The derivation and validation of a novel field test for youth soccer

by

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A thesis submitted in partial fulfilment for the requirements for the degree of Doctor of Philosophy at the University of Central Lancashire

September 2017

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University of Central Lancashire

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ABSTRACT

The physical demands of competitive soccer are shaped by strategic and tactical decisions. Modern soccer is increasingly characterised by shorter and more frequent sprint efforts emphasising the need to accelerate repeatedly. However, while this change is mirrored in the approach to training and conditioning, fitness assessment remains biased towards the assessment of high speed running and repeated sprint ability. The aim of this thesis was to explore the validity of contemporary field-tests for modern soccer so that the value and usefulness of fitness assessment may be improved. The acceleration and deceleration activity during sub-elite youth match-play was determined using integrated technology and confirmed that this activity is crucial for performance. Wide players completed greater distances during high magnitude acceleration/decelerations justifying the inclusion of position specific training. Analysis of the Yo-Yo Intermittent Recovery Test (Level 1), the Hoff-Helgerud Football Endurance Test and the Bangsbo Sprint Test showed comparable tri-axial load. This questions the need to satisfy logical validity with complex field tests and lends support to the use of linear modalities. Each test also provided a high density effect exposing players to an acceleration/deceleration load higher than competition. Evidence of repeated acceleration activity (RAA) was the first reported during competition and analysis showed it was a generic attribute, although wide players tended to complete more bouts. Findings supported the inclusion of RAA conditioning and justified the derivation of a novel field test to assess this component. In response, the Repeated Acceleration Performance Test (RAPT) was designed and validated against the RAA demands of competition. Test re-test reliability was strong, although medium term reliability assessed following a 6-week training intervention was negatively affected by a congested fixture period and requires further investigation. In conclusion, RAA is a crucial element of modern competitive soccer. The absence of a

suitable field test to assess this component was addressed with the derivation and validation of the Repeated Acceleration Performance Test.

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ACKNOWLEDGEMENTS

"The price of success is hard work; dedication to the job at hand."

(Vince Lombardi, 1913-1970).

Beginning my PhD was initially a daunting prospect, so I am pleased and proud to have reached this end point. I wish to thank both Dr. Steve Atkins and Dr. Dave Fewtrell for their patience, support, and guidance during their spells as DoS. I also extend my thanks to Dr. Chris Edmundson for his input during numerous supervisory meetings. I would not have completed this thesis without your combined expertise and knowledge.

I offer my thanks to Chris Pinkett and Gareth Evans for their support and flexibility during my candidature. Similarly, the coaches and players from the Myerscough College Football Academy, for accommodating my frequent requests to schedule fitness testing sessions and gather data during their fixtures. Your enthusiasm and patience were greatly appreciated. Finally, Dr. John Fry for helping to maintain my sanity during this process.

Thanks also go to my friends and family, especially my Parents for their unconditional love and support since day one. To my daughter Eva who has given me so much pride and happiness it is impossible to describe. Finally, to Danielle for your love, support, and friendship since we met.

ABBREVIATIONS

Abbreviation	Meaning
30-15IFT	30-15 Intermittent Fitness Test
ACC	Acceleration
AFL	Australian Rules football
AP	Anterior-Posterior
AU	Arbitrary Units
BL	Blood lactate
BST	Bangsbo Sprint Test
CAM	Centre attacking midfielder
CC	Caudal-Cranial
CD	Centre defender
CDM	Centre defensive midfielder
CMF	Centre midfielder
CNS	Central Nervous System
COD	Change of Direction
CODAT	Change of Direction Test
DEC	Deceleration
DEF	Defender
DOP	Dilution of Precision
FIFA	Fédération Internationale de Football Association
FW	Forward
GPS	Global Positioning System
HDOP	Horizontal Dilution of Precision
Hoff FET	Hoff-Helgerud Football Endurance Test
HR	Heart rate
HSA	High-speed activity
HSR	High-speed running
HSS	High-speed sprint
Hz	Hertz
LSR	Low speed running
LSS	Low speed sprint
MF	Midfielder
MHR	Maximum Heart Rate

ML	Medio-Lateral
MSFT	Multi Stage Fitness Test
MSR	Moderate speed running
MSS	Moderate speed sprint
PL	PlayerLoad
PV	Peak Velocity
RAA	Repeated Acceleration Activity
RAPT	Repeated Acceleration Performance Test
RCOD	Repeated Change of Direction Test
RPE	Rate of Perceived Exertion
RSA	Repeated Sprint Ability
RSSA	Repeated Shuttle Sprint Test
sRPE	Sessional Rate of Perceived Exertion
TCAR	Carminatti's Test
TD	Total distance
VHSR	Very high-speed running
WD	Wide defender
YYIET	Yo-Yo Intermittent Endurance Test
YYIR	Yo-Yo Intermittent Recovery Test
YYIRL1	Yo-Yo Intermittent Recovery Level 1
YYIRL2	Yo-Yo Intermittent Recovery Level 2

PUBLICATIONS

Peer reviewed first author publications from this thesis:

Barron, D.J.; Atkins, S.; Edmundson, C. & Fewtrell, D. (2014). Accelerometer derived load according to playing position in competitive youth soccer. *International Journal of Performance Analysis in Sport*. 14 (3), 734 – 743.

Barron, D.J.; Atkins, S.; Edmundson, C. & Fewtrell, D. (2016). Repeated acceleration activity in competitive youth soccer. *Central European Journal of Sport Science and Medicine*. 14(2), 55 - 61.

Other publications during candidature;

Beenham, M.; **Barron, D.J**.; Fry, J.; Atkins, S.; Figueiredo, A. & Hurst, H. (2017). A comparison of workload demands in match-play and small-sided games, by positional role, in youth soccer. *Journal of Human Kinetics,* 57, 129 – 137.

Chapter 1: Introduction

1.1 Background

Soccer is reliant on the synergy between technical competence, tactical astuteness and efficient physical movement (Drust, Atkinson & Reilly, 2007). Competition is unpredictable and features movement of varying speeds, accelerations and decelerations, changes of direction and discreet movements, including jumping and tackling. Intermittent high-speed activities are performed on an endurance background requiring well developed aerobic and anaerobic capacities. Therefore superior physical condition may prove advantageous. A considerable proportion of team preparation is allocated to fitness training and readiness to compete is evaluated through periodic fitness assessment that forms an essential element of a support programme (Svensson & Drust, 2005).

However, fitness tests have been suggested to merely confirm the evidence of an individual's fitness status and dismissed as irrelevant providing functional competitiveness remains (Mendez-Villanueva & Buchheit, 2013). Instead, complex monitoring systems, particularly Global Positioning Systems (GPS), have been adopted at the elite level to analyse physical performance during games and training (Malone, Di Michele, Morgans, Burgess, Morton & Drust, 2015; Morgans, Adams, Mullen, McLellan & Williams, 2014). Based on the variation of physical data, inferences are made about physical condition, yet, although appealing, this approach does have several shortcomings. Initially, longitudinal data is required to establish the natural variation in physical performance (Carling, Dupont, Bradley & McCall, 2016), something not possible for a new signing. Secondly, soccer performance is complicated by a wide variety of situational factors (Castellano, Blanco-Villaseñor, & Álvarez, 2011) and a decline in any key performance indicator cannot be reliably attributed to fatigue or inferior conditioning. Finally, these systems incur a substantial financial and administrator time burden placing them out of the reach of many clubs. In summary, fitness assessment is the only cost effective and objective way to determine an individual's physical condition, assuming that the procedure selected is valid, reliable and fit for purpose.

A broad range of field based assessments are available, yet the Multi Stage Fitness Test (MSFT) (Leger & Lambert, 1982), Yo-Yo Intermittent Recovery test (YYIR) (Bangsbo, 1996) and Repeated Sprint Ability assessments (RSA) (Rampinini, Bishop, Marcora, Bravo, Sassi & Impellizzeri, 2007; Wragg, Maxwell & Doust, 2000), dominate in soccer. Use of the MSFT is justified by the elevated aerobic demands, and much of the game is spent in low-speed movements like walking and jogging (Bangsbo, 1994). However, authors including Carling, Bloomfield, Nelsen & Reilly (2008), assert that key game changing events occur at high-speeds suggesting that this is an important component of fitness. This standpoint is supported by findings that higher tiered sides are shown to complete greater distances during games (Iaia, Rampinini & Bangsbo, 2009; Mohr, Krustrup & Bangsbo, 2003; Mohr, Krustrup, Anderson, Kiekendal & Bangsbo, 2008).

In response, the YYIR was created to assess this capacity and higher tiered sides also performed better than lower tiered counterparts (Ingebrigtsen, Bendicksen, Randers, Castagna, Krustrup & Holtermann, 2012; Rampinini, Sassi, Azzalin, Castagna, Menaspa, Carlomagno & Impellizzeri, 2010; Teplan, Malý, Zahálka, Hráský, Malá, & Heller, 2012b). Although it is not possible to infer that greater physical performance leads to on field success (Drust, Atkinson & Reilly, 2007), these findings provide convincing support for the importance of high-speed running. Interestingly, Bradley, Carling, Gomez, Antonio, Barnes, Ade, Boddy, Krustrup & Mohr (2013a) recently reported that third tiered English professionals completed greater high-speed running than their Premier

League counterparts in contrast with the consensus of previous literature. The same group suggested that these differences might reflect superior ball retention at the top tier negating the need to chase the ball or a different tactical approach. The contrast in findings between Bradley, Lago-Peñas, Rey & Diaz (2013b) and Iaia, Rampinini & Bangsbo (2009), Mohr, Krustrup & Bangsbo (2003) and Mohr *et al.* (2008) may reflect a change in the prevailing strategic/tactical approach to competition affecting development in the physical demands. As such, high-speed running *per se* might no longer be a key performance indicator in the modern game.

Insight into the evolution of the physical demands of the English Premier League 2006-2012 supports the anecdotal view that soccer is more physically demanding. In the modern era high-speed efforts are shorter in bout duration and distance, but more numerous (Barnes, Archer, Bush & Bradley, 2014; Bush, Archer, Hogg, Barnes & Bradley, 2015), serving to emphasise the importance of repeated accelerations. In support of this standpoint, acceleration activity is impaired following peak activity (Akenhead, Hayes, Thompson & French, 2013) and may compromise an individual's functional potency. To summarise, it is clear that high-speed running remains an important element of match-play. However, the capacity to accelerate repeatedly is increasingly crucial. Recent research highlighted that earlier time motion analysis systems were insensitive to acceleration activity because movement was classified using thresholds/cut-off points. Indeed, maximal accelerations may occur at low movement velocity (Osgnach, Poser, Bernardini, Rinaldo & di Prampero, 2010; Varley & Aughey, 2013) leading to an underestimation of the energetics of the sport.

Exponents of repeated sprint ability may assert that this is semantics and that RSA protocols assess the capacity to accelerate repeatedly. However, despite evidence that RSA performance separates higher from lower tiered sides (Gabbett, 2009; Impellizzeri, Rampinini, Castagna, Bishop, Bravo, Tibauid & Wisløff, 2008; Ingebrigtsen, Dalen, Hjelde, Drust & Wisløff, 2015; Rampinini, Sassi, Morelli, Mazzoni, Fanchini & Coutts, 2009b), evidence in soccer is limited, and its importance in match-play is contentious (Buchheit, Mendez-Villanueva, Simpson & Bourdon, 2010c, Schimpchen, Skorski, Nopp & Meyer, 2016). Further, the majority of RSA protocols lack a change of direction component that fails to replicate the multi-directional nature of soccer.

Recent technological advances, particularly portable GPS and accelerometers, have described for the first time the acceleration activity of match-play previously overlooked by time motion analysis systems (Varley & Aughey, 2013). Presently, our understanding of this activity is limited and requires further investigation, particularly amongst the youth population that is often overlooked by research. The importance of acceleration in soccer has been long established (Chaouachi, Manzi, Chaalali, Wong, Chamari & Castagna, 2012) but assessment is limited to linear 0 - 10 m trials (Little & Williams, 2005) with no consideration for repeated bouts or multi-directional activity. This provides a strong rational to investigate this activity further, and also emphasises that a measure of this capacity is required to bridge the shortcoming in literature. This data may provide a reference point for the design of conditioning programmes at a tier that is generally unable to access expensive analysis systems. Further, a practical and cost effective protocol would facilitate meaningful fitness assessment, enhancing preparation and competition at this level.

1.2 Project aims and objectives

The overall aim of this thesis is, therefore, to evaluate the positional physical demands of sub-elite youth football using acceleration/deceleration profiles, and accelerometer derived metrics, to inform the derivation of a field based testing protocol.

The research aim will be achieved through a series of objectives, specifically;

- The examination of the positional accelerometer/deceleration activity, and tri-axial external load of competitive sub-elite youth soccer.
- Determining the extent that the acceleration/deceleration activity and tri-axial external load of competition is replicated in three contemporary fitness tests.
- Validating a novel field test for sub-elite youth soccer using acceleration/deceleration activity and accelerometer derived metrics.
- Assess the test-retest reliability of the new protocol, and, the sensitivity to detect changes in performance following a short-term training intervention.

Chapter 2: Review of the literature

2.1 Physical demands of soccer: Time motion analysis

The Fédération Internationale de Football Association (FIFA) is responsible for the global governance of the game and stipulates that matches are played on a surface 90-120 m in length and 45-90 m in width, by two teams of 11 players, over two periods of 45 minutes. The increasing interest in soccer from academics is concurrent with the upsurge in media interest and escalating financial rewards for success. Consequently, there are compelling reasons to identify and exploit competitive advantages, but also to identify and develop talented young players. Accordingly, a wealth of literature is available that describes the physical demands of match-play intending to optimising physical preparation. This review, whilst acknowledging earlier research, focusses more on recent work examining the demands of competition typically utilising time motion analysis systems.

Contemporary time motion analysis reports that players cover ~10-14 km during competition, a figure which changes relatively little (Barros, Misuta, Menezes, Figueroa, Moura, Cunha, Anido & Leite, 2007; Bradley, Sheldon, Wooster, Olsen, Boanas & Krustrup, 2009; Dellal, Wong, Moalla & Chamari, 2010b; Di Salvo, Baron, Tschan, Calderon Montero, Bachl & Pigozzi, 2007; Reilly & Thomas, 1976). Total distance (TD) is regularly used as a global indicator of effort (Reilly & Williams, 2003) and midfielders generally cover the greatest TD, as a function of their combined offensive and defensive roles (see Table 1, p.28). The majority of distances are of a sub-maximal level of exertion, representing a large aerobic outlay of energy (Bangsbo, 1994; Reilly & Thomas, 2003). However, the crucial parts of a game are completed at high-speed evidencing the need for a well developed anaerobic capacity (Carling *et al.*, 2008; Gabbett & Mulvey, 2008). The fluctuating aerobic and anaerobic periods characterises soccer as an intermittent sport.

Soccer is unpredictable, requiring players to perform approximately 1000-1500 movement changes during a game, equating to one every 4–4.5 s (Bangsbo, Nørregaard & Thorsø, 1991; Bloomfield, Polman & O'Donoghue, 2007). The multi-directional nature of match-play also increases energy expenditure, which is estimated to range between 1200–1500 kcal per game, according to calculations based on the measurement of heart rate (HR) (Dellal *et al.*, 2010b; Lakomy & Haydon, 2004; Osgnach *et al.*, 2010; Reilly & Bowen, 1984; Williford, Scharff-Olson, Gauger, Duey & Blessing, 1998). Superimposed on this background is the requirement to interact with the ball and to react to the movement of opponents, while demonstrating technical and tactical proficiency.

A key component of soccer is high-speed running (HSR), although consensus is lacking about what constitutes a high-speed effort, and thresholds range from 12 to 24 $km{\cdot}hr^{-1}$ (Burgess, Naughton & Norton 2006; Dellal, Chamari, Wong, Ahmaidi, Keller, Barros, Bisciotti & Carling, 2011). Elite players are reported to cover the greatest distances rendering superior HSR performance desirable (Andersson, Randers, Heiner-Møller, Krustrup & Mohr, 2010; Bangsbo *et al.*, 1991; Iaia, Rampinini & Bangsbo, 2009; Ingebrigtsen *et al.*, 2012; Mohr, Krustup & Bangsbo, 2003; Mohr *et al.*, 2008).

Sprinting is a sub component of high-speed activity (HSA) and may provide a decisive advantage particularly in goal scoring situations (Faude, Koch & Meyer, 2012). Individual bouts of sprinting are generally < 20 m (Burgess, Naughton and Norton, 2006; Di Salvo, Pigozzi, Baron, Gormasz, González-Haro & Bachl, 2010; Gabbett & Mulvey, 2008; Vigne, Rogowski, Hautier, Gauidino & Alloatti, 2010) and TD during games ranges between 200-500 m (Barros *et al.*, 2007; Bradley *et al.*, 2009; Dellal *et al.*, 2010b; Di Salvo *et al.*, 2010). Sprinting ability is shown to discriminate between higher and lower tiered competition (Cometti, Maffiuletti, Poulson, Chatard & Maffuli, 2001), tactical roles of players within a team and consequently, the overall success of a team (Rampinini, Coutts, Castagna, Sassi & Impellizzeri, 2007).

Recovery time between sprints ranges <30 s to >1 minute (Mujika, Santiseban & Castagna., 2009) yet, critically, mean values do not represent the fluctuation in work rates and underestimate the most intense periods of games where consecutive sprints can be required (Fitzsimons *et al.*, 1993). This activity was later defined as repeated sprint ability (RSA), a minimum of three consecutive sprints with less than 21 s between them (Spencer, Bishop, Dawson & Goodman, 2005). Despite some evidence that players are required to repeat maximal, or near maximal sprints, separated by brief recovery (Bansgbo, Norregaard & Thorsø, 1994; Withers, Maricic, Wasilewski & Kelly, 1982), conflicting evidence means that the importance of RSA during match-play is contentious (Buchheit *et al.*, 2010c). Before dismissing the importance of RSA, it is noteworthy that the level of intensity and work rate of competition demonstrates natural variation, meaning certain fixtures are physically more demanding than others necessitating RSA activity (Gregson, Drust, Atkinson & Di Salvo, 2010; Rampinini *et al.*, 2007a).

A greater insight into HSA is achieved by separating sprinting and acceleration. Acceleration is defined as the rate of change in velocity (Aughey, 2011) and the correlation between acceleration and maximum speed ranges r = 0.56–0.87 (Harris, Cronin, Hopkins & Hansen, 2008; Little & Williams, 2005; Vescovi & McGuigan, 2008) emphasising the two are separate qualities (Little & Williams, 2005). Accelerating is an energetic task, more so than running at a constant velocity (Osgnach *et al.*, 2010. Speed is suggested to be related to muscular-tendon stiffness, the stretch-shortening cycle and hip extensor activity (Buchheit *et al.*, 2014; Murphy, Lockie & Coutts, 2003), whereas acceleration is reliant on the concentric extension of the knee and hip (Dorn, Schache & Pandy, 2012).

In the English Premier League, 30 % of sprints were classified as explosive (preceded by a rate of acceleration <3.0 $m{\cdot}s^{-2}$), and the remainder were leading sprints (preceded by a rate of acceleration >3.0 $m{\cdot}s^{-2}$) (Di Salvo, Gregson, Atkinson, Tordoff & Drust, 2009). A higher rate of acceleration evokes a greater energetic cost (di Prampero, Fusi, Antonutto, Sepulcri, Morin, Beli & Antonutto, 2005) emphasising that in order to elucidate the energetic demands of match-play, a system of classifying acceleration activity is required. In addition, because time motion analysis studies overlooked acceleration activities, the energetic demands of competition have been underestimated (Osgnach *et al.*, 2010) and further research is required to describe this activity. Presently, limited research exists and is summarised in Table 2 (p.34).

Despite attempts to standardise the zones used to classify acceleration in field sports, a lack of agreement prevails. Aughey (2011) proposed that 4.00 $m{\cdot}s^{-2}$ be too high for categorising maximum acceleration based on the observation that team sports players accelerated at 3.00 $m{\cdot}s^{-2}$ during a linear test (Góralczyk, Mikolajec, Poprzecki, Zajac, Szyngiera, & Waskiewicz, 2003). However, efforts >4.00 $m{\cdot}s.^{-2}$ have been observed, suggesting higher categories are required (Bradley, Di Mascio, Peart, Olsen & Sheldon, 2010) and reliance on too low a threshold would present limitations with sensitivity and underestimate an individual's performance. In reality, the most reliable way to evaluate performance would define relative zones based on each individual's sprint times.

Unfortunately, this presents significant administrator burden and is very time costly, leading to the adoption of predefined categories.

The myriad of multi-directional activities in soccer confirm it is not a linear activity (Bloomfield, Polman & O'Donoghue, 2007; Reilly & Williams, 2003; Rienzi, Drust, Reilly, Carter & Martin, 2000). As such, understanding of the rigours of competition would be advanced by an assessment of the volume and magnitude of tri-axial external load and would serve to inform conditioning and rehabilitation interventions.

Table 1: A summary of time motion analysis studies into the physical demands of soccer.

Author	Age group	Group	System	TD (m ± SD)	Activity (m ± SD)
Rienzi *et al*. (2000)	Elite Male, (n = 23)	South American (n = 17), English (Premier League) (n = 6)	Video analysis	All positions: 8638 m (± 1158).	
Strudwick & Reilly (2001)	Elite Male, (n = 24)	English (Premier League)	Computer analysis	All positions: 22264 m. MF: 12075 m, WD: 11433 m > CD: 10650 m, $p < 0.05$.	
Mohr, Krustrup & Bangsbo (2003)	Elite Italian Male, (n = 18), Elite Danish Male, (n = 24)	Italian (Serie A) and Danish (SuperLiga)	Computer coded	Italian: 10860 m (± 180) > Danish: 10330 m (± 260), $p = <0.05$. MF: 11000 m (± 210), WD: 10980 m (± 230), FW: 10480 m (± 300) > CD: 9740 m (± 220), $p < 0.05$.	(HSA: 18.0 km•hr^{-1}, Sprinting: 30.0 km•hr^{-1}) HSA; MF: 2230 m (± 150), WD: 2460 m (± 130), FW: 2280 m (± 140) > CD: 1690 m (± 100) $p < 0.05$. Sprinting; FW: 690 m (± 80), WD: 640 m (± 60) > MF: 440 m (± 40), CD: 440 m (± 30) $p < 0.05$.
Castagna, D'Ottavio & Abt (2003)	Amateur Male Youths (n = 11)	Italian (U12)	Computer analysis	All positions: 6175 m (±318).	(HSA: >13 km•hr^{-1}). All positions: 468 m (± 89).

