my co-supervisor. He is up to date with the latest technology and research in TMA. As world rugby's conditioning consultant to referees, he would eventually play a significant role in the final product.

Lastly, I needed to add an expert in biostatistics to the research team. Prof R. Schall was the final addition to the research team. His experience, expertise and knowledge of his field of practice are worth mentioning. Collecting data is one thing, however, presenting it in a highly professional manner requires skills from the very best. All three supervisors played an enormous part in the final product. Their guidance, expertise and patience helped me to deliver and to present it in such a good manner.

Step 2: Don't be shy, ASK!

A wise man once said: *"There's no such thing as a stupid question"*. Not knowing where to start the research process was a frightening experience. However, the professional approach of all three my supervisors made it a lot easier to ask questions whenever something was unclear.

Step 3: Select the right topic

The "what" and "why" of your research project can be overwhelming, but like I've mentioned before, I had a pretty good idea of what and why I wanted to do. Formulating the title and research question was relatively easy. After proper consultation with Prof Coetzee and Mr Blair I formulated the title and research questions.

Step 4: Keep your plan realistic

Stick to the questions you want answered! While I was reading up on the subject, I realised that there is so much more to be done, but that this research project will only focus on certain variables. The GPS device used in the study was the GPSports SPI HPU. The capability of this particular GPS system is astonishing. In keeping things realistic, I made only certain variables part of the current study.

Step 5: Prepare a project timeline

The aim of my research was to determine the physiological demands placed on elite rugby union referees by measuring them on certain variables. As part of the inclusion criteria, the participants had to be part of world rugby's elite panel. Data was collected over a period of two years (18 January 2015 to 16 December 2016) and therefore the timeline for the study was created around the set period. Dates were set to finish the research protocol in time so that ethical clearance was received before the starting the process.

Step 6: Write, write and write

Since Afrikaans is my home language, I faced some challenges in presenting the research in English and still accurately communicating the right message. Research involves doing an intervention and studying what previous researchers have already investigated. Writing the literature review was a time-consuming and frustrating process. However, it is important to understand previous research on your topic; as a matter of fact, this made me even more curious of what the outcomes of my study might be. So my advice would be to start writing from day one. The literature review will also point out shortcomings in previous research. This creates an opportunity to individualise your research project. The part of the study that excited me the most was writing the results and drawing conclusions. Finally, my own findings!

7.3 Personal remarks

Writing a thesis of this kind is not an easy task and I have learnt a great deal through this process. However, this is definitely the first step on my journey in becoming the trendsetter in my field. I have grown as an individual and in my field of practise.

I have formed strong professional friendships on my journey of writing this thesis. I would once again like to express the immense respect I have for my supervisors, Prof Derik Coetzee, Mr Matthew Blair and Prof Robert Schall. Their extensive knowledge, experience and professional guidance must not be underestimated. Lastly, without our heavenly Father this project would not have been possible. I was truly blessed with patience, knowledge and ideas when I expected it the least.

APPENDIX A: Information document

Appendix A : Information sheet (English)

INFORMATION DOCUMENT

Research title: Physical Demands of Elite Rugby Union Referees

Dear Participant

You are asked to participate in a research study conducted by Carel Bester, from the Exercise and Sports Science Department, University if the Free State, the results of which will form part of the dissertation for his Master's Degree. You were selected as a possible participant in this study because you are an international rugby union referee and this dissertation is based on elite rugby union referees

What is involved in the study - The data was collected over a period of two years in the following tournament and matches. These include the following: Rugby World Cup 2015, Six Nations, Rugby Championship, Super Rugby Tournament, European Challenge Tournament, June International Test Window and November International Test Window (2015 & 2016) Information from each game will be exported from the TeamAMS software (GPSports, Canberra, Australia) spread sheet (Microsoft Excel) and will be then uploaded to the SPSS 15.0 statistical program for analysis. Each referee was equipped with a global positioning system (GPS – GPSports: SPI HPU). The referee wore the GPS Unit in a specially designed GPS vest underneath the jersey between his left and right scapula in the upper thoracic spine area. The vest is designed to be comfortable and prevent unwanted movement of the GPS unit but will not hinder performance. The GPS unit is fitted and switched on ten minutes before warm-up starting approximately 30 minutes before kickoff. Warm-up data is also collected but