Burgess, Naughton & Norton (2006)	Elite Males, (n = 45)	Australian (National Soccer League [NSL])	Computer analysis	All positions: 10100 m (± 1400). MF: 10100 m (± 1900), FW: 9900 m (± 1500) > DEF: 8800 m (± 1200), $p < 0.05$.	(HSR: 12-18 km•hr^{-1}, Sprinting 18.0-24.0 km•hr^{-1}) Mean all positions: HSR; 1800 m (± 400), Sprinting; 700 m (± 200). HSR; MF: 2100 m (± 500), FW: 1900 m (± 300) > DEF: 1500 m (± 300) $p < 0.05$). Sprinting; DEF: 600 m (± 200), MF: 800 m (± 200), FW: 800 m (± 200) $p > 0.05$).
Barros *et al*. (2007)	Elite Males, (n = 55)	Brazilian (Campeonato Brasileiro Serie A)	Video	WD: 10642 m (± 663), CMF: 10476 m (± 702), WMF: 10598 m (± 890) > FW: 9612 m (± 772) & CD: 9029 m (± 860), $p < 0.05$.	(HSA = 19-23 km•hr^{-1}, Sprinting > 23.0 km•hr^{-1}). HSA; WD: 779 m, WMF: 756 m, CMF: 719 m, FW: 693 m, CD: 560 m. Sprinting; WD: 562 m, FW: 481 m, WMF: 457 m, CMF: 367 m, CD: 352 m.
Da Silva, Kirkendall & Neto (2007)	Amateur Male Youths (n = 75)	Brazilian U15 (n = 25), U17 (n = 25), U20 (n = 25)	Video analysis	U15: 7007 m (± 545) < U17: 8638 m (± 519) $p < 0.05$), < U20: 9809 m (± 459) $p < 0.05$.	
Di Salvo *et al*. (2007)	Elite Male, (n = 300)	Spanish (La Liga) and UEFA Champions League games	Amisco	All positions: 11393 m (± 1016). CM: 12027 m (± 625), WMF: 11990 m (± 776) > WD: 11410 m (± 708), FW: 11254 m (± 894), CD: 10627 m (± 893) $p < 0.001$.	HSR: 19.1 – 23.0 km•hr^{-1}, Sprinting: >23.0 km•hr^{-1}. HSR; WMF: 738 m (± 174) > WD: 652 m (± 179), CMF: 627 m (± 184), FW: 621 m (± 161), CD: 397 m (± 114) $p = 0.05$.
Bradley *et al*. (2009)	Elite Male, (n = 370)	English (Premier League)	Prozone	All positions: 10714 m (± 991). WMF: 11535 m (± 933), CMF: 11450 m (± 608) >	(HSA = > 14.5 km•hr^{-1}, Sprinting >25.0 km•hr^{-1}). HSA = 9.0 % of total time.

				WD: 10701 m (± 589), CD: 9885 m (± 555), FW: 10314 m (± 1175) $p = 0.01$.	WMF: 3138 m (± 565) > CD: 1834 m (± 256), WD: 2605 m (± 387), CMF: 2825 m (± 473), FW: 2341 m (± 575) p 0.01. Sprinting; WMF: 346 m (± 115), WD: 287 m (± 89) > CD: 152 m (± 50), CMF: 204 m (± 89), FW: 264 m (± 87) $p = 0.01$.
Rampinini, Impellizzeri, Castagna, Coutts & Wisløff (2009a)	Elite Male, (n = 186)	Italian (Serie A)	SICS automatic tracking	All positions; "less successful side" (LS) 12190 m > "most successful side" (MS) 11647 m, $p < 0.01$.	(HSA >14.5 km•hr^{-1}, VHSR >19.0 km•hr^{-1}). HSA; LS: 4263 m > MS: 3787 m, $p < 0.01$. VHSR: LS: 1309 m > MS: 1196 m, $p < 0.01$.
Buchheit, Mendez-Villanueva, Simpson & Bourdon (2010a)	Elite Male Youths, (n = 77)	International Youths	SPI Elite (1 Hz)	All positions. U17: 8448 m (± 118). U18: 8254 m (± 135). WD > CD, FB > CMF, WMF > CD, FW > CD, WMF > FW ($p > 0.05$).	(HSR 13.1 km•hr.$^{-1}$ - 16.0, VHSR 16.1–19.0 km•hr^{-1}, Sprinting >19.1 km•hr^{-1}). All age groups. HSR; WD > CD, WD > CMF, WMF > CD, FW > CD, CMF, WMF > FW ($p > 0.05$). VHSR; WD > CD, CMF > CD, WMF >CD, FW > CD, FW > CD, CMF, WMF >FW ($p > 0.05$). Sprinting; WD > CD, WD > CMF, FW > WD, WMF > CD, CMF > WMF ($p > 0.05$).
Di Salvo *et al*. (2010)	Elite Male, (n = 717)	European Champions League and UEFA Cup	Prozone		(Sprinting >25.2 km•hr^{-1}). Total mean distance 205 m (± 108). CD < WD, CMF, WMF, FW ($p < 0.001$, d = 0.40-1.69). 0-5 m: WMF > CD, WD, CMF, FW ($p < 0.001$). 5-10 m: CD, CMF < WD, WMF, FW ($p < 0.001$). 10-15 m: CD, CMF < WD, WMF, FW ($p < 0.001$). 15-20 m: WMF > WD, CD, CMF, FW ($p < 0.001$).

Dellal *et al*. (2010b)	Elite Male, (n = 3540)	French (Ligue 1)	Amisco	WMF: 12029 m (± 977), CAM: 11726 m (± 984), CDM: 11501 m (± 901) > CD: 10425 m (± 808), WD: 10655 m (± 860), FW: 10942 m (± 978), $p < 0.001$.	(HSA = 21.0-24.0 km•hr^{-1}, Sprinting = >24.0 km•hr^{-1}). HSA; WMF: 335 m (± 64), CAM: 334 m (±62), CDM: 302 m (± 69), FW: 300 m (± 57) > CD: 230 m (± 56), WD: 274 m (± 63) p 0.00. Sprinting; FW: 290 m (± 75)> WMF: 235 m (± 85), CAM: 234 m (± 72), WD: 241 m (± 70), CDM: 220 m (± 77), CD: 199 m (± 66) $p < 0.001$.
Bradley *et al*. (2010)	Elite Male, (n = 100).	English (Premier League)	Prozone	All positions: 10841 m (± 950). Elite: 10666 m (± 566), Domestic: 10859 m (± 980), $p > 0.05$. WMF: 11491 m (± 996), CMF: 11411 m (± 486) > WD: 10763 m (± 627), FW: 10504 m (± 1090), CD: 10057 m (± 582) $p < 0.05$.	(HSA = > 14.5 km•hr^{-1}). Mean = 2725 m (± 656). WMF: 3243 m (± 625), CMF: 2949 m (± 435), WD: 1806 m (± 408), FW: 2618 m (± 745) > CD: 2034 m (± 284), $p = 0.01$.
Njororai (2010)	Elite Male, (n = not disclosed).	USA National Team (2010 FIFA World Cup)	Via. fifa.com	All positions: 90 minutes: 10842 m. 120 minutes: 14823 m (± 1347).	
Harley, Barnes, Portas, Lovell, Barrett, Paul & Weston, (2010)	Elite Male Youths, (n = 24).	English Academy (U16)	Minimax GPS (5 Hz)	All positions: 7672 m (± 2578).	HSR normalised to 10 m flying sprint time. All positions: 2481 m (± 1044)
Lago, Casais, Dominguez & Sampaio, (2010)	Elite Male, (n = 19)	Spanish (La Liga)	Amisco	WMF:11425 m (± 354), CMF: 11320 m (± 610),	HSR: 19.1–23.0 km•hr^{-1} Sprinting: >23.0 km•hr^{-1}) HSR; WMF: 609 m (± 117), FW: 584 m (± 116),

				WD: 11050 m (± 482), CD: 10491 m (± 496).	WD: 576 m (± 135), CMF: 502 m (± 132), CD: 388 m (± 114). Sprinting; FW: 344 m (± 112), WMF: 337 m (± 94), WD: 327 m (± 131), CD: 188 m (± 84), CMF: 179 m (± 84).
Rey, Lago-Peñas, Lago-Ballesteros, Casais, Dellal, (2010)	Elite Male, (n = 42)	Spanish (La Liga)	Amisco	All positions: 10963 – 11053 m.	HSR: 19.1 – 23.0 km•hr^{-1}; VHSR: >23.0 km•hr^{-1}). All positions: HSR: 1760 - 1779 m, VHSR: 522 – 544 m.
Carling (2011)	Elite Male, (n = 21)	French (Ligue 1)	Amisco	All positions; 4-3-3 vs. 4-2-3: 10808 m (± 661) > 4-4-2: 10594 m (± 681), $p < 0.05$, ES 0.32.	(HSR: 14.4 – 19.7 km•hr^{-1}; VHSR: >19.8 km•hr^{-1}) HSR: 4-3-3 vs. 4-3-3 (1630 m ± 376), vs. 4-2-3-1 (1608 m ± 374), vs. 4-4-2 (1577 m ± 373) $p = 0.48$. VHSR: 4-3-3 vs. 4-3-3 (741 m ± 236), vs. 4-2-3-1 (721 m ± 222), vs. 4-4-2 (704 m ± 219) $p = 0.42$.
Bradley, Carling, Archer, Roberts, Dodds, Di Mascio, Paul, Diaz, Peart & Krustrup, (2011)	Elite Male, (n = 153)	English (Premier League)	Prozone	All positions: 4-4-2: 10697 m (± 945), 4-3-3: 19786 m (± 1041), 4-5-1: 10613 m (± 1104), $p > 0.05$). DEF: 4-4-2: 10452 m (± 755) > 4-3-3: 10073 m (± 852), 4-5-1: 10123 m (± 875), $p < 0.05$.	(HSR: >14.4km•hr^{-1}; VHSR: 19.8-25.1 km•hr^{-1}; Sprinting >25.1 km•hr^{-1}). HSR; 4-4-2: 2633 m (± 671); 4-3-3: 2649 m (± 706); 4-5-1: 2585 m (± 734), $p > 0.05$. VHSR; 4-4-2: 956 m (± 302); 4-3-3: 924 m (± 316); 4-5-1: 901 m (± 305). $p > 0.05$. HSR: DEF: 4-4-2: 2454 m (± 632) > 4-5-1: 2218 m (± 625) $p < 0.001$. FW: 4-3-3: 2988 m (± 614) > 4-5-1: 2333 m (± 458) $p < 0.05$; 4-4-2: 2250 m (± 454) $p < 0.01$).

Dellal *et al*. (2011)	Elite Male, (n = 5938)	Spanish (La Liga) and English (Premier League)	Amisco	All positions: La Liga: 10893 m; Premier League: 11095 m. CAM: Premier League: 11779 m (± 706) > La Liga: 11005 m (± 1164), $p < 0.05$.	(HSR: 21.0-24.0 km•hr^{-1}. Sprinting >24.0 km•hr^{-1}). CD; Premier League: 241m (± 64) >La Liga: 226 m (±54) $p < 0.05$. WD; La Liga: 285 m (± 55) > Premier League: 270 m (± 55) $p < 0.01$. CDM; Premier League: 319 m (± 68) > La Liga: 280 m (± 66) $p < 0.00$. CAM; Premier League: 334 m (± 61) > La Liga: 278 m (± 61) $p < 0.001$. WMF; La Liga: 311 m (± 67) > Premier League: 298 m (± 62).
Carling & Dupont (2011)	Elite Male, (n = 60)	French (Ligue 1) and UEFA Europa League	Amisco	Aall positions: 10494 m (± 514) – 10949 m (± 853).	(HSA >14.4 km•hr-^{1}). All positions: 2667 m (± 200) – 2414 m (± 145).
Key: Hz: Hertz; HSA: high speed activity; HSR; high-speed running; VHSR: very high speed running;					

Table 2: Summary of research investigating acceleration/deceleration demands of competitive soccer.

Author	Group	Method	Thresholds	Observations
Osgnach *et al.* (2010)	Elite Male Italian (Serie A) (n = 399)	SICS Automated tracking system	ACC and DEC ±; Max: < 3.0 m·s $^{-2}$; HI ACC: 3.00 to 2.00 m·s $^{-2}$ MO ACC: 2.00 to 1.00 m·s $^{-2}$ LO ACC: 1.00 to 0.00 m·s $^{-2}$.	Low running speeds can generate higher metabolic demands based on rate of acceleration.
Bradley *et al.* (2010)	Elite Male English (Premier League) (n = 100)	ProZone	MO ACC: 2.5 to 4.0 m·s $^{-2}$. HI ACC: > 4.0 m·s $^{-2}$.	No differences between halves.
Di Salvo *et al.* (2009)	Elite Male English (Premier League) (n = 563)	ProZone	Explosive sprints > 3.0 m·s $^{-2}$. Leading sprints < 3.0 m·s $^{-2}$.	Explosive sprints: CD>FW, CMF >WD; Leading sprints: FW>CD, WD>CMF ($p < 0.001$).
Varley & Aughey (2013)	Elite Male Australian (A League) (n = 29)	GPS (SPI Pro) 5 Hz	ACC 0 to 1, 1 to 2, 2 to 3, 3 to 4, >4 m·s $^{-2}$. HI ACC > 2.78 m·s $^{-2}$.	HI ACC: WD > CD, WMF & FW, $p = 0.05$. LO ACC: WD > CD, CMF, FW. 8 fold more maximum ACC than sprints.

Key: ACC = acceleration; DEC = deceleration, WD: wide defender; CD; centre defender; CDM: centre defensive midfielder; CAM: centre attacking midfielder; FW: forward.

2.2 Situational variables influencing physical performance

Analysis of the physical performance of soccer players should not take place in isolation because of the myriad of situational variables that can influence match-play. Indeed, physical performance is not stable and exhibits match-match variation, shaped by the demands each fixture and the individual's ability to regulate their work rate (Gregson *et al.*, 2010), and seasonal variation due to longitudinal changes in fitness status (Gregson *et al.*, 2010; Mohr, Krustrup & Bangsbo, 2003; Rampinini *et al.*, 2007b).

Match-match variation was investigated by Mohr, Krustrup & Bansgbo (2003) over two consecutive games within 3 weeks involving 18 players from a single club, reporting CV 3.1 % for TD and 9.2 % for HSR. In contrast, Rampinini *et al.* (2007b) analysed 20 players during 2 games in one week, reporting CV 14.4 % for VHSR. The generalisability of these findings is limited given the relatively small sample sizes, and in a much larger study (n = 485) over three consecutive seasons Gregson *et al.* (2010) reported HSR activity may vary ~15 – 30% between games. The large discrepancies between the studies highlight the importance of measuring variability on a club-wise basis to retain specificity for the target group (Carling *et al.*, 2016).

When analysed by playing position, HSR appears to vary more for central positions than wide players. Gregson *et al.* (2010) reported reported greater variability in the HSR and sprinting distances of CD (CV 18.8 % ± 5.9 & 16.8 % ± 6.3) and CMF (CV 36.4 % ± 10.4 & 33.6 % ± 11.1) compared to WD (CV 17.9 % ± 6.6; 18.8 % ± 6.8) and WMF (CV 29.4 % ± 10.9; 26.9 % ± 10.2) ($p <0.05$). Similarly, Bush, Archer, Hogg & Bradley (2015) reported greatest variability amongst CD vs. WMF for HSR (CV 20.2 % ± 8.8 vs. CV 13.7 % ±7; $p < 0.05$, ES 0.4-0.8) and sprinting (CV 32.3 % ± 12.8 vs. 22.6 % ± 11.2;

$p < 0.05$, ES 0.5-0.8). These differences are consistent with superior physical capacities of WD as assessed by intermittent running tests (Mohr, Krustup & Bangsbo, 2003; Reilly, Bangsbo & Franks, 2000) and represent a superior recovery capacity.

In contrast to match-match fluctuations in performance, seasonal trends exhibit greater variation and Mohr, Krustup & Bangsbo (2003) reported HSR varied CV 24.8 %, suggesting fitness status improves through the competitive phase (Rampinini *et al.*, 2007b).

Contemporary research asserts that influences on performance may include the strategic approach (playing formation and playing position), match status, quality of opposition, game location, fixture congestion and interaction effects (Lago- Peñas, 2009). Strategic decisions dictate playing formation and intend to optimise offensive and defensive prowess (Bangsbo & Petersen, 2000). By application, team tactics and strategy may limit the opportunity to express physical capacity, and differences in physical performance between playing formations and playing positions, are interpreted cautiously because they do not necessarily reflect differences in physical capacity.

Anecdotally, changes in playing formation are assumed to impact on work rate, yet research is surprisingly limited. Analysis of the effect of playing formation on the physical performance of the reference team (Bradley *et al.*, 2011) and of the opposition formation on the reference side (Carling, 2011) both report that the gross impact is minimal. However, the tactical approach of the reference team does evoke differing physical responses, with ball possession an important consideration. ~30-40 % more HSR was completed in a 4-4-2 and 4-3-3 when in possession compared to a 4-5-1 (Bradley *et* *al.*, 2011), and in contrast, more was completed in a 4-5-1 when not in possession, compared to 4-4-2 and 4-3-3. Coaching philosophy dictates that 4-4-2 and 4-3-3 be inherently offensive, and players are expected to advance into the attacking third. In contrast, 4-5-1 is more defensive and characterised by a reinforced midfield zone (Bradley *et al.*, 2011), and players naturally curtail their offensive work rate, and accumulate more distance when defending.

The strategic role of each playing position also shapes their activity profile. As a function of their combined offensive and defensive role, MF tend to cover greater TD and are stationary for less time than other positions (Bangsbo, 1994; Bloomfield, Polman & O'Donoghue, 2007; Reilly & Williams, 2003). Wide players and FW tend to dribble or run with the ball over greater distances and with greater frequency than other positions. Finally, CD and FW tend to complete more jumps to head the ball and DEF engage in more tackles (Bangsbo. 1994; Bloomfield, Polman & O'Donoghue, 2007; Reilly & Williams, 2003).

In relation to HSR, inferior distances are common amongst CD (Buchheit *et al.*, 2010a; Da Silva, Kirkendall & Neto, 2007; Strudwick & Reilly, 2001), whereas greater TD are completed by WD/WMF and FW (Buchheit *et al.*, 2010a; Da Silva, Kirkendall & Neto, 2007). Sprint activity mirrors that of HSR, and where the distinction is made, WMF and FW, tend to complete greater sprint activity (Buchheit *et al.*, 2010a; Di Salvo *et al.*, 2010; Mohr, Krustrup & Bangsbo, 2003; Rampinini *et al.*, 2007a). Shorter recovery periods reported amongst WD (Da Silva, Kirkendall & Neto, 2007) also confirms that the locomotor activity of wide players tends to be higher than all other positions.

Tactical changes made in response to changes in the scoreline also affect work rate. When winning, the desire to consolidate an advantage promotes positional discipline, curtailed offensive ambition and often reduced possession (James, Mellalieu & Hollely, 2002; Lago & Martin, 2007). Concurrent with this change is a reduction in low speed running (LSR) and moderate speed running (MSR) (Lago *et al.*, 2010) and HSR compared to when the scoreline was level, but this only persisted for ~10 minutes (O'Donoghue & Tenga, 2001). The impact of losing may be unique to the team and their reaction to this situation, for example; increases in HSR reflect the desire to regain a foothold in the game (Bradley *et al.*, 2013b; Bradley & Noakes, 2013) but equally, reductions in work rate may reflect a loss of motivation (Lago *et al.*, 2010; O'Donoghue & Tenga, 2001). Result status also affects positional work rate; with a large winning margin, CD completed less HSA and sprinting compared to a competitive game or a heavy loss ($p < 0.01$). Predictably, the opposite was reported for a FW in the same situations ($p < 0.05$) (Bradley & Noakes, 2013) reflecting enhanced motivation to score.

A final situational variable reported to impact on physical performance is the fixture schedule. Despite the prevalence of post competition muscle soreness and concurrent declines in muscle power (Mohr, Krustrup, Nybo, Nielsen & Bangsbo, 2004; Mohr, Randers, Bischoff, Krustrup, Mujika, Santiseban, Solano, Peltola, Hewitt & Zubillaga, 2010; Paulsen, Ramer Mikkelsen, Raastad & Peake, 2012) and field based measures of HSA (Krustrup, Jensen, Mohr & Zebris, 2010), changes in locomotor activity are minimal during fixture heavy periods (Carling & Dupont, 2011; Dupont, Nedelec, Berthoin, McCall, McCormack & Wisløff, 2010; Odetoyinbo, Wooster & Lane., 2007; Rey *et al.*, 2010). Nevertheless, periods of fixture congestion are comparatively rare, and two games in seven days are normal amongst the top European leagues. Notable exceptions to this are limited to Easter and Christmas periods, but the latter is only applicable to countries that do not incorporate a mid season break. Thus, whether fixture congestion is a geniune concern within the domestic calendar is unclear, especially when player rotation is used to manage an individual's fatigue status (Carling, Gregson, McCall, Moreira, Wong & Bradley, 2015).

2.3 Evidence of fatigue and the impact on physical performance

The key objective of conditioning programmes is the inducement of adaptation in systems crucial for competition (Reilly, Morris & Whyte, 2009) with the implicit aim of reducing a decline in physical performance. In this respect, fatigue is defined as a reduction in maximal power output, or force generation, associated with prolonged exercise (Hawley & Reilly, 1997; Reilly, 1994, Waldron & Highton, 2014), that manifests itself as a decline in work rate (Reilly, Drust & Clarke, 2008). The mechanisms contributing to fatigue can be grouped under central or peripheral factors and may act in isolation, but more likely in combination, to negatively affect performance (Waldron & Highton, 2014). Importantly, this definition of performance relates to locomotor activity, which includes movement distances or intensity (speed) of movement (Waldron & Highton, 2014), but not decision-making or technical components of the game, although these too might be sensitive to changes in fatigue status (Badin, Smith, Conte & Coutts, 2016; Knicker, Renshaw, Oldham & Cairns, 2011).

Peripheral fatigue refers to a biochemical change at the muscular level that inhibits the capacity to complete work (Krustrup, Mohr, Steensberg, Bencke, Kjaer & Bangsbo, 2006b; Mohr, Krustrup & Bangsbo, 2003); in contrast, central fatigue refers to a reduction in central motor drive, or motor unit recruitment (Amann, 2011). Contemporary research has also emphasised the integral role of the Central Nervous System, or the Central

Governor (Noakes, 2012), that functions as a regulator of work rate to avoid premature fatigue (Noakes, St Clair Gibson & Lambert, 2005). Fatigue in soccer can therefore be regarded as multi-faceted and cannot be attributed to a single source.

Fluctuations in physical performance during match-play are evidenced by an apparent decay in work capacity observed at three main junctions; following intense periods of activity, during the initial phase of the second half and towards the end of the game (Mohr, Krustrup & Bansgbo, 2003). Observations of reduced physical performance following intense periods of activity, are consistent with Castastrophe Theory (Noakes, St Clair Gibson & Lambert, 2005) referring to homeostatic disturbances at the muscular level that impair force development (Krustrup *et al.*, 2006b; Mohr, Krustrup & Bangsbo, 2003). Elevated blood lactate (BL) and associated Hydrogen (H+) accumulation are observed during intense periods of match-play, providing some support for the contribution of these mechanisms (Mohr, Krustrup & Bangsbo, 2003). Evidence of game related metrics include a 12-15 % reduction in HSR following the peak 5 minute period (Bradley *et al.*, 2010; Mohr, Krustup & Bangsbo, 2003). However, attributing these reductions to peripheral factors implies that fatigue is task dependent and fails to account for the reduction in work rate in the latter stages of games. Alternatively, advocates of the Central Governor Theory, suggest that players pace themselves through games (Edwards & Noakes, 2009), and, following periods of intense activity, will self select a lower work rate to facilitate a more rapid recovery. According to Edwards & Noakes (2009), the fluctuation of periods of high and lower work rate represents the micromanagement of energy expenditure, that contributes to a wider strategy, ensuring adequate reserves are available for the remainder of the game.

In the 15 minute periods after half time, players are assumed to be well rested, yet performance is often impaired with reductions in TD and HSA common (Bradley *et al.*, 2009; Mohr, Krustrup & Bangsbo, 2003; Weston, Batterham, Castagna, Portas, Barnes, Harley & Lovell, 2011). Although half time provides the opportunity to rehydrate, ingest food and receive tactical instruction, passive recovery also facilitates a decline in muscular temperature, which may reach 2-3 % (Lovell, Kirkie, Siegler, Mcnaughton & Greig, 2007; Mohr *et al.*, 2004). Reductions in muscular temperature are linked to reduced lower body power (Sargeant, 1987) as evidenced by reductions in sprinting, jumping and strength (Mohr *et al.*, 2004; Lovell, Midgley, Barrett, Carter & Small, 2013b). Following 4-10 minutes of the second half, the capacity to complete HSA was recovered, asserting that a decline in muscle temperature contributes to impaired activity (Lovell *et al.,* 2013b), and supports the use of a half-time re-warm intervention to attenuate any temperature decline.

Reductions in TD (~10 %) during the second half demonstrates a lower work rate (Bangsbo, Nørregaard & Thorsø, 1991; Carling & Dupont, 2011; Mohr, Krustrup & Bangsbo, 2003; Reilly, Drust & Clarke, 2008). No single causal factor explains these phenomena and several contributory mechanisms are suggested, including; reduced substrate availability (Krustrup *et al.*, 2006b), dehydration, hyperthermia (Magal, Webster, Sistrunk, Whitehead, Evans & Boyd, 2003), mental fatigue (Reilly & Williams, 2003) and the Central Governor Theory (Edward & Noakes, 2009). In contrast, research is conflicting about a reduction of HSA between halves; some authors report reductions ranging between 5-9 % (Barros *et al.*, 2007; Mohr, Krustrup & Bangsbo, 2003), yet elsewhere no reductions were found (Bradley *et al.*, 2009; Di Salvo *et al.*, 2007).

Segmenting the game into 15 minute periods provides greater insight into the fluctuation in work rate. Amongst elite males, Bradley *et al.* (2010) reported 18 % less HSR, 12 % less sprinting and 17-28 % longer rest intervals, during the last 15 minutes of the game compared to the opening period. However, the outcome of the game may be decided by the 75 minute mark, leading to a concurrent loss of motivation and work–rate in the losing side, meaning any comparison with this period may be misleading.

Inferences about impaired physical performance during the second half are commonly derived through comparison with the opening period of the first half, which is shown to be an atypical period of the game (Carling *et al.*, 2008; Weston, Drust & Gregson, 2011). This period tends to be frantic; players seek to impose themselves on their opponent, and motivation and tempo are at their highest (Carling *et al.*, 2008; Weston, Drust & Gregson, 2011). To nullify this effect, an alternative method using relative comparison using relative mean distances ($m \cdot min^{-1}$) was used in youth football, and this confirmed substantial reductions in HSA, but these were limited to the opening 5 minute period (Lovell, Barrett, Portas & Weston, 2013a). It remains unclear whether this represents an impaired capacity, a self-imposed reduction in work rate linked to tactical instruction, or a pacing strategy to minimise fatigue in the latter stages of the game. Because players are able to complete an additional 30 minutes during tournament play (Njororai, 2010), this would support the standpoint that players do not express their full physical potential during match-play.

Concurrent with physical performance, players must also exhibit technical prowess and changes in skill related performance are inconsistent (Carling & Dupont, 2011; Rampinini *et al.*, 2009a). A drop in the number of ball involvements during the second half

(Rampinini *et al.*, 2009a), may, initially, appear to indicate fatigue, yet might be explained by a strategic decision or change in style of play. On the other hand, pass completion remains stable between halves (Carling & Dupont, 2011; Rampinini *et al.*, 2009a), illustrating that reductions in physical performance are not, necessarily, to the detriment of technical performance.

2.4 Monitoring the physical response to soccer

Traditionally group training sessions are common in soccer and a generic approach to conditioning has prevailed for many years, but this may provide a suboptimal stimulus for the fitter players (Hoff, Wisløff, Engen, Kemi & Helgerud, 2002; Impellizzeri, Marcora, Castagna, Reilly, Sassi, Iaia & Rampinini, 2006). Physiological adaptation to training is a product of training load, and the magnitude of adaptation is largely dependent on the dose response relationship (Stagno, Thatcher & Van Someren, 2007). Monitoring training load is increasingly common during practice and competition, and facilitates micro-management on an individual basis (Akubat, Barrett & Abt, 2014; Gaudino, Iaia, Strudwick, Hawkins, Alberti, Atkinson & Gregson, 2015).

When monitoring training it is possible to evaluate both internal and external load. Internal load refers to the physiological response to a training stimulus (Impellizzeri *et al.*, 2004), and typically is evaluated by examining heart rate data (mean heart rate, time spent in zones of maximum heart rate) (Achten & Jeukendrup, 2003), oxygen consumption (Burnley & Jones, 2007), blood lactate concentration (Bourgois, Coorevits, Danneels, Witrouw, Cambier & Vrijens, 2004) or RPE (Impellizzeri, Rampinini, Coutts, Sassi & Marcora, 2004).

In contrast, external load refers to the combined locomotor stress and mechanical load experienced during match-play. Typically, time motion analysis systems have evaluated locomotor metrics, such as distances completed in various categories of movement speed (i.e. moderate speed running, high speed running and sprinting) (Mohr, Krustrup & Bangsbo, 2003; Castagna, D'Ottavio & Abt, 2003). However, a truer representation of external load is achieved by incorporating GPS and accelerometer technology to quantify mechanical work; i.e. acceleration/deceleration activity, during jumping, changing direction and impact/collisions (Boyd *et al.*, 2013; Varley & Aughey, 2013). The following section reviews, in detail, the methods of monitoring, and evaluating, internal and external training load.

2.4.1 Internal training load

Heart rate (HR) monitoring is used extensively in soccer as a non-invasive method to monitor the physiological response to training and match-play (Dellal *et al.*, 2011; Owen, Twist & Ford, 2004). Based on the relationship between HR and VO_{2max} during steady state exercise (Achten & Jeukendrup, 2003; Alexiou & Coutts, 2008; Bernard, Gavarry, Bermon, Giacomoni, Marconnet & Falgairette, 1997; Krustrup & Bangsbo, 2001), average game intensity is estimated to be ~85-95 % maximum heart rate (MHR) or 75-85 % VO_{2max} (Ali & Farrally, 1991; Bangsbo, 1994; Helgerud, Engen, Wisløff & Hoff, 2001; McMillan, Helgerud, Macdonald & Hoff, 2005; Reilly & Williams, 2003).

Importantly, the estimation of intensity based on HR is not reliable during intermittent activity, because of the time delay response (Alexiou & Coutts, 2008; Borreson & Lambert, 2009). Soccer features numerous discrete activities including, jumping, sprinting, tackling and turning (Bloomfield, Polman & O'Donoghue, 2007) and their duration is too short to elicit changes in HR placing a reliance on anaerobic metabolism (Achten & Jeukendrup, 2003; Borresen & Lambert, 2009). Furthermore, HR may overestimate physical stress based on dehydration, hyperthermia, prior exercise, diet and mental stress (Borreson & Lambert, 2009; da Silva, Fernandes & Fernandez, 2008). In short, HR alone is not suited to monitoring soccer activity (Little & Williams, 2007).

Rate of Perceived Exertion (RPE) is a simple, non-invasive method for monitoring internal training load (Impellizzeri *et al.*, 2004) that has demonstrated reliability for measuring steady state (Foster, Florhaug, Franklin, Gottschall, Hrovatin, Parker, Doleshal & Dodge, 2001) and intermittent activity (Foster *et al.*, 2001; Impellizzeri *et al.*, 2004). As a derivative of RPE, sessional RPE (sRPE) (RPE * session duration) provides a global indication of workload, and is correlated (r = 0.50-0.96) with heart rate based assessments of training load in field based intermittent sports (Alexiou & Coutts, 2008; Coutts, Rampinini, Marcora, Castagna & Impellizzeri, 2009; Impellizzeri *et al.*, 2004; Little & Williams, 2007; Lovell, Sirotic, Impellizzeri & Coutts, 2013c).

More recently, moderate correlations were reported between sRPE and soccer specific external load metrics (HSR; r = 0.11; CI 0.07–0.16; accelerations; r = 0.37; CI 0.33–0.41), illustrating that sRPE presents a useful global indicator of soccer specific load (Gaudino *et al.*, 2015). It is noteworthy that sRPE represents the cumulative load of the whole session, and soccer training incorporates a range of activities that may evoke different physiological responses. For example, small-sided games require frequent changes of direction providing a greater internal and external load, compared to larger scale games and linear running (Gaudino, Alberti & Iaia, 2014). Evidently, the ability of sRPE to differentiate between individual sessions components is limited. Nevertheless it presents a useful, low cost global estimation of training load (Gaudino *et al.*, 2015; Impellizzeri *et al.*, 2004; Lovell *et al.*, 2013c).

A limitation of RPE is that it represents an individual's self perception of training stress (Borg, 1982) and is influenced by a range of psychological factors, including; stress, fatigue, motivation or session enjoyment (Impellizzeri *et al.*, 2004; Little & Williams, 2007; Lupo, Capranica & Tessitore, 2014; Snyder, Jeukendrup, Hesselink, Kuipers & Foster, 1993). Psychological factors reportedly account for up to 30 % variability in sRPE, meaning athletes may under, or, overestimate their training load (Impellizzeri *et al.*, 2004; Morgan, 1994; Winter, Jones, Davison, Bromley & Mercer, 2007). Delaying the assessment of sRPE by 30 minutes is recommended to avoid the influence of dyspnea or temporary fatigue (Impellizzeri *et al.*, 2004; Kelly, Gregson, Reilly & Drust, 2013), and a period of familiarisation improves measurement reliability (Alexiou & Coutts, 2008; Impellizzeri *et al.*, 2004; Lovell *et al.*, 2013c).

As a metabolic by product of anaerobic metabolism, blood lactate measurement is a valid method of predicting endurance performance (Bourgois *et al.*, 2004) and is used widely to individualise endurance training programmes (Dantas, Doria, Pietrangelo, FanòIllic, Naknamura, Rossi & Rosa, 2015). Muscular lactate accumulation occurs during activity above the anaerobic threshold, and is linked to muscular acidosis and an associated decline in work rate (Allen, Lamb & Westerblad, 2008; White & Wells, 2015). The intermittent nature of soccer dictates that the contribution of anaerobic metabolism to energy production may be elevated during periods of high-intensity activity (Bangsbo, Mohr & Krustrup, 2006). During match-play average values range from 2-14 mmol·L^{-1} (Bangsbo, 1994; Krustrup *et al.*, 2006b; Reilly, 1997), but may reach >16 mmol·L^{-1}

during elevated periods of activity (Krustrup *et al.*, 2006b), suggesting BL may be a valid method to monitor work rate in soccer. However, the relationship between BL, muscle lactate accumulation and fatigue during intermittent activity is more complex. Periods of reduced work rate accelerate muscular lactate clearance (Devlin, Paton, Poole, Sun, Ferguson, Wilson & Kemi, 2014; Krustrup *et al.*, 2006b) meaning BL is not an accurate reflection of the muscular environment (Bangsbo, Johansen, Graham & Saltin, 1993; Krustrup, Mohr, Amstrup, Rysgaard, Johansen, Steensberg, Pedersen & Bangsbo, 2003; 2006b). Furthermore, BL values during match-play may reflect an accumulation of prior activity rather than any single bout of activity (Bangsbo, Mohr & Krustup, 2006). In addition, that a slight reduction in muscular pH was weakly correlated to decreased sprint performance during match-play (r = 0.13–0.14) (Krustup *et al.*, 2006b), asserts that muscle lactate accumulation is not a causal mechanism of fatigue. Given this apparent limitation, BL is also intrusive, expensive and labour intensive, leading practitioners to favour alternative methods of monitoring training load, including HR and sRPE (Dantas *et al.*, 2015; Gaudino *et al.*, 2015).

2.4.2 External training load

GPS is satellite navigational technology devised originally for military purposes, but in their portable form are used in everyday life to quantify distance travelled and velocity, in air, land and sea environments (Cummins, Orr, O'Connor & West, 2013). Positional location is determined through communication with orbiting satellites, and optimum satellite orientation termed Dilution of Precision (DOP) is achieved with one satellite directly overhead and a minimum of four spaced equally around the horizon (Witte & Wilson, 2004). Calculation of distance is reliant on an internal atomic clock that measures the time taken for a signal originating from the satellite to reach the GPS unit (Aughey, 2011), and deviation from the initial location can be used to determine movement velocity. The frequency at which GPS gathers data is specification dependent, ranging from 1–15 hertz (Hz) rate of refresh.

Concurrent with the increasing presence of sports science in soccer has been the desire to monitor the physical rigours of training and competition more accurately. Modern portable GPS circumvents the major limitation of stadia housed time motion analysis systems (Witte & Wilson, 2004), and, GPS is used extensively at the elite level. The capacity to record basic physical movements, i.e.; distance travelled, the velocity of movement, acceleration and decelerations, has led to many studies describing the work rate and movement patterns (external load) within; Rugby League (Austin & Kelly, 2013; McLellan, Lovell & Gass, 2011; Waldron, Twist, Highton, Worsfold & Daniels, 2011), Australian Rules Football (AFL) (Brewer, Dawson, Heasman, Stewart & Cormack, 2010; Coutts, Quinn, Hocking, Castagna & Rampinini, 2010; Gray & Jenkins, 2010; Wisbey, Montgomery, Pyne & Rattray, 2010), Field Hockey (Gabbett, 2010; Jennings, Cormack, Coutts & Aughey, 2012), Cricket (Petersen, Pyne, Portus & Dawson, 2009; 2011) and Soccer (Portas, Harley, Barnes & Rush, 2010). Until recently, GPS was not permitted during official soccer fixtures, and match data reported in the literature was based on non-competitive fixtures. However, in 2015, this rule was relaxed allowing the use of Electronic Performance and Tracking System (FIFA, 2015). Acceptance of GPS technology into the mainstream of performance analysis is contingent on acceptable validity and reliability (Johnston, Watsford, Kelly, Pine & Spurris, 2014; Rawstorn, Gant, Maddison, Ali & Foskett, 2014). Validity is essentially the level of agreement between the new technology and the criterion, or gold standard measure, whereas, reliability determines the reproducibility of the measurement.

2.4.2.1 Measurement of distance: Validity and reliability

Analysis of the validity of GPS to measure distance is complicated by the lack of a criterion measure. Best practice dictates that validation be determined by comparing the distance of a predetermined course, measured using a trundle wheel or tape measure (Varley & Aughey, 2013). However, both methods have their limitations and conclusions drawn about the validity of GPS based on these comparisons are best interpreted as indicative, rather than definitive. Nevertheless, early research highlighted the tendency for GPS to overestimate distance during continuous motion (see Table 3, p.55), yet the functional size of the error was relatively small, leading to the conclusion that GPS was suitable for this activity (Barberó-Álvarez, Coutts, Granada, Barebero-Álvarez & Castagna, 2010; Edgecomb & Norton, 2006; Townshend, Worringham & Stewart, 2008; Williams & Morgan, 2009). However, soccer is multi-directional and features acceleration, deceleration and changes of direction, therefore, the impact of these variables on the validity of GPS is a more pertinent discussion. The current consensus is that measurement error is magnified as speed increases and distance travelled decreases (Jennings, Cormack, Coutts, Boyd & Aughey, 2010b). During separate linear trials featuring walking and sprinting over 10 m, the error of measurement (SEE) of 1 and 5 Hz models increased with greater movement speed, but decreased with increased sampling frequency; walking: 1 Hz: SEE 23.8 % (± 5.9); 5 Hz: SEE 21.3 % (± 5.8); sprinting: 1 Hz: SEE 32.4 % (± 6.9); 5 Hz: SEE 30.9 % (± 5.8). Similarly, when walking and sprinting over 20-40 m the greater errors were observed with higher speeds; walking: 1 Hz: SEE 15.0 % (± 3.2); 5 Hz: SEE 11.9 % (± 2.5); sprinting: 1 Hz: SEE 18.5 % (± 3.9); sprinting: SEE 12.9 % (± 2.7) (Jennings *et al.*, 2010b). Similar observations were reported by Castellano, Casamichana, Calleja-González, San Román, & Ostojic, (2011), Petersen *et al.* (2009) and Portas *et al.* (2010) implying that GPS sampling at lower frequencies is not suitable for high-speed movements particularly over short distances.

Multi-directional activities involving changes of direction are used to replicate sports activity, and during trials within the penalty area, errors were more pronounced with lower sampling frequency consistent with linear tests; SEE 1 Hz; 6.6–8.0 %; 5 Hz; 2.2–4.4 % (Portas *et al.*, 2010).

During sprint trials incorporating gradual and acute turns, 1 Hz GPS reported greater error than 5 Hz; gradual turn: 1 Hz: SEE 12.7 % (± 3.0); 5 Hz: SEE 11.7 % (± 3.0); acute turn: 1 Hz: 12.5 % (± 3.3); 5 Hz: SEE 11.5 % (± 3.0) (Jennings *et al.*, 2010b). A similar trend for lower error with higher sampling frequency was also reported elsewhere (Coutts & Duffield, 2010; Grey *et al.*, 2010; Rawstorn *et al.*, 2014). Similarly, 10 Hz GPS reported SEM > 6 % during linear 15 m trials, > 3 % during 30 m trials (Castellano *et al.*, 2011) and minimal differences during a team sport simulation (Johnston *et al.*, 2014) hence 10 Hz GPS offer a greater validity of distance measurement than 1 and 5 Hz models. In summary, greater sampling frequencies increase the validity of measurement during multi-directional activity.

Of interest to practitioners is the inter unit reliability, this being the agreement between separate units over the same distance, and intra unit reliability, or the ability of the same GPS to reproduce a measurement. Broadly, the factors that affect validity also affect the reliability of GPS to measure distance. Thus, high-speed, multi-directional activities over short distances demonstrate the greatest issues with reproducibility (Coutts & Duffield, 2010; Jennings *et al.*, 2010b; Johnston *et al.*, 2014).

During sprint activity involving tight changes of direction, reliability was poorer in 1 Hz than 5 Hz GPS (CV 12.0 % vs. 9.2 %) (Jennings *et al.*, 2010b) consistent with previous findings. However, comparison to a 10 m linear sprint exhibited inferior reliability (1 Hz: 77.2% vs. 5 Hz: 39.5 %) (Jennings *et al.*, 2010b). Although multi-direction courses incorporate more changes in speed, the rate of acceleration would be smaller compared to a linear sprint, meaning acceleration is a key limiting factor in the reliability of GPS to measure distance (Jennings *et al.*, 2010b). During change of direction (COD) tasks the participant is assumed to run from point to point, which is not the case, rather, participants deviate from the *true* path and the distance reported represents the *actual* path taken (Coutts & Duffield, 2010). Similarly, while turning, the participant alters their body position and leans into the turn, shortening the path adopted by the GPS (Witte & Wilson, 2004). The error in measurement is also exacerbated during HSR/sprinting when body lean is at its greatest (Gray & Jenkins, 2010; Townshend, Worringham & Stewart, 2008). Correction of body lean reduced measurement bias by half during nonlinear running, emphasising that reliability statistics overestimate measurement error (Gray & Jenkins, 2010).

Sampling frequency is also a limiting factor, and improved reliability is reported amongst 10 Hz GPS evidenced by CV < 1.5 % during 15-30 m trials (Castellano *et al.*, 2011). Interestingly, amongst team sport simulation trials, reliability was superior in the 10 Hz rather than the 15 Hz model (TEM 1.3 % vs. 1.9 %) (Johnston *et al.*, 2014). However, both represent a good level of repeatability for determining TD. TEM during HSR ranged 11.5-12.1 %, which is an improvement compared to 1 Hz and 5 Hz models (32 % & 17 %) (Coutts & Duffield, 2010; Johnston, Watsford, Pine, Spurrs, Murphy & Pruyn, 2012) supporting improvements in sampling frequency will improve reliability further.

By comparison, intra unit studies are fewer, and variability in measurements has led to the recommendation that athletes use the same unit wherever possible (Coutts & Duffield, 2010; Duffield, Reid, Baker, & Spratford, 2010; Petersen *et al.*, 2009). During linear trials, less variability was found in comparison to nonlinear trials when walking (CV 1.85 % & 2.71 %) and sprinting; (CV 2.79 % & 4.80 %) (Gray & Jenkins, 2010). Also, during team sports simulation, greater variability is observed during very high-speed movement (CV 11.5-30.45 %) and HSA (CV 11.2-32.4 %), compared to low-speed (CV 4.3-12.5 %) (Coutts & Duffield, 2010). Castellano *et al.* (2011) also reported the tendency for greater measurement stability over longer distances (CV 1.3-0.7 % over 15 m and 30 m).

In accounting for intra unit variability during repeated trials, it is that plausible satellite availability, or orientation, may be a contributory factor, yet, during trials held at 09.00, 13.00 and 16.00 on the same day, there were no significant differences (MacLeod, Morris, Nevill & Sunderland, 2009). Assuming the prevailing weather conditions are stable, this suggests that time of day does not affect reliability. GPS reliability is optimal with an unobstructed view of the sky, and the extent to which variable weather conditions would influence reliability is unclear.

GPS manufacturers regularly release software updates to eliminate bugs or improve data analysis, and measures of distance were unaffected during intra unit trials held before, and after, software update (Buchheit, Al Haddad, Simpson, Palzzi, Bourdon, Di Salvo & Mendez-Villanueva, 2014). However, measurement of acceleration and deceleration activity was significantly changed (Buchheit *et al.*, 2014a) suggesting that data reliability might be dependent on the nature of the update. From a practical standpoint, this complicates comparison of historical data gathered by units of differing software versions, model or manufacturer (Buchheit *et al.*, 2014a).