will be separated from match play data during analysis. GPS units are switched off directly after the match by the referee. After the match, data is downloaded to a personal computer and then send to WR database. Further analysis is carried out using TeamAMS Software.
The following variables will be investigated and analyzed the following variables: % of the time spent above 51% of maximal speed (% HIA Sp), time spent in minutes above 51% of maximal speed (HIA Sp time minutes), distance in meters covered above 51% of maximal speed (HIA Sp distance), % of maximum speed reached (% Max Sp reached), number of Lo and hi speed accelerations, number of Lo and hi speed decelerations, number of surges (sprints), range of the surges (sprints), total distance covered (m), % of time spent above 80% of maximal heart rate (% HIA HR), time spent in minutes above 80% of maximal heart rate (HIA HR time minutes), metabolic power (W/KG), high intensity work completed considering high speed running and accelerations – decelerations, body load and rate of perceived exertion on a scale from 0 (nothing) – 10 (supra-maximal).

Participation is voluntary: Participants can choose whether to be part of this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't feel comfortable answering and still remain in the study. Your position in the WR rankings will not be affected based on whether or not you choose to participate in this study.

Possible benefits: This research project will provide valuable information to governing bodies regarding the specific nature of the physical requirements placed on elite rugby union referees during matches. The results will also provide conditioning coaches and referees with valuable information that can assist with the development of physical programmes that are both individualised and specific.

Confidentiality: Any information that is obtained in connection with this study and that can be identified as your information will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of allocating numbers to referees. Information will be kept with the investigator only and raw data held under lock and key. All processing of data will be governed by a PC password protector. Only the findings will be published with the strictest of confidentiality to the individual athletes.

Contact details of researchers:

Carel Bester

Tel: 0835006958

Email: bester.c@sacr.fs.gov.za

Dr FF Coetzee

Tel: 051 401 2944

Contact details of secretariat and Chair: Ethics committee of the Faculty of Health Sciences, University of the Free State – for reporting of complaints/problems:

Telephone number: 051 405 2812

Thank you for your participation in the research project.

Regards

Carel Bester

APPENDIX B: Informed consent

Appendix B: Written consent form (English)

Physiological demands of elite rugby union referees

You are asked to participate in a research study conducted by Carel Bester, from the Exercise and Sports Science Department, University if the Free State, the results of which will form part of the dissertation for his Master's Degree. You were selected as a possible participant in this study because you are an international rugby union referee and this dissertation is based on elite rugby union referees.

1. PURPOSE OF THE STUDY

The primary aim of this study is to provide accurate, up-to date information on the physiological response and work rate demands placed on elite rugby union referees during matches

2. PROCEDURES

The testing will involve analysis of global positioning satellite (GPS) data from 22 WR (World Rugby) elite southern and northern hemisphere panel referees who officiated at an international level. Each of the 22 referees were equipped with a global positioning system (gps – GPSPORTS: SPI Pro X). The GPS data was captured over a period of four years. The following variables will be measured during a full game of Rugby Union: % of the time spent above 51% of maximal speed (%HIA Sp), time spent in minutes above 51% of maximal speed (HIA Sp time minutes), distance in metres covered above 51% of maximal speed (HIA Sp distance), % of maximum speed reached (%Max Sp reached), number of Lo and hi speed accelerations, number of Lo and hi speed decelerations, number of surges (sprints), range of the surges (sprints), total distance covered (m), Metabolic Power (W/Kg): High intensity work completed considering Hi speed running and accelerations – decelerations,, % of time spent above 80% of maximal heart rate (%HIA HR), time spent in minutes above 80% of maximal heart rate (HIA HR time minutes), body load and rate of perceived exertion on a scale from 0 (nothing) – 10 (supra-maximal) and % Leg Imbalance during each full game.

3. POTENTIAL RISKS AND DISCOMFORTS

These tests will not cause any additional discomfort or injury risk.

4. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

This research project will provide valuable information to governing bodies regarding the specific nature of the physical requirements placed on elite rugby union referees during matches. The results will also provide conditioning coaches and referees with valuable information that can assist with the development of physical programmes that are both individualised and specific.