2.4.2.2 Measurement of velocity: Validity and reliability

GPS categorises athletic activity into defined thresholds, and measurement validity is crucial. Criterion measures used within literature are electronic timing gates and lasers, which both demonstrate excellent validity and reliability (Varley, Fairweather & Aughey, 2012). Limitations in measuring velocity are also acceleration dependent. During linear trials, 5 Hz and 10 Hz GPS displayed greater underestimations of velocity when accelerations commenced from lower initial movement speeds; 1-3 $m{\cdot}s^{-1}$: Bias -9.6 % (± 1.3); -2.9 % (± 0.3); 3-5 $m{\cdot}s^{-1}$: Bias -5.0 % (± 1.0); -3.6 % (± 0.3); and 5-8 $m{\cdot}s^{-1}$; Bias -5.2 % (± 1.4); -2.1 % (± 0.2) (Varley, Fairweather & Aughey, 2012) (See Table 4, p.58). During linear trials where 10 Hz GPS units were affixed to a towed sled, errors also increased in an acceleration dependent manner; 0-1 $m{\cdot}s^{-2}$; CV 0.7 % (± 0.1); 1-2 $m{\cdot}s^{-2}$; CV 1.1 % (± 0.1); 2-3 $m{\cdot}s^{-2}$; CV 2.2 % (± 0.2); 3-4 $m{\cdot}s^{-2}$; CV 3.9 % (± 0.4); >4 $m{\cdot}s^{-2}$; CV 9.1 % (± 1.0) (Akenhead *et al.*, 2013). Notwithstanding this evidence, it is noteworthy that the majority of accelerations during match-play occur < 2.0 $m{\cdot}s^{-2}$ and minimal distance is accrued > 4.0 $m{\cdot}s^{-2}$ (Akenhead *et al.*, 2013; Russell, Sparkes, Northeast, Cook, Love, Bracken & Kilduff, 2016; Bradley *et al.*, 2010) meaning 10 Hz GPS is suitable for measuring acceleration during the majority of soccer activities.

Acceleration dependent limitations are also greater during accelerations from lower starting speeds, regardless of sampling frequency; 1-3 $m{\cdot}s^{-1}$: 5 Hz: CV 16.2 % (± 1.99); 10 Hz: CV 4.3 % (± 0.24); 3-5 $m{\cdot}s^{-1}$: 5 Hz: CV 9.5 % (± 1.18); 10 Hz: CV 4.2 % (± 0.26); 5-8 $m{\cdot}s^{-1}$: 5 Hz: CV 11.0 % (± 2.29); 10 Hz: CV 1.90 % (± 0.15) (Varley, Fairweather & Aughey, 2012). However, the differences for the 10 Hz (CV 1.69-4.3 %) illustrate a good to moderate level of reliability during running involving accelerations. Similar observations during constant velocity (CV 2.0-5.3 %) and during movement involving deceleration (CV 6.0 %) assert that 10 Hz can provide reliable measures during soccer type activity (Scott, Scott & Kelly, 2014; Varley, Fairweather & Aughey, 2012; Vickery, Dascombe, Baker, Higham, Spratford & Duffield, 2014).

Interestingly, inter unit reliability for peak speed was greater in the 10 Hz Minimax (TEM 1.6 %) than the 15 Hz GPSports GPS (TEM 8.1 %) (Johnston *et al.* 2014). Both margins represent a significant improvement compared to 1 Hz (<33 %) (Coutts & Duffield, 2010) and 5 Hz GPS (17 %) (Johnston *et al.*, 2012) during similar activity, meaning both 10 and 15 Hz can be used reliably (Johnston *et al.*, 2014). However, differences between the systems led the same authors to conclude that comparison between different manufacturers is not methodologically sound, in agreement with Buchheit *et al.* (2014a).

The high-speed movement, and swift changes in direction characterising match-play, compromise the validity and reliability of GPS to measure velocity and distance. Literature has demonstrated that inaccuracies are strongly attributed to sampling frequencies meaning 1 Hz and 5 Hz models are likely suboptimal for measuring soccer activity. Alternatively, 10 Hz GPS demonstrates acceptable validity and reliability for the measurement of velocity and distance during simulated team sport activity. Best practice dictates that players use the same unit where possible in order to reduce the impact of inter unit measurement error. Finally, comparison of units from different manufacturers should be done cautiously given the apparent differences in reliability.

Table 3: A summary of research into the validity and reliability of GPS for measuring distance in team sport scenarios.

Author	GPS Model	Hz	Task	Criterion measure	Validity	Reliability	Conclusions
Edgecomb & Norton (2006)	GPSports	Not stated	Running around a marked oval	Trundle wheel	TE 6.30 % (± 6.0).	TEM 5.50 %.	GPS overestimated TD
Petersen *et al.* (2009)	GPSports and Catapult	5 Hz	Linear trials over varying running speeds	Athletics track	SEE 0.50 % (± 0.20) – 23.80 % (± 8.80)	CV 0.30 % (0.30-0.50) – 30.0 % (23.20-43.30)	Reduced validity / reliability with increasing movement velocities
MacLeod *et al.* (2009)	GPSports	1 Hz	Various tasks to replicate Hockey activities	Trundle wheel	LOA 2.50 m (± 15.80)		Error increased during movement incorporating frequent, tight changes of direction and backwards movement
Gray & Jenkins. (2010)	GPSports	1 Hz	Linear course Nonlinear course	Trundle wheel	Bias 2.00 % LOA -1.23 – 5.25 % Bias: -6.00 % LOA 2.00 – -13.40 %.		Validity and reliability of GPS is affected by velocity and path linearity
Coutts & Duffield (2010)	GPSports	1 Hz	Multi-directional activity course	Measuring tape	<5.00 %	CV 3.60-7.10 %	May not be reliable for higher speed activities
Jennings *et al.* (2010b)	Minimax	1 Hz and 5 Hz	Multi-directional activity course	Measuring wheel	SEE 1 Hz: 3.60 (± 0.60 %) 5 Hz: 3.80 (± 0.60 %)	TE 1 Hz: 4.60 m (±4.10-5.30) 5 Hz: 4.70 m (±4.20-5.20)	GPS unable to accurately assess movement during rapid speed over short distances, which are critical for team sports

Portas *et al.* (2010)	Minimax	1 Hz & 5 Hz	Multi-directional activity course Soccer specific course	Measuring wheel	SEE 1 Hz: 1.80 – 2.70 %. 5 Hz: 2.20 – 3.60 %. 1 Hz: 1.30 - 3.00 %. 5 Hz: 1.50 – 2.20 %.	CV 1 Hz: 4.13 – 7.71 % 5 Hz: 3.71 – 6.11 % 1 Hz: 2.03 – 4.86 % 5 Hz: 2.21 – 4.49 %	GPS validity / reliability decreased with increasingly complex movement including tight turns.
Jennings, Cormack, Coutts, Boyd & Aughey, (2010a).	Minimax	5 Hz	Multi-directional activity course Match-play	Not stated		CV 11.10 % (± 4.20) 10.30 % (± 6.20)	To minimise variability, the same unit should be worn by the same player repeatedly
Castellano *et al.* (2011)	Minimax	10 Hz	Linear sprinting.	Measuring tape		15m: TE 0.20 m SEM 10.90 %. 30m: TE 0.30 m SEM: 5.10 %.	Validity improves over longer distances
Waldron *et al.* (2011)	GPSports	5 Hz	Linear running.	Measuring tape	CV 4.81 – 8.09 %	CV 1.99 – 2.30 %	Systematic underestimation of distance
Johnston *et al.* (2012)	Minimax	5 Hz	Multi-directional activity course.	Measuring tape	TEM <5.00 %	TEM 3.30 – 12.32 %	Amount of error increased exponentially with the intensity of the exercise
Rawstorn *et al.* 2014.	GPSports	15 Hz	Loughborough Intermittent Shuttle Test and Curvilinear protocol.	Measuring tape	Shuttle run: r = 0.99. Curvilinear protocol: r = 1.00.	Shuttle run: SEM 119 m; Curvilinear protocol: SEM 0 m.	Multidirectional running compromised validity of measurement.

Vickery *et al.* (2014)	Minimax and GPSports	5 Hz & 15 Hz	Team sport simulation circuit.	VICON	SEE 10.00-28.00 %	90º COD; 5 Hz: CV 17.7 % 10 Hz: CV 6.2 %. 45º COD; 5 Hz: CV 22.7 % 10 Hz: CV: 12 % Random COD; 5 Hz: CV 22.8 % 10 Hz: CV 8.2 %.	Greater reliability with increased sampling frequency. Reliability decreased with increased severity of turn.

Table 4: A summary of research into the validity and reliability of GPS for measuring velocity in team sport scenarios.

Author	GPS Model	Hz	Task	Criterion measure	Validity	Reliability	Conclusions
Macleod *et al.* (2009)	GPSports	1 Hz	Team sport simulation circuits	Electronic timing gates	T shaped shuttle: 95 % LOA 0.00 (± 0.07); Linear shuttle: 95 % LOA 0.00 (± 0.05); Zig zag shuttle: 95% LOA -0.1 (± 0.08).		Provides a valid tool for measuring speed and distance during match-play.
Barberó-Álvarez *et al.* (2010)	GPSports	1 Hz	Linear sprinting	Electronic timing gates	Fastest sprint time: R^2= 0.93, p < 0.00.		Greater validity over longer distances (30m).
Waldron *et al.*, (2011)	GPSports	5 Hz	Linear sprinting	Manual calculation	10 m: CV 9.81 %; 20 m: CV 8.54 %; 30 m: CV 6.61 %.	10 m: CV 1.13 %; 20 m: CV 1.00 %; 30 m: CV 1.35 %.	Underestimation of velocity at all measure intervals.
Johnston *et al.* (2012)	Minimax	5 Hz	Team sport simulation circuit and linear sprinting	Electronic timing gates and radar gun.	Average peak speed: no difference (no data reported). Instantaneous speed: r = 0.36 – 0.46.		Underestimated average, and instantaneous, peak speed.
Varley, Fairweather & Aughey, (2012)	Minimax	5 Hz & 10 Hz	Linear running	Laser	Constant velocity; 1-3 $m{\cdot}s^{-2}$: CV 11.1 % (± 0.58); 8.3 % (± 0.27); 3-5 $m{\cdot}s^{-2}$: CV 10.6 % (± 0.59); 4.3 % (± 0.59); 5-8 $m{\cdot}s^{-2}$: CV 3.6 % (± 0.26); 3.1 % (± 0.26)	Constant velocity; 1-3 $m{\cdot}s^{-2}$: TEE 0.21 (± 0.02) ; 0.12 (± 0.00); 3-5 $m{\cdot}s^{-2}$: TEE 0.27 (± 0.03); 0.13 (± 0.01); 5-8 $m{\cdot}s^{-2}$: TEE 0.35 (± 0.05); 0.11 (± 0.01);	Both 5 & 10 Hz underestimated velocity during acceleration. Constant velocity underestimated at higher velocities and overestimated at lower velocities.

					Acceleration: 1-3 m·s^{-2}: CV 14.9 % (± 1.16); 5.9 % (± 0.23); 3-5 m·s^{-2}: CV 9.5 % (± 0.79); 4.9 % (± 0.21) 5-8 m·s^{-2}: CV 7.1 % (± 0.87); 3.6 (± 0.18).	Acceleration: 1-3 m·s^{-2}: TEE 0.50 (± 0.06); 0.18 (± 0.01); 3-5 m·s^{-2}: TEE 0.43 (± 0.05); 0.20 (± 0.01); 5-8 m·s^{-2}: TEE 0.60 (± 0.12); 0.13 (± 0.01).	
Akenhead, French, Hayes & Thompson (2014)	Minimax	10 Hz	Linear sled towing	Laser	1m·s^{-2}: SEE 0.12 (± 0.02); 1-2 m·s^{-2}: SEE 0.16 (± 0.02); 2-3 m·s^{-2}: SEE 0.18 (± 0.03); 3-4 m·s^{-2}: SEE 0.19 (± 0.02); >4 m·s^{-2}: SEE 0.32 (± 0.06)	1m·s^{-2}: TEE 0.05 (± 0.01); 1-2 m·s^{-2}: TEE 0.06 (± 0.01) 2-3 m·s^{-2}: TEE 0.09 (± 0.01); 3-4 m·s^{-2}: TEE 0.10 (± 0.01); >4 m·s^{-2}: TEE 0.12 (± 0.01)	Validity greater during lower speed accelerations. Inter unit reliability decreased with increasing rates of acceleration.
Johnston *et al.* (2014)	GPSports & Minimax	10 Hz & 15 Hz	Team sport simulation circuit	Electronic timing gates	10 Hz: r = 0.89; 15 Hz: r = 0.64.		Superior validity with 10 Hz GPS.
Vickery *et al.* (2014)	GPSports & Minimax	5 Hz & 15 Hz	Team sport simulation circuit	VICON		90^{o} COD; 5 Hz: CV 26.3 % 10 Hz: CV 14.5 %. 45^{o} COD; 5 Hz: CV 20.9 % 10 Hz: CV 20.0 % Random COD; 5 Hz: CV 31.5 % 10 Hz: CV 11.9 %.	Superior reliability with 15 Hz GPS. Reliability decreased with greater severity of turn.

2.4.3 Accelerometers

Acceleration is proportional to the force applied and quantifying acceleration can, therefore, reflect the energetic cost and intensity of effort during athletic endeavours (Chen & Bassett, 2005). The most common accelerometers are piezoelectric and contain a seismic mass and a piezoelectrical element. During acceleration the seismic mass causes proportional deformation of the piezolectrical element which is, in turn, converted to a digital reading (Chen & Bassett, 2005). Uni-axial accelerometers measure accelertion in the vertical direction, whereas, multiple piezoelectrical elements positioned on each anatomical axes (Anterior-Posterior [AP]; Medio-Lateral [ML] and Caudal-Cranial [CC]), are required for tri-axial measurement. Contemporary accelerometers sample at 100 Hz providing a highly sensitive measure of acceleration during jumping, changes of direction, collisions/impacts.

Uni-axial accelerometers are used widely in the general population providing insight into the frequency, intensity and duration of free living and physical activity (Freesdon & Miller, 2000; Montgomery, Pyne & Minahan, 2010). In a lab setting, validity was established against indirect caliometery (Freesdon & Miller, 2000; Nichols, Morgan, Chablot, Sallis & Calfas, 2000) and in the field, against HR and energy expenditure during several types of activity (Coe & Pivarnik, 2001; Durant, Baranowski, Davis, Thompson, Puhl, Greaves & Rhodes, 1993; Janz, 1994; Kozey, Lyden, Howe, Staudenmayer & Freedson, 2010). However, uni-axial accelerometers are unsuitable for monitoring the stochastic activity in soccer, unlike tri-axial accelerometers that are sensitive to three dimensional movement (Boyd, Ball & Aughey, 2011; Chen & Bassett, 2005). Accelerometers measure the total mechanical stress experienced during quick changes in direction, jumping and collisions (Barrett, Midgley & Lovell, 2014; Dellaserra, Gao & Randsell, 2014).

In comparison to the abundance of literature examining the validity and reliability of GPS, research relating to accelerometers is limited. Nevertheless, of concern to practitioners is performance during static and dynamic trials. Static validity is the ability of the unit to detect a constant value (acceleration due to gravity) (Boyd, Ball & Aughey, 2011), and is important because periods of inactivity, when players are stationary are numerous (O'Donoghue, 2002). During these intervals, the data recorded by the accelerometer should be zero, otherwise external load may be overestimated. To date, only one paper has investigated static validity, and SPI-Pro (GPSports, Canberra, Australia) underestimated constant value by ~30 % (Kelly, Murphy, Watsford, Austin & Rennie, 2015) representing a significant limitation. In contrast, the static reliability of the Catapult MinimaxX (Catapult Innovations, Sowersby, Australia) is reported; inter unit (CV 1.01 %), and intra unit (CV 1.10 %) (Boyd, Ball & Aughey, 2011). According to manufacturer recommendations, scheduled periodic recalibration is sufficient to ensure static validity and reliability, and may explain the paucity of data of this nature (Sprint software, Catapult Innovations, Sowersby, Australia).

Dynamic reliability has, in the main, been established using lab based oscillation tests in which the unit is fixed to a calibrated mechanical arm. During vertical oscillation at 3 Hz to 8 Hz, the Catapult MinimaxX demonstrated acceptable within unit (CV 0.9-1.05 %) and between unit reliability (CV 1.02-1.04 %) (Boyd, Ball & Aughey, 2011). The same authors explained that the choice of oscillation speed replicated non contact human locomotion. In contrast, when assessing the SI-Pro (GPSports) Kelly *et al*. (2015) opted for higher frequency (5-15 Hz), to replicate high-intensity collision and locomotor activities from AFL competition, and findings showed similar within unit reliability (CV 1.87-2.21 %) (Kelly *et al*., 2015). Notwithstanding this evidence, the reliability of accelerometers during sporting activity is crucial and, to date, has focussed on running

(Tran, Netto, Aisbett & Gastin, 2010; Wundersitz, Netto, Aisbett & Gaston, 2013), multi-directional simulations (Wundersitz *et al*., 2013) and, tackles/collisions (Gabbett, 2010; Gastin, Mclean, Breed & Spittle, 2014; Wundersitz, Gastin, Robertson & Netto, 2015b).

Acceleration is proportional to the external force applied, and therefore running impact force can reflect the intensity of movement and total external load (Wundersitz, Gastin, Richter, Robertson & Netto, 2015a). In comparison to a force plate platform, measurement was not significantly different during linear running and COD trials, ranging 45-180° ($p = 0.68$-1.00) but, measurement error increased with increased severity of turn; 45°: CV 14.5 %; 90°: 17.2 %; 180°: 23.9 % (Wundersitz *et al*., 2013). Similarly, the measurement error during countermovement jumping and drop landing trials was CV 16.8 % and 21.4 % respectively (Tran *et al*., 2010). A contributory factor to these shortcomings may be accelerometer placement on the body or unit artefact that may result in erroneous data.

Centre of mass is the criterion location for an accelerometer and distance from this point increases measurement error because of compensatory postural movements (Barrett, Midgley & Lovell., 2014; Derrick, 2004; Halsey, Shepard & Wilson, 2011; Netto, Tran, Gastin & Aisbett, 2010). Contemporary integrated technology needs to be located at the scapula to enhance satellite communication (Barrett, Midgley & Lovell, 2014), but also increases the distance from the impact site and increases shock attenuation in the body (Zhang, Derrick, Evans & Yu, 2008). The effect of this placement was highlighted during treadmill running when the centre of mass elicited higher AP (14.7 % ± 22.2), ML (35.0 % ± 20.3) and CC (7.9 % ± 14.6) load compared to the scapula (Barrett, Midgley & Lovell, 2014). During linear running, athletes adopt a forward lean (Barrett, Midgley &

Lovell, 2014) and a crouched position during lateral movement (Keller, Weisberger, Ray, Hasan, Shiavi & Spengler, 1996), and both alter the vertical orientation of the GPS unit (Wundersitz *et al*., 2013). During changes of direction, this is exacerbated, and lateral trunk orientation has been observed to range 5-10 % outside vertical (Houck, Duncan & Haven, 2006; Tran *et al*., 2010). The degree of postural changes during running is also athlete specific complicating between individual comparison. It is therefore recommended that longitudinal data be used to monitor the intensity, and volume, of external load on an individual basis (Barrett, Mideley & Lovell, 2014).

The accuracy of integrated technology is also compromised by "noise" in the accelerometer signal. Noise refers to data that is not attributed to movement i.e. vibration produced during physical contact, that adds to the true signal (Tran *et al*., 2010; Winter, 2009; Wundersitz *et al*., 2015b). Data filtering algorithms reduce error by removing noise that exceeds "cut-off points" or thresholds (Gastin, Aisbett, Netto & Tran, 2010; Robertson *et al*., 2004; Wundersitz *et al*., 2015b). Investigation of the impact of a range of filter frequencies on the validity of accelerometer impact data during three physical collision tasks, reported that 20 Hz filtering frequency demonstrated the best accuracy, agreement and precision in comparison with a 3-dimensional motion analysis system (Raptor-E, Motion Analysis Corp, USA) (Wundersitz *et al*., 2015b). In the same study, 6-10 Hz underestimated impact acceleration (-1.87 g ± 1.14 to -0.92 g ± 0.82), while 20-30 Hz overestimated acceleration (0.01 g ± 0.75 to 0.60 g ± 1.09). During multiple linear sprinting trials, smoothed data was more accurate than raw data (SEE: 0.19 % ± 0.01 vs. 0.29 % ± 0.01), and, although the filter frequency was not reported, an acceleration dependent overestimation was still apparent; 0-1 $m{\cdot}s^{-2}$; SEE: 0.12 % ± 0.02; >4.0 $m{\cdot}s^{-2}$; SEE: 0.32 % ± 0.06 (Akenhead *et al*., 2013). However, during soccer minimal acceleration activity is recorded > 4.0 $m{\cdot}s^{-2}$ (Akenhead *et al*., 2013; Bradley *et al*., 2010;

Russell *et al.*, 2016) therefore the practical significance of overestimating accelerations >4.0 m·s^{-2} may be minimal.

A contributory factor to the underestimation of acceleration may be too low a filter frequency which effectively removes too many data points. In contrast, too high a filter frequency would fail to remove sufficient noise. Consequently, differences in filtering algorithms may explain some of the variability in data reported between integrated technology of different manufacturers discussed above. At present, a specific study into the optimum filtering frequency for soccer is absent from the literature, but, considering Wundersitz *et al.* (2015b) featured impacts > 5.0 g, consistent with data from contact sports (Gastin *et al.*, 2014), it is feasible that a 20 Hz filter might be too high.

2.4.4 PlayerLoad (PL)

The combination of locomotor activity, measured by GPS, and mechanical load, provided by tri-axial accelerometers, can quantify total external load. External load is reported as a vector magnitude termed PL (Boyd, Ball & Aughey, 2011) and is epressed in arbitrary units (AU). Proprietry software automatically separates total PL and reports the contribution of load according to each anatomical plane. PL is calculated as follows;

Figure 1: The equation for calculating PlayerLoad (Boyd, Ball & Aughey, 2011)**.**

$$\text{PlayerLoad} = \sqrt{\frac{([fwd_{y1} - fwd_{y-1}]^2 + [side_{x1} - side_{x-1}]^2 + [up_{z1} - up_{z-1}]^2)}{100}}$$

Where;

fwd_{y1} = Forward accelerometer

$side_{y1}$ = Sideways accelerometer

up_{z1} = Vertical accelerometer

The validity of PL to reflect training load has been established against RPE during soccer (*r* = 0.73-0.84) (Scott, Lockie, Knight, Clark & De Jonge, 2013b), and AFL practices (*r* = 0.78-0.81) (Scott, Black, Quinn & Coutts, 2013a). Also, very strong correlations with TD covered during training (*r* = 0.93 & 0.94) (Boyd, Ball & Aughey, 2013;Scott *et al.*, 2013a), assert that PL is an acceptable measure of external load, and, related to the internal physical response to training. Limited research has been conducted on the reliability of PL during sports activities, but during treadmill running test-retest reliability was moderate to high (ICC 0.80–0.93, CV 5.3-14.8 %) (Barrett, Midgley & Lovell, 2014), lending support to the use of PL in measuring accumulated external load.