5. PAYMENT FOR PARTICIPATION

Unfortunately there is no payment for your participation in this study, but a comprehensive report of the outcomes will be issued on request.

6. CONFIDENTIALITY

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of allocating numbers to referees. Information will be kept with the investigator only and raw data held under lock and key. All processing of data will be governed by a PC password protector. Only the findings will be published with the strictest of confidentiality to the individual athletes.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. Your position in the WR rankings will not be affected whether or not you choose to participate in this study.

8. IDENTIFICATION OF INVESTIGATORS

If you have any questions or concerns about the research, please feel free to contact Carel Bester (+27 835006958; email: bester.c@sacr.fs.gov.za or Dr FF Coetzee (051 401 2944- Exercise and Sports Science Department, University of the Free State).

9. RIGHTS OF RESEARCH SUBJECTS

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Dr Katinka De Wet (+27 (0)51 4012918 at the Research Ethics Committee ("REC") of the Faculty of Humanities of the University of the Free State ("UFS").

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

The information above was described to me, _________________________, by Carel Bester in *English* and I am in command of this language. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent to voluntarily participate in this study /I hereby consent that the subject/participant may participate in this study. I have been given a copy of this form.

____

Name of Subject/Participant

____

Name of Legal Representative (if applicable)

____

Signature of Subject/Participant or Legal Representative

____

Date

SIGNATURE OF INVESTIGATOR

I declare that I explained the information given in this document to __________________ and his/her representative ____________________ was encouraged and given ample time to ask me any questions. This conversation was conducted in English and *no translator was used.*

____________________	_____________
Signature of Investigator	**Date**
____________________	_____________
Participants signature	**Date**
____________________	_____________
Researcher's signature	**Date**

APPENDIX C: Permission letter – Unions

Appendix C

Permission letter – Unions

25 Forsyth Street
Universitas
Bloemfontein
9301
29 June 2016

Dear Mr
Referee Manager:

REASEARCH PROJECT (Magister Artium): PHYSICAL DEMANDS OF ELITE RUGBY UNION REFEREES

C. Bester (Masters Student) and The Department Exercise and Sport Sciences, University of the Free state hereby request permission to conduct research on Elite Panel Rugby Union Referee's from World Rugby. The research will be done in accordance with Prof. Derik Coetzee (Adjunct Professor & Head of Department: Department of Exercise and Sport Sciences, who was also the head conditioning coach of the Springboks 2004-2007).

Rugby union is also evolving globally as a professional sport; as such it is vital that the referees are optimally prepared for the physical demands of the game. Sport officials are regularly placed in the media spotlight as their decisions affect the outcome of games and competitions. Therefore, the ability of the referee in rugby union to keep up with play and to be in good position is critical and contributes to effective decision making. Thus, the ability of the rugby union referee to meet physical demands imposed during match play is believed to be a necessary prerequisite for optimal positioning and successful refereeing. Due to the dearth of research done on rugby union referees worldwide, the researchers found it necessary to:

- Determine the current physiological stress placed on international referees during match-refereeing.
- To implement time motion analysis to ascertain the movement activities of international rugby referees and to determine the frequency and duration of each component involved.

The Benefits of this study are:

- Updated data with regards to the physical demands placed on international referees during matches will be provided to the Unions.
- The results will give an indication how the game is evolving physically for elite referees.
- The results can be used by the unions for the specific physical development of referees.

In order to complete the research, permission is hereby requested to obtain GPS data from World Rugby's Elite Panel Referee's (22) on:

- Distance Travelled
- Heart Rate
- Speed
- Metabolic Power

Please note:

- During World Rugby's referee camp held Stellenbosch (30 May – 1 June 2016) I gave a presentation to al referee's attending on what the project entails.
- Data and referee identity will be treated with the utmost confidentiality
- If accepted each referee will complete informed consent forms

Your assistance in this matter will be greatly appreciated.

I, ______________________________, hereby give permission to C. Bester to collect GPS data from World Rugby's Elite Panel Referee's, meeting the criteria, affiliated with World Rugby.

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Carel Bester
Master's Degree Student

(Referee Manager:)

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