Research to date has used PL to quantify the external demands of a number of sports including; AFL (Boyd, Ball & Aughey, 2011; 2013), Basketball (Montgomery, Pyne & Minahan, 2010), Netball (Cormack, Smith, Mooney, Young & O'Brien, 2013) and Soccer (Barrett, Midgley, Reeves, Joel, Franklin, Heyworth, Garrett & Lovell, 2016a; Dalen, Ingebrigtsen, Ettema, Geir Harvard & Wisløff, 2016). Dalen *et al.* (2016) presented a comprehensive study of PL in soccer, across three consecutive seasons demonstrating that during match-play, WD exhibited lower PL than CD (12 %), CMF (18 %), WMF (26 %) and FW (8 %). However, WD accelerated more than CD (39 %), CMF (15 %) and FW (15 %), which is consistent with other studies (Ingebrigtsen *et al.*, 2015), at face value these findings seem inconsistent. During match-play, positional differences exist in unorthodox activities, i.e., tackles, jumping, heading the ball, collisions or falling (Bloomfield, Polman & O'Donoghue, 2007) and all contribute to PL. Significantly, these discreet game activities occur without a discernable change in physical location, and therefore, PL is accumulated in different ways (Dalen *et al.*, 2016). The precise contribution of a single activity to PL is unclear. However, a detailed classification would provide a greater understanding and enhance the specificity of training.

Comparison of PL between individuals is complicated by running efficiency and postural issues because it is an accelerometer derived metric (see earlier discussion). However, longitudinal within individual comparison may serve to highlight changes in physical performance attributed to residual fatigue. A study by Cormack *et al.* (2013) in AFL revealed that, in comparison to non fatigued players, fatigued individuals had a -5.8 $m \cdot min^{-1}$ (± 6.1 %) impairment in CC axis activity. Impairment in musculotendinous stiffness is linked to increased ground contact time (Girard, Micallef & Millett, 2011) and decreased vertical jump performance (Gathercole, Sporer, Stellingwerff & Sleivert, 2015), indicative of neuromuscular fatigue (Cormack *et al.*, 2013). Similarly, towards the end of matches injury incidence is higher (Woods, Hawkins, Maltby, Hulse, Thomas & Hodson, 2004) and may be explained by compromised stability of lower limb joints (Hughes & Watkins, 2006). Increases in PL in the last 15 minutes of each half of simulated match-play (Barrett, Midgley, Towlson, Garrett, Portas & Lovell, 2016b) and match-play (Barrett *et al.*, 2016a) are consistent with alterations in movement efficiency (Barrett *et al.*, 2016a; 2016b; Cormack *et al.*, 2013) and injury incidence (Hughes & Watkins, 2006), suggesting PL may be a useful tool to identify fatigue during match-play.

In summary, the preceding section has emphasised the inherent difficulties when assessing the physical stress of competition. Based on the available evidence, internal measures appear are compromised by the intermittent high-speed nature of soccer and cannot accurately measure the stress of competition. By extension, the validation of contemporary field tests based on internal responses is questioned. In comparison, external measures, notably integrated technology, can reflect the mechanical load imposed by competition that is not offered by traditional time motion analysis systems. Whether current field tests reflect the external load of competition is also unclear and requires investigation. However, in order to select a range of tests for evaluation, it is first necessary to review contemporary fitness assessment in soccer.

2.5 Contemporary fitness assessment in soccer

Periodic fitness assessment is an important element of the athlete support programme (Svensson & Drust, 2005) and field based tests present a low cost and convenient method of determining fitness status (Currell & Jeukendrup, 2008; Krustrup, Mohr, Nybo, Jensen, Nielsen & Bangsbo, 2006a). Performance on a test, no matter how ecologically valid, cannot predict on field success so data is used to inform training prescription and increase the likelihood of success (Drust, Atkinson & Reilly, 2007; Svensson & Drust, 2005). Soccer is reliant on the synergy of aerobic and anaerobic capacities presenting a challenge when implementing fitness assessment. Sport specific protocols are appealing and perhaps a logical choice because they purport to replicate soccer activity, but do not isolate a single physical capacity presenting difficulties when planning training interventions (Mendez-Villanueva & Buchheit, 2013). Alternatively, the assessment of a single component in isolation can provide a more meaningful assessment, but several tests are required to achieve a full evaluation. In the absence of a gold standard approach, fitness testing is influenced by the purpose of the assessment and the philosophy of the practitioner.

This section will review a range of protocols available according to fitness component and it is limited to those used in a soccer context that have been subject to academic scrutiny.

2.5.1 Maximal aerobic capacity

Of particular interest to coaches and sports scientists has been cardiovascular fitness given the heavy aerobic demands of the game (Hoff, 2005). VO_{2max} is the maximum rate of oxygen consumption during maximal exercise, and values ranging 55-70 ml·kg·min^{-1} are reported at elite levels (Al-Hazzaa, Almuzaini, Al-Refaee, Sulaiman, Dafterdar, Al-Ghamedi & Khuraiji, 2001; Tønnessen, Hem, Leirstein, Haugen & Seilier, 2013; Williams, 2013). The importance of aerobic power to modern soccer is contentious (Tønnessen *et al.*, 2013); on one hand, VO_{2max} may differentiate between successful and unsuccessful sides because higher ranked sides had superior values (Bangsbo & Lindquist, 1992; Wisløff, Helgerud & Hoff, 1998). Also, an 11% improvement in VO_{2max} led to a 20 % increase in HSR (Helgerud *et al.*, 2001) suggesting VO_{2max} is sensitive to soccer endurance training (Hoff, Wisløff, Engen, Kemi, & Helgerud, 2002). However, the high anaerobic contribution has led some to assert that VO_{2max} is not a sensitive measure of soccer (Bangsbo & Lindqvist, 1992; Reilly, Bangsbo & Franks, 2000; Svensson & Drust, 2005). Importantly, game changing events are preceded by HSA diminishing the importance of aerobic capacity (Faude, Koch & Meyer, 2012). Finally, recent longitudinal studies report that although the HSA of players has increased substantially (Barnes *et al.*, 2014; Bush *et al.*, 2015b), TD has remained relatively unchanged (+ ~2 %) (Barnes *et al.*, 2014; Barros *et al.*, 2007; Bradley *et al.*, 2009) which is consistent with minimal changes in VO_{2max} over time (Tønnessen *et al.*, 2013). Assessments of VO_{2max} are separated into shuttle running protocols and sport specific procedures.

2.5.1.1 Shuttle running protocols

The MSFT (Leger & Lambert, 1982) was modified by Ramsbottom, Brewer & Williams (1988) and has been used widely in sport and studied extensively. Participants run continuously over 20 m between two markers at increasing speeds until volitional exhaustion. Prediction of VO_{2max} is based on a regression equation (see Figure 2, p.70), and within the general population correlation between MSFT and criterion measure ranges r = 0.71-0.94 (Leger, Mercier, Gadoury & Lambert, 1988; Leger & Lambert, 1982; Ramsbottom, Brewer & Williams, 1988). However, amongst athletes, inconsistent relationships are found (r = 0.43-0.78) (Aziz, Mukherjee, Chia & Teh, 2007; Castagna, Manzi, Impellizerri, Weston & Barberó-Álvarez, 2010; Williford, Scharff-Olson, Duey, Pugh & Barksdale, 1999) suggesting the MSFT may not be suitable for this population, or that these studies were unable to elicit a maximal effort. Elsewhere, the strong relationship between the MSFT and YYIR Level 1 (YYIRL1) (r = 0.89) suggests the MSFT is more similar to field tests than lab based criterion measures (Castagna *et al.*, 2010; Williams, 2013). The frequent requirement to change direction and increasing running speed, impact on O_2 kinetics (Da Silva, Natali, de Lima, Filho, Garcia & Marins, 2011), placing an increasing demand on anaerobic processes (Grant, Corbett, Amjad, Wilson & Aitchison, 1995; Flouris, Metsios, Famisis, Geladas & Koutedakis, 2010) and may explain these differences.

Although the MSFT features frequent COD and changes in running speed, it does not replicate the intermittent nature of soccer (Nassis, Geladas, Soldatos, Sotiropoulos, Berkis & Souglis, 2010). Also, the sensitivity of the MSFT is questionable after it was unable to differentiate between elite and recreational players unlike a soccer specific, intermittent, protocol (Edwards, MacFadyen & Clark, 2003). Similarly, no performance improvement was found following an eight week training intervention (Odetoyinbo & Ramsbottom, 1997). Nevertheless, it is used widely in soccer (Aziz *et al.*, 2007; Castagna *et al.*, 2010; Russell & Tooley, 2011; Strudwick, Reilly & Doran, 2002; Tumilty, 1993) despite questionable validity and specificity.

Figure 2: The equation for calculating VO_{2max} based on performance on the Multi Stage Fitness Test (Leger & Lambert, 1982).

$$Y = 24.4 + 6.0 \text{ MAS}$$

Where MAS = maximum aerobic speed reached during the test.

In contrast to the MSFT, the Yo-Yo Intermittent Endurance Test (YYIET) (Bangsbo, 1996) incorporates rest periods and aims to assess the capacity to "repeatedly perform intervals over a prolonged period of time" (Bangsbo, 1996. p.16), and TD covered is the performance measure.

The YYIET stresses the aerobic system evidenced by near maximal heart rates (Bradley *et al.*, 2011; Castagna, Impellizzeri, Belardinelli, Abt, Coutts, Chamair & D'Ottavio, 2006) and test–retest reliability for HR was good (CV 3.9 %) (Bradley *et al.*, 2011). In the most comprehensive review to date, an ability to differentiate between performance in relation to competitive level, different stages of the season and playing position was reported (Bradley *et al.*, 2011). Interestingly CD outperformed FW (2000 m ± 247 vs. 1786 m ± 306, $p < 0.05$) which contrasts with the observations of TD covered in games (Bangsbo, Nørregaard, & Thorsø, 1991; Bradley *et al.*, 2009; 2011) but may reflect the more anaerobic nature of forward play.

Finally, the Intermittent Shuttle Run Test (Lemmink & Visscher, 2003) was based on the MSFT but has a higher initial running speed (10 $km \cdot h^{-1}$ vs. 8 $km \cdot h^{-1}$) and increments of 1 $km \cdot h^{-1}$ up to 13 $km \cdot h^{-1}$ vs. rather than 0.5 $km \cdot h^{-1}$. Performed incrementally, work intervals of 30 s are spaced by 15 s rest in which participants walk 16 m (2x8 m). Each work/rest cycle is repeated twice, and stages are 90 s. These amendments were made to measure the intermittent endurance capacity of team sports players and produce higher peak velocity (PV). Failing to meet the running speed three successive times or voluntary withdrawal terminates the test. The relationships with VO_{2max} (r = 0.72-0.77) highlights the intermittent nature of the test (Lemmink, Verheijen & Visscher, 2004; Lemmink & Visscher, 2003).

While assessing footballers of different competitive levels, near maximum HR was reached, and BL was elevated (+8 $mmol \cdot L^{-1}$) indicating a maximal effort. In addition, ICC ranged 0.86–0.96 in men and 0.95–0.99 in women demonstrating acceptable reliability (Lemmink, Verheijen & Visscher, 2004). Discriminative power was observed as professional players were differentiated from amateurs (Lemmink, Verheijen & Visscher, 2004) ($p < 0.05$), yet has not been widely adopted.

2.5.1.2 Sport specific assessments

Linear shuttle running protocols are criticised because they do not reflect the various modes of locomotion or the multi-directional nature of competition. In response, a limited number of soccer specific tests have been proposed, including the Ekblom Soccer Specific Endurance test (Ekblom, 1989), the Bangsbo Intermittent Field Test (Bangsbo & Lindquist, 1992) and the Hoff-Helgerud Football Endurance Test (Hoff FET) (Kemi, Hoff, Engen, Helgerud & Wisløff, *et al.*, 2003). A summary of research investigating the validity and reliability of field assessments is found in Tables 5 and 6 (p.79 & 82).

The Ebklom Soccer Specific Endurance Test (Ekblom, 1989) is a multi-directional four lap time trial and has received little attention in the literature. Available evidence demonstrates acceptable reliability (SEM ± 3 s), sensitivity to detect a smallest worthwhile change in performance (Williams, Wiltshire, Lorenzen, Wilson, Meehan &

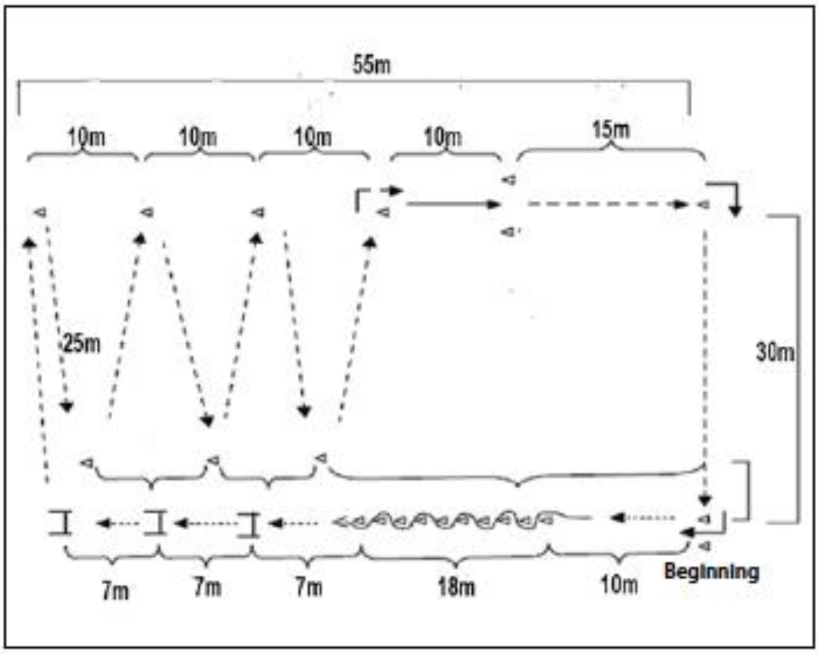
Kolsky, 2009) and the ability to differentiate between stages of the season (Ekblom, 1989). Fundamentally, however, the test is flawed because there are no specific instructions over pitch dimension; only that it is completed on a soccer field, and thus, the test cannot be transported to another venue. Finally, test performance is not been correlated to VO_{2max} or match distance metrics questioning the usefulness of findings.

The Intermittent Field Test (Bangsbo & Lindquist, 1992), requires the alternation of HSR (15 s) and LSR (10 s), over 16.5 minutes, dictated by an audio cue. The combined aerobic and anaerobic contribution was evidenced by elevated blood lactate values (9 mmol·L^{-1} ± 3.7) (Chamari, Hachana, Ahmed, Galy, Shaier, Chatard & Wisløff, 2004). Although mean data correlated to $_vVO_{2max}$ (R^2 = 0.55), the SEE was too large to allow for an accurate prediction of VO_{2max}, and precision is lacking (Chamari *et al.*, 2004). For example, when estimating distance covered during the test at $_vVO_{2max}$ of 18 km·hr^{-1}, values ranged 1700-1950 m (Chamari *et al.*, 2004).

In contrast, the Hoff FET (Kemi *et al.*, 2003) was adapted from a soccer specific training drill and aims to assess aerobic capacity. Uniquely, players dribble a soccer ball continuously around a multi-task obstacle course designed to replicate the demands of soccer (see Figure 3, p.74). According to the authors, an advantage of the test is the positive effect on motivation that dribbling the ball has, compared to straight line running (Chamari *et al.*, 2005; Kemi *et al.*, 2003). However, during match-play, players spend ~2 % of the total time with the ball and whether this represents a worthwhile inclusion is debatable (Reilly & Gilbourne, 2003), especially because it presents a high technical demand that may underestimate physical performance in lower ability players. Finally, along with the high administrator burden, the Hoff FET presents significant limitations for use in an applied setting.

Notwithstanding these drawbacks, the original study reported a strong relationship between test performance and VO_{2max} (*r* = 0.87) (Kemi *et al.*, 2003), but elsewhere, poorer relationships were found. Amongst young player's test performance correlated to VO_{2max} (*r* = 0.68) (Chamari *et al.*, 2005), and in comparison to distance metrics during match-play, the Hoff FET demonstrated a relationship with sprinting distance (*r* = 0.70), but not TD or HSR (Castagna *et al.*, 2010). Elsewhere, performance correlated with MSFT performance (*r* = 0.44-0.49) suggesting it may be used as a broad indicator of aerobic capacity rather than a precise measure (Nassis *et al.*, 2010; Zagatto, da Silva, Santiago, Papoti, Miyagi, Brisola & Milioni, 2015). The moderate correlations reported may be partially explained by the contribution of anaerobic metabolism during frequent changes in direction or running speed (Zagatto *et al.*, 2015). To the best of my knowledge, only one study has reported on the sensitivity of the Hoff FET, and following a short training intervention improvements in VO_{2max} were detected by the Hoff FET (Chamari *et al.*, 2005). However, the combined evidence suggests that, although demonstrating strong logical validity, the Hoff FET is not a suitable predictor of aerobic capacity.

Figure 3: The structure and dimensions of the Hoff-Helgerud Football Endurance Test (Adapted from Chamari *et al.*, 2005) (m).



2.5.2 High-speed running

Commensurate with the increasing importance of HSA during competition, has been a growing focus on evaluating the ability to perform this work, and to this end, the YYIR tests were devised by Bangsbo (1996). The YYIRL1 measures the capacity to perform repeated aerobic high-speed work, whereas the Level 2 (YYIRL2) assesses the ability to "perform intense, intermittent exercise with a large anaerobic component in combination with a significant aerobic contribution" (Bangsbo, Iaia & Krustrup, 2008. p.40). Both tests have been used extensively in literature and the field, to assess the soccer specific endurance capacity of players and referees (Deprez, Coutts, Lenoir, Fransen, Pion, Philippaerts & Vaeyens, 2014; Krustrup & Bangsbo, 2001; Krustrup *et al.*, 2003; Mohr, Krustrup & Bangsbo, 2003).

Both procedures involve progressive shuttle running between two 20 m markers, except unlike the MSFT, a 2x5 m walk, equating to 10 s, separated each repetition. Performance on the YYIRL1 correlates with HSR completed during games demonstrating good construct validity (r = 0.71-0.81) (Castagna, Impellizzeri, Cecchini, Rampinini & Barbero-Alvarez, 2009; Krustrup & Bangsbo, 2001; Krustrup *et al.*, 2003). Also, high level of reproducibility (CV 4.9 % & 9.6 %) is evidenced between trials separated by seven days (Krustrup *et al.*, 2003; 2006a). Although both levels stress the aerobic system maximally, evidenced by near maximum HR (Krustrup *et al.,* 2003; 2006a; Ingebrigtsen *et al.*, 2012; Rampinini *et al.*, 2010), a high anaerobic contribution is reflected by moderate correlation to VO_{2max} (YYIRL1: r = 0.74-0.76); YYIRL2: r = 0.47-0.48) (Ingebrigtsen *et al.*, 2012; Rampinini *et al.*, 2010).

At exhaustion, the YYIRL2 showed lower Creatine Phosphate levels, higher muscle lactate, lower muscle pH, higher muscle Hydrogen and a faster BL accumulation than the YYIRL1 (Krustrup *et al.*, 2003; 2006a; Rampinini *et al.*, 2010). Evidently, aerobic power is not the sole determinant of performance in the YYIRL2 and may be more related to O_2 kinetics. Rampinini *et al.* (2010) observed that quickly activating the aerobic systems would delay the anaerobic contribution perhaps delaying fatigue. Also, superior muscular oxidative capacity, running economy and acid-base control helps to explain the better performances of professionals versus amateurs on the YYIRL2 (Ingebrigtsen *et al.*, 2012; Rampinini *et al.*, 2010).

Another important characteristic of the YYIR is sensitivity. Professional and amateur players were differentiated significantly by YYIR2 performance (2231 m ± 294 vs. 1827 m ± 292) despite similar VO_{2max} values (58.5 ml·kg·min^{-1} ± 3.8 vs. 56.3 ml·kg·min^{-1} ±

4.3) ($p < 0.05$) (Rampinini *et al.*, 2010). International elite and second division players were characterised by a 37 % difference in YYIR2 performance (1059 m ± 35 vs. 771 m ± 26) (Krustrup *et al.*, 2006a). Following a twelve week training block, referee's YYIRL1 performance improved 31 % (± 7) and HSR during games increased 23 % (± 8), despite no significant changes in VO_{2max} (Krustrup & Bangsbo, 2001). Elsewhere elite males were separated from elite youth (Castagna *et al.*, 2009; Chaouachi, Manzi, Wong, Chaalali, Laurencelle, Chamari & Castagna, 2010), successful from less successful sides (Ingebrigtsen *et al.*, 2012; Teplan *et al.*, 2012b;) and U17 from U16 players (Teplan, Malý, Zahálka, Hráský, Kaplan, Hanuş, & Gryc, 2012a). Differences in YYIRL2 performance are observed between pre-season and competitive stages of the season (Krustrup *et al.*, 2006a), and combined these findings provide a compelling case for the YYIR tests to evaluate soccer specific intermittent exercise.

A criticism of the YYIR is that the fixed 20 m distance is not reflective of the range of distances covered during games. As an alternative, Carminatti's Test (TCAR) (Carminatti, Lima-Silva, & De-Oliveira, 2004) is a progressive distance shuttle running test, the initial running distance is 30 m (2x15 m) and increases 1 m each stage, and TD is the performance measure. Participants complete 5x12 s shuttle runs at increasing speeds until exhaustion or voluntary withdrawal. Each stage is separated by 6 s of active recovery involving a 5 m walk (2x2.5 m); making each stage 90 s. Initial running speed is 9 $km{\cdot}h^{-1}$ and is dictated by an audio CD. A distinct advantage over fixed distance protocols is that the varied running distances exhibit greater logical validity, however rather than VO_{2max}, or HSR, the TCAR aims to determine peak running velocity to inform training prescription (Carminatti, Lima-Silva, & De-Oliveira, 2004).

When examining PV, no significant differences were found in comparison to a treadmill protocol (r = 0.73) (J. Da Silva, Guglielmo, Carminatti, De Oliveira, Dittrich & Paton, 2011) and this is in contrast to the MSFT and YYIR alternatives run over shorter distances (Castagna *et al.*, 2009). The test also differentiated between the PV of juvenile and youth athletes demonstrating construct validity (J. Da Silva *et al.*, 2011). These findings are useful because PV may be used to assess changes in performance after training interventions (Billat, Flechet, Petit, Muriaux & Koralsztein, 1999). Furthermore, a correlation between PV and vVO_{2max} (r = 0.74, r = 0.55) suggests that maximum aerobic power may be calculated from PV (J. Da Silva *et al.*, 2011; Dittrich, da Silva, Castagna, de Lucas & Guilherme, 2011). Similarly, estimates of Onset of Blood Lactate Accumulation between lab based tests and the TCAR were strong (r = 0.63) (J. Da Silva *et al.*, 2011). To date evidence of validity and reliability is limited but HR was not significantly different from a treadmill protocol (r = 0.62) (J. Da Silva *et al.*, 2011; Dittrich *et al.*, 2011). Regarding sensitivity, the TCAR detected changes in performance after nine weeks of training in young athletes (J. Da Silva *et al.*, 2011) and also to adaptations during the competitive season (Floriano, Ortiz, Souza, Liberali, Navarro & Cavinatto, 2009). Further research is warranted into whether the TCAR is a robust, valid and reliable option; but the ability to measure physical variables associated with aerobic power differentiates it from the YYIR tests (J. Da Silva *et al.*, 2011).

The 30-15 Intermittent Fitness Test (30-15IFT) (Buchheit, 2008) was developed to individualise interval training that features a COD, based on final test running velocity. 30 s shuttle runs over 40 m are separated by 15 s of active rest. The initial speed is 8 $km \cdot h^{-1}$ increasing 0.5 $km \cdot h^{-1}$ thereafter and is dictated by an audio cue, and ends when the participant is unable to reach a 3 m zone at each end line or withdraws voluntarily. The performance indicator is the velocity during the final stage (Buchheit, 2008) and, is "simultaneously related to maximal aerobic function, anaerobic capacity, neuromuscular, change of direction qualities and inter effort recovery qualities" (Buchheit, 2008 p.5). It is hard to separate any one physical component during shuttle running, thus, a lower running economy or poor change of direction ability would lead to an underestimation of PV. Supporting evidence is provided by a comparison between the original 30-15IFT and a linear version (turns removed) where a higher PV was noted (19.7 km·h^{-1} ± 1.2 vs. 21.7 km·h^{-1} ± 1.9) (Haydar *et al.,* 2011). For tests that rely on PV to predict VO_{2max}, this is a consideration.

Amongst Handball players TEE 0.3 km·h^{-1} was reported, and VO_2 peak and peak HR were correlated with MSFT performance (r = 0.76; r = 0.84 respectively) (Buchheit, 2008). Combined this data shows the 30-15IFT elicited a maximal effort comparable to the MSFT. However, the final velocity is approximately 5 km·h^{-1} faster than vVO_2max deriving a significant anaerobic contribution thus providing a more sport specific stimulus (Buchheit, 2008).

Performance improvements, amongst footballers (+7 %), following an 8-week training block, demonstrates that the 30-15IFT is sensitive to sport specific training (Buchheit & Rabbani, 2013). In the same study performance correlated with YYIRL2 (r = 0.75) suggesting a degree of similarity yet the likelihood is that the tests assess slightly different variables (Buchheit & Rabbani, 2013).

Table 5: A summary of research investigating the validity of field based assessments in soccer.

Study	Test	Participants	Age	Comparison measure	HR	$VO2_{max}$
Deprez *et al.* (2014)	YYIRL1	Male Youth (n = 228) 150 Elite (Professional) 78 Sub-elite (National & Regional league)	11-17 yrs	Test performance: Elite > Sub-elite; p <0.00		
Krustrup *et al.* (2003)	YYIRL1	Male (n = 37) Elite (Professional)	22-32 yrs	HSR in game. *r* = 0.71, p <0.05.		Vs. treadmill. *r* = 0.71, p <0.05.
Martínez-Lagunas & Hartmann. (2014)	YYIRL1	Female (n = 18) German (Bundesliga 2)	21.5 yrs (± 3.4)			Vs. treadmill. *r* = 0.83, p <0.00.
Ingebrigtsen *et al.* (2012)	YYIRL1 & YYIRL2	Male (n = 203) Elite: 76 Norwegian (Tippligaen), 127 Danish (SuperLiga). Sub-elite: Norwegian (2 Divisjon), Danish (2nd Division)	20-31 yrs			Vs. treadmill test. YYIRL1: Sub-elite: *r* = 0.73, p <0.01 Elite: *r* = 0.76, p <0.01. YYIRL2: Sub-elite: *r* = 0.48, p<0.01 Elite: *r* = 0.59, p <0.10.

Shin-Ya Ueda, Yamanaka, Yoshikawa, Katsura, Usui, Orita & Fujimoto, (2011)	YYIRL1 & YYIRL2	Male (n = 82) University Soccer club	20-22 yrs			Vs. treadmill test. YYIRL1: r = 0.79, p <0.00 YYIRL2: r = 0.49, p <0.05.
Krustrup *et al.* (2006a)	YYIRL2	Male (n = 132) Sub-elite (13 Trained individuals) Elite (119 Scandinavian professionals)	22-30 yrs	Test performance: Elite > sub-elite; p <0.05.	Vs. treadmill test. r = 0.64, p <0.05.	Vs. treadmill test. r = 0.56, p <0.05.
Rampinini *et al.* (2010)	YYIRL1 & YYIRL2	Male (n = 25) Elite (13 Professional) Sub-elite (12 Amateur)	25 yrs (± 4)	Test performance: Elite vs. sub-elite. YYIRL12 p <0.01, d = 1.14. YYIRL2 p <0.01, d = 1.66.		Vs. treadmill test. YYIRL1 r = 0.74, p<0.05. YYIRL2 r = 0.47, p <0.05.
Wong, Chaouachi, Castagna, Lau, Chamari & Wisløff, (2011)	YYIET	Male (n = 62) Regional representative side	13.7 yrs (± 0.15)			Vs treadmill test. r = 0.63, p < 0.001.
Bradley, Bendicksen, Dellal, Mohr, WIlkie, Datson, Omtoft, Zebris, Gomez-Dias, Bangsbo & Krustrup (2012)	YYIETL2	Female (n = 13) Elite (European National squad)	22 yrs (± 3)	TD in game; r = 0.55, p <0.05. Vs. HSA distance in game; r = 0.70, p <0.01.		

Chamari *et al.* (2005)	Hoff-FET	Male (n = 18) Sub-Elite (National league club)	14 yrs (± 0.4)		Vs. treadmill test. *r* = 0.68, p <0.01.
Buchheit, Al Haddad, Millet, Lepretre, Newton & Ahmaiai, (2009)	30-15IFT	Male (n = 20) Moderately trained team sport athletes	20.9 yrs (± 2.2)	Vs. treadmill test. *r* = 0.84, p <0.01)	Vs. treadmill test. *r* = 0.76, p <0.00.
J. Da Silva *et al.* (2011)	TCAR	Male (n = 28) Brazilian Youths (National league club)	17.9 yrs (± 1.0)	Vs. treadmill test. *r* = 0.62, p <0.01	

Table 6: A summary of research investigating the reliability of field based assessments in soccer.

Study	Test	Group	Age	Distance	HR	BLa	Time to complete test
Deprez *et al.* (2014)	YYIRL1	Male Youths (n = 78) Elite (Professional) and Sub-Elite (National & Regional league) Numbers not specified	11-17 yrs	U13: ICC 0.82, CV 17.3 % U15: ICC 0.85; CV 16.7 % U17: ICC 0.94, CV 7.9 %.	U13; ICC 0.87, CV 1.4 % U15: ICC 0.80, CV 1.5 % U17: ICC 0.95. CV 1.3 %.		
Krustrup *et al.* (2003)	YYIRL1	Male (n = 17) Active individuals	25-36 yrs	CV 9.4 %, p >0.05	CV 1 %, p >0.05	CV 17 %, p >0.05	
Krustrup *et al.* (2006a)	YYIRL2	Male (n = 13) Active individuals	22-30 yrs	CV 9.6 %, p >0.05.		CV 31 %, p >0.05.	
Bradley *et al.* (2012)	YYIETL2	Female (n = 27) Domestic league sides	18-27 yrs	CV 4.5 %, TE 67m, p >0.05			
Williams *et al.* (2009)	Ekblom Football Specific Endurance test	Male (n = 19) University soccer club	20.5 yrs (±2.5)				ICC = 0.98, p >0.05

2.5.3 Repeated sprint ability

The distribution of HSA is unequal across match-play, leading to periods of elevated activity (Carling & Dupont, 2011; Impellizzeri *et al.*, 2008; Withers *et al.*, 1982), in which players complete maximal sprints of short duration (1-7 s) with brief recovery (Bangsbo, Nørregaard, & Thorsø, 1991; Rampinini *et al.*, 2007b; Withers *et al.*, 1982). Later described as, RSA and defined as the "ability to perform repeated straight sprints, or shuttle sprints, with minimal recovery between sprint bouts" (Wong, Chan & Smith, 2012, p.2324). This definition is preferred to Dawson, Fitzsimons & Ward (1993) who, in an original definition of RSA, did not include a COD component.

An array of RSA tests are available that are completed over 15-40 m, and incorporate 3-15 repetitions separated by 15-30 s rest (Haugen, Tønnessen, Hisdal & Seiler, 2014). Other than being broadly consistent with the characteristics of periods of elevated work rate described above, the construct of RSA procedures appears to be largely subjective and based on logical validity (Bishop, Spencer, Duffield & Lawerence, 2001; Impellizzeri *et al.*, 2008). Further, whether procedures replicate, or predict, match performance is largely unexplored in literature, with only Barberó-Álvarez, Pedro & Nakmura (2013) and Rampinini *et al.* (2007a) reporting relationships between RSA performance and match-play metrics. Strong relationships between HSR during and RSA best time (RSA_{best}) $r = 0.78$ (Barbero- Álvarez, Pedro & Nakamura (2013), and $r = 0.65$ (Rampinini *et al.*, 2007a), and mean RSA time (RSA_{mean}) and VHSR ($r = 0.60$); and sprinting ($r = 0.65$) (Rampinini *et al.*, 2007a) suggest a predictive ability of RSA performance. The different procedures might explain the observed differences; Barbero-Álvarez, Pedro & Nakamura (2013) used a linear 7x30 m (24 s rest) and Rampinini *et al.* (2007a) opted for a 6x40 m (2x20 m) (20 s rest). Furthermore, the latter employed elite adult professionals, while Barbero- Álvarez, Pedro & Nakamura (2013) used young males. Test performance has also distinguished between elite and non-elite players (Gabbett, 2009; Impellizzeri *et al.*, 2008; Rampinini *et al.*, 2009b), teams of different standards (Ingebrigtsen *et al.*, 2012) and detected training induced adaptations (Impellizeri *et al.*, 2008). However, whether RSA is a crucial component of soccer is contentious, and research is inconclusive (Schimpchen *et al.*, 2016).

In game sprints frequently involve COD and, therefore, reliance on linear running procedures lacks construct validity (Currell & Jeukendrup, 2008; Dellal, Keller, Carling, Chaouachi, Wong & Chamari, 2010a; Wong, Chan & Smith, 2012). This assertion is strengthened by the observation that linear running and COD speed are distinct qualities (Buchheit, Simpson, Peltola, & Mendez-Villanueva, 2012). The impact of turning angle (45°, 90°, and 135°) was investigated during sprinting (Buchheit *et al.*, 2012), revealing that performance is angle dependent when the turn is < 45°. Turning at 45° was strongly related with linear sprinting (r = 0.76), emphasising that relatively obtuse turns do not alter running mechanics greatly. However, increasingly sharp turns showed weaker relationships (90° r = 0.63; 135° r = 0.68) and can be explained by changes in body orientation, stride adjustments, deceleration, and acceleration. Further, muscle activation is greater with increased severity of turn (Besier, Lloyd & Ackland, 2003); indicating construct validity is improved by including the range of turns involved in match-play.

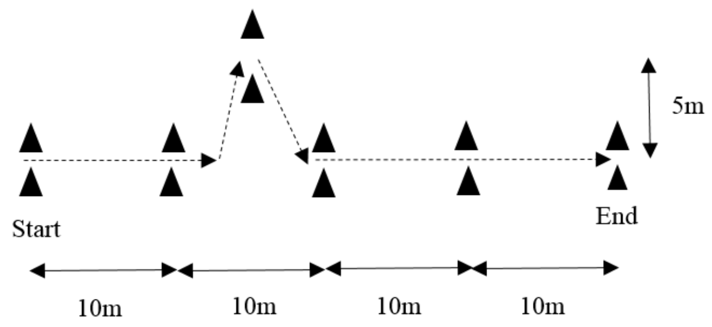
Two soccer specific protocols incorporating COD, and have received attention in the literature, are the Repeated Shuttle Sprint test (RSSA) (Impellizzeri *et al.*, 2008) and the Bangsbo Sprint Test (BST) (Bangsbo, 1994). The RSSA compromises 6x40 m (20+20 m) shuttle runs, featuring an 180° turn, whereas the BST features 7x34.2 m interspersed by 25 s active rest and incorporates two COD (see Figure 4, p.86). Due to the lack of a "gold standard" against which to examine criterion validity (Bishop *et al.*, 2001), comparison of match-play work rest ratios have been used, in addition to match running metrics. Both the RSSA and BST have similar work rate profiles (RSSA: 1:2.8; BST: 1:3.1) compared to match-play (1:4.3) (Rampinini *et al.*, 2007a; Withers *et al.*, 1982; Wragg, Maxwell & Doust, 2000) suggesting comparable metabolic demands (Dawson, 2012; Rampinini *et al.*, 2007a; 2007b; Spencer *et al.*, 2005; Stølen, Chamari, Castagna & Wisløff, 2005).

In relation to reproducibility, the RSSA demonstrated a superior absolute value for RSA_{mean} across trials during pre-season (CV 1.0 %), mid-season (CV 0.8 %) and end of season (CV 0.9 %) (Impellizzeri *et al.*, 2008), compared to the BST (CV% 1.8) during six sequential trials (Wragg, Maxwell & Doust, 2000). When compared to RSA_{best}, the superior reproducibility of RSA_{mean} at each test interval (pre-season: CV 1.6 % vs. 36.7 %; mid-season: CV 1.1 % vs. 21.6 %; end of season: CV 1.0 % vs. 29.8 %) render it the preferred method of evaluating RSA performance (Impellizzeri *et al.*, 2008).

The importance of repeated COD ability during competition was recently highlighted (Wong, Chan & Smith, 2012). The same authors sought to determine whether an individual's training focus should be RSA or repeated COD (RCOD), using an RSA/RCOD ratio. The RSA protocol featured linear 6x20 m with 25 s active recovery, and the RCOD 6x20 m with 25 s active recovery, including four x 100° COD at every 4 m. Although, RSA and RCOD demonstrated similar metabolic demands, the shared variance (R^2 48-50 %) supported earlier speculation that they were separate qualities (Brughelli, Cronin, Levin & Chaouachi, 2008), and justified the use of separate training and testing modalities.

In summary, both the RSSA and BST demonstrate reliability and a degree of validity for use within soccer. However, match analysis demonstrates between player variation in activity profiles, questioning a generic approach to RSA assessment and offering some support for the use of position specific protocols.

Figure 4: The structure and dimensions of the Bangsbo Sprint Test (Bangsbo, 1994) (m).



2.5.4 Agility/change of direction ability.

Agility is defined as "a rapid whole body movement with change of velocity or direction in response to a stimulus" (Brughelli *et al.*, 2008, p.1046) and is regarded as a fundamental attribute of soccer performance (Hachana, Chaabène, Ben Rajeb, Khlifa, Aouadi, Chamari, & Gabbett, 2014; Sporis, Jukic, Milanovic & Vucetic, 2010). A plethora of agility tests have been used to assess soccer players, including the T-Test (Lovell, Towlson, Parkin, Portas, Vaeyens & Cobley, 2015; Pojskić, Pagaduan, Babajic, Užicanin, Muratovic, & Tomljanovic, 2015; Sporis *et al.*, 2010) the Illinois test (Brughelli *et al.*, 2008; Caldwell & Peters, 2009; Kutlu, Yapici, Yoncalik & Çelik, 2012), the Zig Zag test (Kutlu *et al.*, 2012), the 505 test (Draper & Lancaster, 1985), and the Balsom Agility run (Balsom, 1994). However, the perceptual decision making process is often absent, rendering the assessment of COD ability instead (Ellis, Gaston, Lawrence, Savage, Buckeridge & Tumilty, 2000). COD ability reflects the mechanical element of agility and is increasingly assessed using custom procedures, including the Change of Direction and Acceleration Test (CODAT) (Lockie *et al.*, 2013).

During agility/COD tests, the learning effect may be neutralised by the provision of one trial repetition (Sporis *et al.*, 2010). Both the Illinois and T-Test demonstrate strong within participant reliability (CV < 3.3 %) during repeated trials (Hachana *et al.*, 2014; Lockie *et al.*, 2013; Sporis *et al.*, 2010), and between participant reliability (ICC > 0.94) (Hachana *et al.*, 2014; Lockie *et al.*, 2013; Munro & Harrington, 2011; Sporis *et al.*, 2010). The CODAT (ICC 0.84, CV 3.0 %) (Lockie *et al.*, 2013) and Balsom Agility run (ICC 0.88) (Garcia-Pinillos, Martinez-Amat, Hita-Contreras, Martinez-López & Latorre-Roman, 2014; Garcia-Pinillos, Ruiz-Ariza, Moreno del Castillo & Latorre-Román, 2015) show similar results, also indicating a high level of reliability.

The validation of agility tests is difficult because there is no criterion measure. Agility is multifaceted and reliant on several fitness components, including, strength, balance, coordination, acceleration and velocity (Gamble, 2010; Serpell, Ford & Young, 2010). The Illinois test, and the T-Test, are correlated with velocity (r = 0.47; r = 0.46-0.57) (Draper & Lancaster, 1985; Paoule, Madloe, Garhammer, Lacourse & Rozenek, 2000), whereas the 505 agility test is correlated with acceleration (Draper & Lancaster, 1985), suggesting that the choice of test should be related to the purpose of the assessment (Paoule *et al.*, 2000; Sporis *et al.*, 2010). In contrast, Stewart, Turner & Miller (2014) reported high correlations between performance on the Illinois test and the T-Test (r = 0.89) and the 505 test (r = 0.89) suggesting that the tests assess the same components. Regardless, the assessment of agility, or COD, has differentiated between professionals and amateurs (Kaplan, Erkmen & Taskin, 2009), professionals and youths (Rebelo, Brito, Maia, Coelho-e-Silva, Figueiredo, Bangsbo, Malina & Seabra, 2013), playing positions (Rebelo *et al.*, 2013) and gender (Mujika, Santisteban, Impellizzeri & Carlo, 2009).

Agility and COD tests include fixed running distances and a limited range of turning angles, but whether these characteristics reflect the activity profile of soccer is questionable. Analysis of turns during match-play reported that the majority are <90º, but differences exist depending on positional role (Bloomfield, Polman & O'Donoghue, 2007). Similarly sprinting distances range one to >20 m (Di Salvo *et al.*, 2010), and activity profiles differ by position. In conclusion, greater specificity would improve the validity and the usefulness of the result.

2.6 Conclusion

The preceding review highlights that soccer presents an energetic challenge to players and relatively modest VO_{2max} values (55-70 ml·kg·min^{-1}) (Al-Hazzaa *et al.*, 2001; Tønnessen *et al.*, 2013; Williams, 2013) accentuates the crucial anaerobic contribution. Further, high-speed activities are crucial to match-play, and superior physical performance may increase the likelihood of on field success (Faude, Koch & Meyer, 2012; Rampinini *et al.*, 2007a).

Time motion data reveals subtle differences in physical performance between playing positions; broadly, CMF cover the greatest TD and CD the least and, wide players, and FW tend to cover greater HSA distance. However, it is apparent that several factors influence positional profiles, including active playing time, score line and playing formation, yet a large proportion of research does not consider the impact of these variables. Admittedly, researchers have limited ability to control extraneous variables related to tactics and strategy, but insight would be improved by investigating these links further. The greatest shortcoming in literature is the positional tri-axial acceleration activity during competition, and this would inform the design of conditioning programmes.

The emphasis on HSA is reflected in literature that is biased towards the YYIR. This test has received considerable academic scrutiny and demonstrates strong validity and reliability (Castagna *et al.*, 2009; Krustrup & Bangsbo, 2001; Krustrup *et al.*, 2003; Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005) making it a popular choice in the field. The intermittent nature of the YYIR purports to replicate match-play, but reliance on 20 m linear shuttles and 180^{o} turns presents a limitation.

Soccer science is characterised by a desire to optimise physical conditioning and is facilitated by monitoring the internal physical response to training load, chiefly through HRM and RPE, and external load or the variables manipulated to induce physical stress, using a combination of GPS and accelerometers. Combined, these measures are used to micro manage individual training load and achieve specificity of training. An important finding from this review is that neither internal nor external measures adequately quantify the universal physical demands of soccer activity in isolation. Alternatively, a combined approach would provide the most comprehensive evaluation.

Popular measures of external load evaluate tri-axial external load, or the total mechanical stress experienced during movement (Barrett, Midgley & Lovell, 2014), and are used to tailor conditioning programmes. However, the availability of micro-technology also presents the opportunity to evaluate the tri-axial load of contemporary field tests to determine whether they replicate soccer activity. By reviewing the magnitude and frequency of acceleration/decelerations, it is possible to establish the validity of field tests using a modern metric that circumvents the limitations of internal measures.

Finally, a large proportion of research in soccer examines elite adult and youth populations but overlooks the sub-elite youth tier. This omission ignores a very large demographic from which future professionals emerge and greater insight into competition at this level would aid talent development. In addition, the application of field tests derived and validated in other populations may not be specific to participation at this level. Sub-elite clubs experience significant financial limitations meaning a cost effective, easy to use test that is valid in the context of competition at this level is a necessity.

Chapter 3: The external load experienced during competitive youth soccer

3.1 Introduction

Chapter 2 highlighted that research into the external load of competitive, sub-elite youth soccer is lacking, despite a growing body of knowledge about the professional game. At the highest tier of competition, the measurement of locomotive distances, or mechanical work, using GPS in particular, has proved advantageous in micro-managing players' daily workload, optimising physical conditioning programmes and tailoring end-stage rehabilitation (Cummins *et al.*, 2013). More recently, accelerometer derived metrics such as PlayerLoad (PL) (Catapult Sports), enable the measurement of acceleration associated with changes in direction and impacts, on a tri-axial basis (Wundersitz *et al.*, 2015a). The addition of PL to locomotor activity provides a more holistic evaluation of the physical activity performed during competition, and a full evaluation of the demands of sub-elite youth competition would inform physical conditioning at this level.

During competition, players perform dynamic, unpredictable movements that vary in intensity and duration, presenting an energetic challenge (Bloomfield, Polman & O'Donoghue, 2007). The execution of these movements is founded on the ability to accelerate and decelerate, which are energetically costly maneuvers (Osgnach *et al.*, 2010). Maximum accelerations are more frequent than maximum sprints, but, do not always proceed maximum sprints (Varley & Aughey, 2013) meaning that the work rate of players is underestimated when these variables are ignored (Akenhead *et al.*, 2013; Osgnach *et al.*, 2010). In summary, the measurement of acceleration and deceleration activity is imperative should the true physical work rate of players be determined.

A limited body of research has reported the acceleration characteristics of competition, differentiating between explosive and leading sprints (Di Salvo *et al.*, 2009), revealing playing positional differences (Ingebrigtsen *et al.*, 2015) and reporting time dependent profiles (Bradley *et al.*, 2010). Explosive sprints are defined as those proceeded by an acceleration of > 3.00 $m{\cdot}s^{-2}$ and accounted for 30 % of sprints during the English Premier League (Bradley *et al.*, 2010). In relation to positional differences, Ingebrigtsen *et al.* (2015) concluded wide players completed 13% more accelerations ($p < 0.001$; $d = 1.54$) suggesting an influence of positional role. However, the comparison between studies is tentative because wide and central positions are not always separated and, the influence of contextual variables is not always considered, e.g., playing formations, tactics, and strategy (Carling, 2011).

Time dependent reductions between playing halves are reported suggesting fatigue may hinder acceleration. Within an English professional reserve side; 7.5 % reduction in total acceleration distance and 6.8 % less total deceleration distance (Akenhead *et al.*, 2013). However, Bradley *et al.* (2010) reported no significant reductions in a sample of elite English sides. Importantly, these differences may be methodological due to different classification systems or may depict superior conditioning at the elite level offering improved immunity to the effect of fatigue. However, any link with fatigue is tentative because of the myriad of factors that can influence second half work rate.

A shortcoming amongst the body of literature is that no study has elucidated the tri-axial load of competitive soccer. Positional differences in locomotor activity (Bradley *et al.*, 2009) and discreet activities (Bloomfield, Polman & O'Donoghue, 2007) are common and are reasonably expected to manifest themselves in differences in tri-axial load. Establishing how positional role shapes tri-axial load would be of interest to practitioners and help to inform conditioning, and rehabilitative, programmes. Therefore the aims of this study were to; 1) establish the external load of competitive youth soccer according to playing position, as measured by distances covered in acceleration/deceleration zones, total PL and individual planar components, 2) investigate time dependent changes in acceleration/deceleration activity and 3) investigate HSA according to playing position and 4) time dependent changes in HSA.

Hypothesis 1: Positional differences in tri-axial external load will be exhibited and demonstrate time dependent changes.

3.2 Methodology

3.2.1 Participants

Thirty eight well trained sub-elite youth soccer players (17.3 ± 0.9 yrs., 71.3 ± 8.1 kg, 177 ± 6 cm) volunteered for the study, and were classified by playing position (WD = 8, CD = 6, CMF = 11, WMF = 6, FW = 7). All participants were training in a high performance environment comprising four, two hour field based sessions, two, sixty minutes supervised strength and conditioning sessions and up to two competitive games per week. Players or parents/guardians provided informed consent where appropriate in accordance with the Declaration of Helsinki. The experimental procedure was approved by the BuSH committee at the University of Central Lancashire.

3.2.2 Procedures

Eight home English College fixtures were monitored during the competitive phase of the 2012-2013 season. All games were played on a full size synthetic 3G surface; a 4-2-3-1 formation was preferred and only players completing 90 minutes, in the same playing position, were included. Consequently, this produced uneven group numbers given the tendency for WD, WMF, and FW to be substituted more often. There were also periods of limited GPS unit availability and, therefore, WMF and FW were prioritised for data collection. Game activity was limited to 90 minutes and excluded additional time at the end of each playing half.

Portable GPS units (Catapult Sports, Minimax, 5 Hz) equipped with 100 Hz accelerometer were worn by players and located securely between the scapulae in a custom made harness. GPS units were switched on 10 minutes before use to allow satellite locking consistent with manufacturer's guidance, Horizontal dilution of precision (HDOP) indicated accuracy of GPS in a horizontal plane (Catapult Sports) and optimum satellite availability (HDOP = 0) is where one satellite is directly overhead with a minimum of four spaced equally around the horizon. During these trials, HDOP ranged between 0.8-1.6 and is a good signal. Acceleration activity was calculated using the Doppler shift method.

PL was reported as total load, this being the square root of the sum of the squared instantaneous rate of change in acceleration in each anatomical vector (ML, AP, and CC) divided by 100 (see Figure 1, p. 64) (Boyd, Ball & Aughey, 2011). Proprietary software also recorded and reported PL in each contributory anatomical plane. PL is reported in arbitrary units (AU).

When starting the study there was no consensus in literature about a system for classifying acceleration/deceleration activity, therefore a modified version of the default Sprint software team sport settings were used. This meant that the Sprint software zone one (-

20.0 to -5.0 $m \cdot s^{-2}$) and zone 2 (-5.0 to -4.0 $m \cdot s^{-2}$) were combined to simplify analysis. Distance covered during acceleration/deceleration was coded as follows; zone 1: -20.0 to -4.0 $m \cdot s^{-2}$; zone 2: -4.0 to -2.0 $m \cdot s^{-2}$; zone 3: -2.0 to 0.0 $m \cdot s^{-2}$; zone 4: 0.0 to 2.0 $m \cdot s^{-2}$; zone 5: 2.0 to 4.0 $m \cdot s^{-2}$; zone 6: 4.0 to 20.0 $m \cdot s^{-2}$). To investigate time dependent changes in acceleration/deceleration activity, the game was divided into six, 15 minute periods; P1 (0-15), P2 (15-30), P3 (30-45), P4 (45-60), P5 (60-75) and P6 (75-90).

The classification of locomotor activity was consistent with Aslan, Açıkada, Güvenç, Gören, Hazır, & Özkara, (2012) in a similar population; HSR: 15.1 to 18.0 $km \cdot hr^{-1}$; Low speed sprint (LSS): 18.1 to 21.0 $km \cdot hr^{-1}$; Moderate speed sprint (MSS): 21.1 to 24.0 $km \cdot hr^{-1}$; High speed sprint (HSS) > 24.1 $km \cdot hr^{-1}$).

3.2.3 Statistical analysis

Data files were uploaded to Catapult Sprint software (version 5.0) and manually edited to exclude non-game activity. All data was tested for normality using a Shapiro-Wilk's test and Levene's established homogeneity. When using repeated measures Maulchy's test confirmed sphericity and when violated a Greenhouse-Geisser correction was applied (Field, 2013). Data are presented as mean ± SD unless otherwise stated.

One-way ANOVA was used to detect the main differences between playing positions for distances covered in acceleration/deceleration and locomotor zones, total PL and PL per anatomical plane. Repeat measures ANOVA was used to detect the main differences between playing positions for distances covered in acceleration/deceleration zones during each time period. All significant main effects were investigated using a Gabriel post hoc test, which is suitable for comparing groups of uneven sizes (Field, 2013). Paired T-Tests compared differences playing halves for acceleration/deceleration distance and locomotor activity.

Statistical significance was ≤0.05. Cohen's *d* (1988) determined the magnitude of the effect for Paired T-Test and One-way ANOVA, and interpreted using the scale outlined by Batterham & Hopkins (2006); trivial (< 0.2), small (> 0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0) or very large (>2.0-4.0). Cohen's *d* was calculated using the formula; *d* = Mean group 1 - Mean group 2 / SD pooled, where SD pooled = SQRT [(SD^2 group 1 + SD^2 group2) / 2]. Eta^2 (Ƞ) measured effect size for repeated measures ANOVA, where 0.10 = small, 0.30 = medium and 0.50 = large (Cohen, 1988). Eta^2 was calculated using the formula; Sum of $Squares_{Effect}$ / Sum of $Squares_{Total}$ (Field, 2013). All statistical procedures were completed using SPSS 20.0 (SPSS Inc. Chicago, USA).

3.3 Results

3.3.1 Tri-axial PlayerLoad

There was a significant effect of playing position on total PL; F (4, 49) = 2.62, p = 0.05. Follow up tests revealed significant differences; CMF vs. CD (p = 0.04, *d* = 1.26). There was no significant effect of playing position on ML or CC load respectively; F (4, 49) = 2.08, p = 0.10; F (4, 49) = 21657.74, p = 0.08. There was a significant effect of playing position on AP load; F (4, 49) = 12444.54, p = 0.02. Follow up tests revealed significant differences; CMF vs. CD (p = 0.01, *d* = 1.56) (See Table 7).

Table 7: The tri-axial PlayerLoad load of match-play by playing position (AU). Mean (SD).

	Total load	ML axis	AP axis	CC axis
WD	982.25 (169.40)	247.50 (48.05)	257.26 (65.63)	477.50 (84.26)
CD	745.84 (161.40)	191.31 (38.61)	191.25 (56.50)	363.27 (161.40)
CMF	991.49[a] (223.23)	240.66 (58.53)	287.54[b] (65.97)	463.30 (113.29)
WMF	866.12 (147.40)	208.36 (36.17)	262.92 (45.14)	394.84 (77.90)
FW	892.33 (209.21)	222.08 (27.57)	258.59 (63.38)	411.66 (110.19)
Mean	912.62 (204.46)	225.47 (50.96)	257.53 (66.74)	429.60 (102.30)

Sig: [a]: CMF vs.CD, p = 0.04, *d = 1.26*; [b]: CMF vs. CD, p = 0.01, *d = 1.56*.

3.3.2 Distance covered in different acceleration/deceleration zones

CMF (5923 m) completed the greatest total acceleration distance (FW: 5621 m; WD: 5567 m; WMF: 5366 m; CD: 4909 m). CMF (3165 m) completed the greatest total deceleration distance (WD: 3121 m; WMF: 2963 m; FW: 2947 m; CD: 2710 m). Activity in zones 3-5 accounted for 93 % of the total acceleration/deceleration distance (see Table 8, p.99).

There was a significant effect of playing position on the distance covered in zone 1; $F(4, 35) = 9.77$, $p < 0.001$. Follow up tests revealed significant differences: WMF > WD ($p < 0.01$, $d = 1.60$), CD ($p < 0.01$, $d = 2.53$), CMF ($p < 0.01$, $d = 1.53$) and FW > CD ($p < 0.01$, $d = 2.69$). There was a significant effect of playing position on the distance covered in zone 2; $F(4, 35) = 3.669$, $p = 0.02$. Follow up tests revealed significant differences: WMF > CD ($p = 0.02$, $d = 2.79$), and FW > CD ($p = 0.04$, $d = 3.38$). There was no significant effect of playing position on the distance covered in zone 3: $F(3, 35) = 1.965$, $p = 0.13$. There was no significant effect on the distance covered in zone 4: $F(3, 35) = 2.296$, $p = 0.08$. There was no significant effect on the distance covered in zone 5: F (3,

35) = 2.243, p = 0.07. There was a significant effect of playing position on the distance covered in zone 6: F (3, 35) = 3.605, p = 0.02. Follow up tests revealed significant differences; WMF > CD (p = 0.03, d = 1.59).

Analysis of mean TD covered in each acceleration/deceleration zone between playing halves showed significant declines in each zone aside from Zone 6 (see Table 9).

Table 8: Total distance (m) covered in each acceleration/deceleration zone during match-play, by playing position. Mean (SD).

Zone	1	2	3	4	5	6
$m \cdot s^{-2}$	-20.00 to -4.00	-4.00 to -2.00	-2.00 to 0.00	0.00 to 2.00	2.00 to 4.00	4.00 to 20.00
WD	38.37 (7.46)	193.65 (34.61)	2889.50 (332.58)	5207.25 (469.66)	277.88 (15.31)	82.12 (17.18)
CD	24.00 (7.46)	153.83 (28.24)	2532.67 (395.13)	4618.83 (698.70)	226.67 (39.36)	63.83 (17.70)
CMF	39.00 (8.82)	207.09 (63.56)	2918.86 (373.56)	5574.18 (686.54)	275.45 (59.19)	74.73 (17.36)
WMF	63.00[a] (20.41)	239.17[c] (32.59)	2660.83 (180.67)	4969.33 (884.60)	301.33 (41.53)	95.83[e] (20.03)
FW	49.20[b] (10.92)	234.60[d] (18.57)	2663.40 (180.67)	5269.40 (371.76)	297.60 (2237)	64.60 (10.11)

Sig: [a]: WMF > WD, CD and CMF ($p \leq 0.001$), [b]: FW > CD (p = 0.01), [c]: WMF > CD (p = 0.02), [d]: FW > CD ($p \leq 0.04$), [e]: WMF > CD (p = 0.03).

Table 9: The distances (m) covered in each acceleration/deceleration zone by playing position during each half of match-play. Mean (SD).

Zone	$m \cdot s^{-2}$			First half	Second half	Difference	Sig.
1	-20.0	to	-4.0	22.17	19.62	-2.55	p = 0.04, d = 0.28
2	-4.0	to	-2.0	107.42	96.94	-10.48	p < 0.01, d = 0.38
3	-2.0	to	0.0	1423.50	1345.83	-77.67	p = 0.02, d = 0.39
4	0.0	to	-2.0	2738.69	2450.19	-288.50	p < 0.01, d = 0.66
5	-2.0	to	-4.0	143.36	131.89	-11.47	p < 0.01, d = 0.42
6	-4.0	to	-20.0	38.58	37.94	-0.67	p = 0.62, d = 0.61

There was no significant effect of time period on distance covered in zone 1; $F(5, 170) = 2.078$, $p = 0.07$, $\eta = 0.06$. For zone 2, Maulchy's test indicated that the assumption of sphercity had been violated; $\chi^2(14) = 27.215$, $p = 0.02$, therefore Greenhouse-Geisser corrected tests are reported ($\varepsilon = 0.77$). The results show that there was a significant effect of time period on distance covered in zone 2; $F(5, 170) = 4.479$, $p < 0.01$, $\eta = 0.12$. Post hoc tests showed that P1 > P2 ($p = 0.05$), P1 > P5 ($p = 0.05$), P1 > P6 ($p = 0.01$). There was a significant effect of time period on distance covered in zone 3; $F(5, 170) = 3.779$, $p < 0.01$, $\eta = 0.10$. Post hoc test showed that P1 > P2 ($p < 0.05$), P1 > P5 ($p = 0.05$), P1 > P6 ($p < 0.01$). For zone 4, Maulchy's test indicated that the assumption of sphericity had been violated; $\chi^2(14) = 34.165$, $p < 0.01$, therefore Greenhouse-Geisser corrected tests are reported ($\varepsilon = 0.74$). The results show that there was a significant effect of time period on distance covered in zone 4; $F(5, 170) = 8.409$, $p < 0.001$, $\eta = 0.20$. Post hoc tests showed that P1 > P4 ($p < 0.01$), P1 > P5 ($p < 0.001$), P1 > P6 ($p < 0.01$). For zone 5, Maulchy's test indicated that the assumption of sphericity had been violated; $\chi^2(14) = 28.219$, $p = 0.01$, therefore Greenhouse-Geisser tests are reported ($\varepsilon = 0.75$). The results show that there was a significant effect of time period on distance covered in zone 5; $F(5, 170) = 5.640$, $p < 0.001$, $\eta = 0.14$. Post hoc tests showed that P1 > P2 ($p = 0.01$), P1 > P6 ($p = 0.05$), P1 > P6 ($p < 0.01$). There was no significant effect of time period on distance covered in zone 6; $F(5, 170) = 0.716$, $p = 0.62$, $\eta = 0.02$ (see Table 10).

Table 10: The total distance (m) covered in each acceleration/deceleration zone according to time period during match-play. Mean (SD).

Zone	1	2	3	4	5	6
$m \cdot s^{-2}$	-20.0 to -4.0	-4.0 to -2.0	-2.0 to 0.0	0.0 to 2.0	2.0 to 4.0	4.0 to 20.0
P1	8.31 (4.74)	38.80[a,b,c] (10.83)	481.49[d,e,f] (71.59)	933.63[g,h,i] (125.14)	51.00[j,k,l] (11.82)	12.57 (4.57)
P2	7.47 (3.24)	35.06 (10.49)	455.66 (58.62)	893.77 (112.97)	45.37 (9.39)	12.77 (3.65)
P3	6.71 (3.09)	35.09 (9.20)	466.06 (60.53)	887.869 (103.49)	46.94 (10.07)	12.91 (3.66)
P4	6.63 (3.52)	34.09 (9.23)	456.35 (64.23)	844.57 (109.98)	46.71 (9.28)	13.23 (5.00)
P5	6.77 (3.35)	33.49 (10.83)	455.66 (60.46)	849.60 (107.40)	44.86 (9.95)	12.60 (4.22)
P6	6.60 (3.65)	30.91 (11.23)	441.37 (69.23)	844.03 (121.58)	41.14 (13.95)	11.95 (4.29)

Sig: [a]; P1 > P2 (p = 0.05), [b]; P1 > P5 (p = 0.05), [c]; P1 > P6 (p = 0.01), [d]; P1 > P2 (p = 0.05), [e]; P1 > P5 (p = 0.05), [f]; P1 > P6 (p < 0.01), [g]; P1 > P4 (p < 0.01), [h]; P1 > P5 (p < 0.001), [i]; P1 > P6 (p < 0.001), [j]; P1 > P2 (p = 0.01), [k]; P1 > P5 (p = 0.05), [l]; P1 > P6 (p < 0.01).

3.3.3 Distance covered during high-speed activity.

There was no significant effect of playing position on HSR distance; F4, 35) = 1.69, p = 0.18, *d* = 0.93. There was no significant effect of playing position on LSS distance; F (4, 35) = 1.80, p = 0.15, *r* = 0.93. There was a significant effect of playing position on MSS distance; F (4, 35) = 7.01, p < 0.001, *d = 1.88*. Follow up tests revealed significant differences; WMF (269.83 m ± 69.02) vs. CD (123.50 m ± 30.34, p < 0.001, *d* = 2.74), FW (256.60 m ± 61.53) vs. CD (p = 0.01, *d* = 2.74); WMF vs. CMF (130.64 m ± 83.50, p < 0.001, *d* = 1.81), FW (256.60 m ± 61.62) vs. CMF, p = 0.01, *d* = 1.71). There was a significant effect of playing position on the distance covered at HSS; F (4, 35) = 5.00, p < 0.001, *d = 1.59*. Follow up tests revealed significant differences; WMF (214.17 m ±114.19) vs. CD (60.17 m ± 22.66, p = 0.01, *d* = 1.87), vs. CMF (67.55 m ± 63.72, p = 0.01, *d* = 1.55).

Table 11: A comparison of distance (m) covered in each velocity zone by playing position during each half of match-play. Mean (SD).

Locomotion category	**No. of events**	**Distance covered (m)**
HSR	31.1 (11.3) 30.4 (9.1)	323.7 (120.8) 281.8 (118.2)[a]
LSS	12.6 (4.6) 12.4 (5.3)	154.0 (65.6) 128.5 (60.4)[b]
MSS	7.4 (2.9) 7.6 (3.4)	94.3 (43.8) 88.2 (50.8)
HSS	3.9 (2.6) 3.2 (2.6)	63.3 (51.5) 53.7 (48.5)

Sig: [a]: $p = 0.02$, $d = 0.35$; [b]: $p < 0.001$, $d = 0.40$

Average TD was 8872 m (± 1061) and greater distance was covered in the first (4592 m ± 525) compared to second half (4279 m ± 667, $p \leq 0.01$, $d = 0.52$). There was no significant effect of playing position on TD covered; $F (4, 34) = 2.10$, $p = 0.10$, $d = 0.43$; CMF (9367.36 m ± 1218.10), WMF (8994.00 m ± 619.75), WD (8896.13 m ± 881.15), FW (8752.00 m ± 687.79), CD (7910.33 m ± 177.00) (See Table 11).

3.4 Discussion

This study set out to investigate the external load of competitive youth soccer with a particular focus on acceleration/deceleration activity, total PL and individual planar components. Secondary aims were to examine time dependent changes in acceleration/deceleration activity, profile HSA and investigate time dependent changes. Key findings can be summarised as follows; CMF reported higher total PL compared to CD (991.49 AU ± 223.23 vs. 745.84 AU ± 161.40, $p = 0.04$, $d = 1.26$) and higher AP load (287.54 AU ± 65.97 vs. 191.25 AU ± 56.50, $p = 0.01$, $d = 1.56$) (see Table 7, p.98). WMF covered greater distance in zone 1 (-20.00 to -4.00 $m \cdot s^{-2}$) compared to WD, CD and CMF ($p < 0.001$, $d = 1.53 - 2.53$), zone 2 (-4.00 to -2.00 $m \cdot s^{-2}$) compared to CD ($p = 0.02$, $d =$

2.79) and zone 6 (4.00 to 20.00 m·s^{-2}) compared to CD ($p = 0.03$, $d = 1.59$). FW covered greater distance in zone 1 and 2 compared to CD ($p \leq 0.04$, d 2.69 - 3.38) (see Table 8, p.99). Distances covered in zones 2 - 5 were reported to decline significantly between playing halves ($p \leq 0.02$, d = 0.38 - 0.66) (see Table 9, p.99). Also, greater activity was found in Period 1 (0 - 15 minutes) compared to P2, P5 and P6 in zone 3 and 4 ($p \leq 0.05$, η = 0.10 - 0.12), compared to P4, P5 and P6 in zone 5 ($p \leq 0.01$, η = 0.02 - 0.20) (see Table 10, p.101). Differences in MSS activity were; WMF (269.83 m ± 69.02) vs. CD (123.50 m ± 30.34, $p < 0.001$, $d = 2.74$), FW (256.60 m ± 61.53) vs. CD ($p = 0.01$, $d = 2.74$); WMF vs. CMF (130.64 m ± 83.50, $p < 0.001$, $d = 1.81$), FW (256.60 m ± 61.62) vs. CMF, $p = 0.01$, $d = 1.71$). Also, in HSS, WMF (214.17 m ±114.19) vs. CD (60.17 m ± 22.66, $p = 0.01$, $d = 1.87$), ·vs. CMF (67.55 m ± 63.72, $p = 0.01$, $d = 1.55$). However, reductions in distance covered between playing halves were limited to HSR ($p = 0.02$, $d = 0.35$) and LSS ($p < 0.001$, $d = 0.40$) (see Table 11, p.102).

The positional PL data reported extends the body of literature about the external demands of soccer competition. Presently the use of GPS during sport is in its infancy, but total PL has differentiated between playing positions in Basketball (Montgomery, Pyne & Minahan, 2010), Netball (Cormack *et al.*, 2013) and Australian Rules football (Boyd, Ball & Aughey, 2013). In this study, differences in total PL were evident, but for the most part failed to reach significance. Given the differences in the discreet actions completed by players (headers, tackles, sideways or backward running, etc...) (Bloomfield, Polman & O'Donoghue, 2007; Carling *et al.*, 2008) it was surprising that planar contributions were similar across playing positions. However, it is feasible that PL is accumulated differently by each playing position. The impact of the 0.6 s event threshold is also unclear, but it is likely that some activities were too short to be included in the analysis.

Further research could investigate the impact of a shorter cut-off point on PL to determine the most appropriate threshold.

Accelerometers are sensitive to the magnitude of acceleration caused by impact force, landing and physical contact (Young, Hepner & Robbins, 2012; Wundersitz *et al.*, 2015a). A strong correlation (r = 0.93) between PL and TD (Scott *et al.*, 2013b) reflects elevated activity in the vertical axis. Based on this relationship it was anticipated that CMF would exhibit higher total PL as a product of greater TD and elevated CC impact force. However, differences in total PL and planar contributions were limited to CMF vs. CD in total PL and AP load. The placement of GPS units at the scapula and the formulaic construct of total PL means it is sensitive to changes in upper body orientation, particularly during changes in velocity or direction (Barrett, Midgley & Lovell, 2014; Keller *et al.*, 1996; Wundersitz *et al.*, 2013). During linear running over 14-16 km·hr^{-1}, AP load was higher due to biomechanical alterations in running mechanics (Barrett, Midgley & Lovell, 2014; McGregor, Busa, Yaggie & Bolt, 2009) suggesting differences in AP load are consistent with frequent changes in movement speed. Support can be found by the greater total acceleration and deceleration distance covered by CMF in comparison to CD.

GPS unit location and between athlete differences in posture and gait during all forms of locomotion can also be reasonably assumed to impact on tri-axial load. Contemporary GPS is located at the scapula to optimise satellite communication, however, this reduces sensitivity to hip rotation at the centre of mass, leading to an underestimation of ML load (35 % ± 20.3) (Barrett, Midgley & Lovell, 2014). In addition, increased vertical load at the scapula compared to the centre of mass (55.7 % ± 5.3 vs. 49.5 % ± 6.9) could reflect arm swing and forward lean during running (Barrett, Midgley & Lovell, 2014). It is, therefore, recommended that comparisons of PL be made on a within-athlete basis only (Barrett, Midgley & Lovell, 2014).

The trend for WMF to complete more distance > 2.00 $m{\cdot}s^{-2}$ compared to central players is similar to findings from Norway (Ingebrigtsen *et al.*, 2015). Also, positional differences suggest that there is a requirement for wide players to accelerate more often, compared to central players. These findings are similar to observations that higher running speeds are achieved by wide players (Bradley *et al.*, 2010) highlighting they enjoy greater space, and are required to participate in offensive and defensive sequences of play (Di Salvo *et al.*, 2010). This combined role requires them to minimise both "attacking reaction time," defined as the "lapse between winning the ball and a shot on target" (Garanta, Maia & Basto, 1997. P.246), and defensive reaction time, or the lapse between the start and end of a defensive period (Barreira, Garganta, Machado & Anguera, 2014). The subtle differences between the studies may reflect the tactical or strategic approach to competition, or the differences in technical competence between levels of competition (Carling, 2011) which help to shape the positional roles.

Comparison between time periods showed that acceleration/deceleration activity in zones 2-5 (-4.00 to 4.00 $m{\cdot}s^{-2}$) was highest during the opening period, consistent with elevated work rate during this stage of the game (Akenhead *et al.*, 2013; Lovell *et al.*, 2013a; Weston, Drust & Gregson, 2011). This period has been described as atypical, and its use as a reference for comparison has received criticism (Carling, 2013). Instead, relative comparisons using $m{\cdot}min^{-1}$ during 5 minute periods, revealed that elevated work rate only persisted for the initial 5 minutes (Lovell *et al.*, 2013a). However, shorter periods are influenced by active playing time that may limit the opportunity to engage in game related activity (Bradley & Noakes, 2013; Carling & Dupont, 2011), and therefore, 15 minute periods were preferred in the present study.

Time-dependent reductions in acceleration activity from the beginning to the end of the game were found in zones 1-5 (d = 0.28 - 0.66) providing support for previous studies in professional teams (Akenhead *et al.* 2013; Ingebrigtsen *et al.* 2015). Reductions are suggested to reflect declines in the rate of force development (Thorlund, Aagaard & Madsen, 2009) and maximum force production (Rampinini, Bosio, Ferraresi, Petruolo, Morelli & Sassi, 2011), as a consequence of game related peripheral fatigue (Akenhead *et al.*, 2013; Rahnama, Reilly, Lees & Graham-Smith, 2003). In contrast, Bradley *et al.* (2010) found no differences in the number of medium (2.5 to 4.0 $m{\cdot}s^{-2}$) or high (> 4.0 $m{\cdot}s^{-2}$) accelerations between the first and last 15 minutes of the game. Inconsistency between the studies might be methodological or due to differences in competition level. Bradley *et al.* (2010) quantified accelerations > 2.5 $m{\cdot}s^{-2}$, Ingebrigtsen *et al.* (2015) > 2.0 $m{\cdot}s^{-2}$, whereas Akenhead *et al.*, (2013) and the present study used > 1.0 $m{\cdot}s^{-2}$. In relation to competition level, only Bradley *et al.* (2010) analysed players from an elite domestic league (English Premier), which is shown to complete more high-intensity running than domestic leagues (Bradley *et al.*, 2010; Mohr, Krustrup & Bangsbo, 2005). Allied to this, higher level players are also found to recover quicker from high intensity activity (Mohr *et al.*, 2003) and repeated sprint bouts (Impellizeri *et al.*, 2008; Rampinini *et al.*, 2009b) which might also be the case for acceleration activity.

HSR is an integral part of soccer activity (Mohr, Krustrup & Bangsbo, 2003) and analysis of HSA showed that positional differences were limited to MSS and HSS, whereby WMF and FW covered greater distances than central players. In a similar age group, MSS and HSS activity was less for defenders than FW ($p < 0.05$, $d = 1.02$) and midfielders ($p < 0.05$, $d = 0.68$) respectively (Aslan *et al.*, 2012), but comparison is limited by a lack of positional separation. Similar findings are found amongst professionals, where WMF are widely reported to complete greater total sprint distances and CD the least (Bradley *et al.*, 2009; 2010; Di Salvo *et al.*, 2009) which can be attributed to a tactical role in the team. However, a direct comparison between studies is complicated by methodological issues and the threshold for sprinting ranges from 19.80 km·hr^{-1} - 25.2 km·hr^{-1} (Bradley *et al.*, 2009; 2010; Di Salvo *et al.*, 2009; 2010).

Comparison of sprinting activity showed that only LSS (18.1 to 21.0 km•hr^{-1}) reduced significantly between playing halves, unlike MSS/HSS (> 21.1 km•hr^{-1}) activity. Interestingly, WMF and FW from the English Premier League exhibited significant reductions in sprint activity (> 19.8 km•hr^{-1}) (ES < 0.5) between playing halves, whereas CMF and CD increased their activity (ES <0.3) (Di Salvo *et al.*, 2009). While the authors offered no explanation for these findings, wide players and FW are required to complete more HSR during games, and this could be a fatigue related decline. Within the present study, the pattern of decline reported might represent a pacing strategy whereby players self-regulate their running to preserve the capacity to complete MSS and HSS. Such activity is described as slow-positive where the intensity of running declines progressively during the match but is interrupted by periods of high speed activity when required (Waldron & Highton, 2014).

While the acceleration/deceleration activity reported contributes to the body of knowledge about soccer activity, it is important to recognise the limitations associated with measurement of distance using the Doppler shift method. Individual sprint bouts are on average < 10 m (Di Salvo *et al.*, 2010) and during this activity 5 Hz GPS exhibited SEE 30.9 % ± 5.8 for measuring distance (Jennings *et al.*, 2010b). Soccer is characterised by random movements and, during gradual and tight changes of direction, the same equipment demonstrated CV 7.9% and 9.2 % respectively, when sprinting (Jennings *et al.*, 2010b). In addition, Varley, Fairweather & Aughey (2012) demonstrated poorer validity measuring instantaneous velocity from a lower starting speed (1-3 $m \cdot s^{-2}$) compared to a higher starting speed (5-8 $m \cdot s^{-2}$) (CV 14.9 % ± 1.16 vs. 7.1 % ± 0.87). It is therefore prudent to view GPS data as indicative rather than definitive, yet the data reported could still be used to help to prescribe position specific training programmes.

The activity profile reported in this study was derived from a single collegiate academy, and issues arising during data collection limited the scope of the findings. Player interchange during games led to bias in the dataset whereby CMF contributed more files than CD and WMF. The differences in the physical performance between wide and central players are well documented (Buchheit *et al.*, 2010a; Di Salvo *et al.*, 2007; Gregson *et al.*, 2010), and this would have influenced the findings. Substitutes are also shown to exhibit higher work rates than starting players (Carling, Espie, Le Gall, Bloomfield & Jullien, 2010) and the tendency for five substitutions to be made per game, might have influenced the overall work rate of the team.

The collection was limited to home games which could be interpreted as a limitation to the study but could equally be advantageous. Consistency in the match location helped to reduce data variability because pitch surface (Nédélec, McCall, Carling, Le Gall, Berthoin & Dupont, 2012), pitch dimensions, playing strategy/tactical approach (Bradley *et al.*, 2010) and the advantage of playing at home (Lago-Peñas, 2009), were all controlled (Morgans *et al.*, 2014). Nevertheless, the findings are unique to the interaction effect of these variables. Home fixtures are associated with higher ball possession, regaining possession more quickly and attacking more frequently (Almeida, Ferreira & Volossovitch, 2014; Lago-Peñas, 2009; Lago-Peñas & Lago-Ballesteros, 2011). The academy teams analysed are amongst the strongest in the region, and of the fixtures analysed, only one resulted in a loss, so it is feasible that the data reported does not represent the full physical potential of the players. Amongst professionals, positive score lines were found to reduce high speed activity because there was no requirement to chase the ball (Lago *et al.*, 2010; Lago & Martin, 2007).

In addition to the limitations of 5 Hz GPS discussed above, the accumulation of PL may have included erroneous data arising from unit artifact and player-player collisions and/or falls. To address this, Catapult Sprint software automatically removes data collected during poor GPS reception (HDOP > 2.5) in combination with excessive velocity (> 10 $m \cdot s^{-2}$) to reduce reliability issues. Additional steps were also taken according to manufacturer advice; players were fitted with appropriately sized custom fitted garments, and, units were calibrated periodically. However, due to the changing availability of GPS units, it was not always possible to assign the same GPS unit to minimise between-unit variability (Jennings *et al.*, 2010a). Finally, although the playing surface remained the same throughout this study, 3G artificial surfaces are suggested to produce higher ground reaction forces which may complicate comparison with future studies utilising a natural playing surface (Nédélec *et al.*, 2012).

3.5 Summary

This study was the first to report total PL and planar contributions during competitive soccer. Findings highlighted that differences in total PL were limited to CMF vs. CD and that only AP load differed significantly between CMF and CD. Wide players completed more activity ($\pm$ 2.00 m·s $^{-2}$) in contrast to central players, providing some justification for the inclusion of position specific conditioning regimes. In addition, time-dependent changes were evident for acceleration/deceleration activity, but these declines cannot be attributed to fatigue given the influence of game location, score line and the level of game competitiveness.

3.6 Perspective

A key finding from chapter two was the limited information about the acceleration/deceleration activity during competition. Considering the additional energetic demands of accelerating compared to steady state motion (di Prampero *et al.*, 2005), it is important to quantify this activity to optimise readiness to compete. Activity is quantified according to pre-determined thresholds, however, perhaps individualised zones would be more appropriate. In a small cohort (n = 8) comparison of mean distance covered during high speed running (>14.4 km·hr^{-1}) across 5 games, differed by ~5 % (167 m). However, when normalised according to respiratory compensation threshold (VT_2) CMF_1 and CMF_2 differed by 41 % (2712 m vs. 3814 m) (Lovell & Abt, 2013). Although these data suggest meaningful differences and have potential implications for the evaluation of player's physical performance, the practical challenges of implementing individualised categories at the youth level are significant.

On a practical level, insight and understanding of physical performance can be extended by contextual information, and this is perhaps, more accessible to the coach than the advanced methodology outlined by Lovell & Abt (2013). Whether it is possible to infer the likelihood of on field success from physical performance is debatable. In fact, it is suggested that technical and tactical effectiveness has a greater impact on league standing than physical performance, although the latter underpins the former (Carling, 2013) and underlines the complexity of analysing soccer performance. The present reductionist approach to performance analysis (Mackenzie & Cushion, 2012) seems to be at odds with the complex nature of competition that is reliant on the interaction of technical, strategic and physical components.

During this study, emergent research highlighted that measure of external load are used increasingly to micro-manage player workload on a daily basis (Cummins *et al.*, 2013). In addition, longitudinal data allows practitioners to monitor an individual's natural variation in their physical performance and make inferences about their fatigue status and readiness to compete (Anderson *et al.*, 2016; Hulin, Gabbett, Lawson, Caputi & Sampson, 2015; Malone *et al.*, 2015). Increasingly, this approach is preferred over regular fitness assessment, given the challenges to scheduling because of time restrictions allied to congested games programmes and associated travel commitments (Casajús, 2001; Pyne, Spencer & Mujika, 2014). However, financial constraints place integrated technology out of the reach of the majority of clubs at the sub-elite youth level. Consequently, valid and reliable field based fitness tests are the only practical method of determining fitness status at the sub-elite youth level.

Among the criteria when devising a field test is, construct validity, this being how test performance compares to game performance (Paul & Nassis, 2015). Given the growing attention paid to external load measures when analysing competition, and the emphasis on these metrics when micro-managing players, it is surprising that contemporary field tests have not been validated using these measures. Further, the shelf life of contemporary field tests is unclear given the continual development in the physical demands of competition (Barnes *et al.*, 2014; Bush *et al.*, 2015b). Consequently, it is necessary to determine the validity of contemporary field based fitness tests using measures of external load.

Chapter 4: A comparison of the external load of contemporary field tests and match-play.

4.1 Introduction

Chapter 3 presented the tri-axial external load of competitive soccer revealing subtle differences between playing positions providing justification for the individualisation of training load. At the elite level, the same variables are monitored during training sessions on an individual basis and manipulated to deliver a training load appropriate for the player, the training outcome and the phase of the season (Anderson, Orme, Di Michael, Close, Morgans, Drust & Morton, 2016). The development of integrated technology has facilitated this approach and brought about a shift away from reliance on internal measures. Internal measures exhibit shortcomings when evaluating intermittent high speed sports (see Chapter 2 for a full review) and led to systematic underestimation of the energetics of competition, attributed to the omission of acceleration/decelerations (Osgnach *et al*., 2010). Importantly, internal measures such as HR and BL were used to validate contemporary field tests, like the YYIRL, Hoff FET, and RSA, consequently, the tri-axial external load of field tests may not reflect the modern game necessitating a re-evaluation of their validity.

Tri-axial accelerometers measure instantaneous changes in direction in each anatomical plane (Cummins *et al*., 2013) and for convenience, a global indicator of external load, termed PL, is also widely used (Barrett, Midgley & Lovell, 2014). PL can reliably differentiate between playing positions, level of competition and training drills in a number of sports (Boyd, Ball & Aughey, 2013; Cormack *et al*., 2013; Ingebrigtsen *et al*., 2015; Montgomery, Pyne & Minahan, 2010), but an assessment of the external load of contemporary field tests is absent from literature. To satisfy scientific rigour, demonstrable validity, reliability, specificity and objectivity are essential (Pyne, Spencer & Mujika, 2014), hence addressing this shortcoming would permit existing procedures to be used confidently, and performance measures hold value for the practitioner.

Three criteria shaped the selection of tests evaluated in this study. Firstly, the validity and/or reliability of the test should have been established within existing literature. Secondly, given the importance of HSA, each procedure should assess this component. Finally, the protocol should be maximal and widely used in the applied setting. After consideration, three tests were chosen, the YYIRL1, the BST, and the Hoff FET. The YYIRL1 was selected because it evaluates the ability to complete HSR, test performance is correlated to in game HSR, and its intermittent nature demonstrates logical validity (Bangsbo, Iaia & Krustrup, 2008; Chamari *et al.*, 2005; Kemi *et al.*, 2003; Krustrup *et al.*, 2005). As a measure of RSA, the BST is unlike other protocols because it incorporates changes of direction and active recovery, and has demonstrable reliability (Wragg, Maxwell & Doust, 2000). Finally, although the Hoff FET predicts aerobic capacity (Kemi *et al.*, 2003), it demonstrates strong logical validity and provides an interesting comparison with the linear YYIRL1.

Presently there are no studies that have described the tri-axial external load of field based fitness tests and this knowledge will establish whether they evoke an equitable physical load. It is acknowledged that the unpredictable nature of soccer renders a true representation impossible (Paul & Nassis, 2015), but the principle of specificity requires that differences between the two be minimal. Therefore, the primary aim of this study was to investigate the external load of three contemporary field test in comparison with competition, with a focus on total PL, individual planar contributions and acceleration/deceleration activity. Secondary aims were to compare HSR, LSS, MSS and HSS during each test with competition. Hypothesis 2: The tri-axial external load of three contemporary field tests will be different in comparison to competitive sub-elite youth soccer

4.2 Methodology

4.2.1 Participants

Seventy six well trained male sub-elite youth soccer players (17.3 ± 0.9 yrs, 71.3 ± 8.1 kg, 177 ± 6 cm) volunteered for the study and were divided by playing position (WD = 15, CD = 14, WMF = 12, CMF = 16, FW = 19). All participants were training in a high performance environment involving four, two hour field based sessions, two, sixty minute supervised strength and conditioning sessions and up to two competitive games per week. Players or parents/guardians provided informed consent where appropriate in accordance with the Declaration of Helsinki. The experimental procedure was approved by the BuSH committee at the University of Central Lancashire.

4.2.2. Procedures

Acceleration/deceleration activity and PL data for the field tests was gathered during a scheduled battery of field based fitness tests administered to the academy playing squads on two separate days, separated by no more than seven days. Due to time constraints imposed by the academic teaching programme, it was not possible to standardise the timing of testing and, consequently, some players were assessed in the morning and some in the afternoon. Only the players completing the Hoff FET, YYIRL1 and BST were included in the analysis, and this produced an uneven number of players in each playing position. An outline of the testing schedule is provided in Table 12 (see p.118). The game data used for comparison is the same as reported in Chapter 3.

Participants were instructed to follow their usual diet, arrive hydrated and be suitably attired. Testing followed the regular warm up of approximately ten minutes that included a short preparatory period of ball work and dynamic flexibility. The Hoff FET was administered using the guidelines provided by Chamari *et al.* (2005), whereby players dribbled the ball continuously for 8 minutes around a predetermined activity course. Participants were familiarised with the course beforehand, and assistants were on hand to replace displaced equipment and provide verbal encouragement. Completion of the YYIRL1 followed the procedure outlined by Bangsbo (1996) and participants were familiar with the test, so no practice was required. During the trial, all participants received verbal encouragement. The BST followed the procedure outlined by Bangsbo (1994) and to avoid participants pacing themselves, they were told that the sum of their seven repetitions would be the performance measure. Participants familiarised themselves with the procedure by completing two trial efforts and were fully rested before the recorded trial began. Electronic timing gates (Smartspeed, Cardiff, UK) positioned at the start and finish line recorded time to the nearest tenth of a second. All field tests were completed on a 3G artificial playing surface.

Portable GPS units (Catapult Sports, Minimax, 5 Hz) equipped with 100 Hz accelerometer were worn by players and located securely between the scapulae in a custom made harness. GPS units were switched on 10 minutes before use to allow satellite locking consistent with manufacturer's guidance. Horizontal dilution of precision (HDOP) indicated accuracy of GPS in a horizontal plane (Catapult Sports) and optimum satellite availability (HDOP = 0) is where one satellite is directly overhead with a minimum of four spaced equally around the horizon. During these trials, HDOP ranged between 0.8-1.6 and is a good signal. Acceleration activity was calculated using the Doppler shift method.

PL was expressed as total load (AU) this being the square root of the sum of the squared instantaneous rate of change in acceleration in each anatomical vector (ML, AP, and CC) divided by 100 (see Figure 1, p.64) (Boyd, Ball & Aughey, 2011). Proprietary software also recorded and reported PL in each contributory anatomical plane. PL is reported in arbitrary units (AU). The contributions to PL were also categorised by proprietary software using the following scale: 0-1 AU, 1-2 AU, 2-3 AU, 3-4 AU, 4-6 AU and 6-10 AU, and reported as a percentage of total PL. Distance covered during acceleration/deceleration activity was categorise as follows; zone 1: -20.0 to -4.0 $m{\cdot}s^{-2}$; zone 2: -4.0 to -2.0 $m{\cdot}s^{-2}$; zone 3: -2.0 to 0.0 $m{\cdot}s^{-2}$; zone 4: 0.0 to 2.0 $m{\cdot}s^{-2}$; zone 5: 2.0 to 4.0 $m{\cdot}s^{-2}$; zone 6: 4.0 to 20.0 $m{\cdot}s^{-2}$). Locomotor activity was categorised as per Aslan *et al.* (2012); HSR: 15.1 to 18.0 $km{\cdot}hr^{-1}$; Low speed sprint (LSS): 18.1 to 21.0 $km{\cdot}hr^{-1}$; Moderate speed sprint (MSS): 21.1 to 24.0 $km{\cdot}hr^{-1}$; High speed sprint (HSS) > 24.1 $km{\cdot}hr^{-1}$).

Table 12: The **s**equence of fitness assessments administered to the participants.

Day one	Day two
Height	BST
Weight	Hoff FET
Body fat	
Counter movement jump	
Linear speed (5, 10, 30 m)	
YYIRL1	

4.2.3 Statistical analysis

Data was uploaded to Catapult Sprint software (version 5.0), pooled into four groups; 1: Hoff FET; 2: YYIRL1; 3: BST; 4: Game, and was manually edited to exclude non-test activity. All data was tested for normality using a Shapiro Wilks test and Levene’s established homogeneity. To enable comparison between each procedure the effect of duration was controlled using a univariate ANCOVA. Post hoc analysis was completed using a Bonferroni correction chosen to reduce the chance of a Type 1 error (Hopkins, 2000b). Statistical significance was accepted $p \leq 0.05$. Eta^2 (η) determined the magnitude of the main effect; it was calculated using the formula; Sum of Squares$_{Effect}$ / Sum of Squares$_{Total}$ (Field, 2013) and interpreted using the scale 0.10 small; 0.30 medium and 0.50 large (Cohen, 1988). Cohen's *d* determined the magnitude of effect for pairwise comparisons, and was calculated using the formula; Mean group 1 - Mean group 2 / (SQRT mean squared error). It was interpreted using the scale outlined by Batterham and Hopkins (2006): trivial (< 0.2), small (> 0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0) or very large (>2.0-4.0). Pearson's correlation coefficient measured the strength of the relationship between in-game and test HSA activity (HSR + LSS + MSS + HSS). According to Hopkins (2015a), the magnitude of correlation coefficients was considered as trivial (r = 0.1), small (r = 0.1 - 0.3) moderate (r = 0.3 - 0.5), large (r = 0.5 - 0.7), very large (r = 0.7 - 0.9) nearly perfect (r = 0.9 - 9.9), and perfect (r = 1.0). Agreement between test distance and GPS distance was examined using typical error (TE) and the magnitude of the difference was expressed as coefficient of variation (CV %). Calculations were made using a customised spreadsheet for validity and reliability (Hopkins, 2015b). All statistical procedures were completed using SPSS 20.0 (SPSS Inc. Chicago, USA).

4.3 Results

4.3.1 Tri-axial PlayerLoad

The planar contribution to total PL was proportionally similar (see Table 13, p.120). There was no significant effect of duration on total PL; $F(1, 183) = 0.861$, $p = 0.46$, $\eta = 0.01$. Estimated marginal means showed adjusted values; Hoff FET: 450.37 AU, YYIRL1: 424.79 AU, BST: 458.26 AU, Game: 59.09 AU. There was no significant effect of duration on AP load; $F(1, 183) = 0.342$, $p = 0.80$, $\eta = 0.01$. Estimated marginal means show adjusted values; Hoff FET: 105.67 AU, YYIRL1: 99.31 AU, BST: 100.50

AU, Game: 78.32 AU. There was no significant effect of duration on ML load; F (1, 183) = 0.862, p = 0.46, η = 0.01. Estimated marginal means show adjusted values; Hoff FET: 116.43 AU, YYIRL1: 112.33 AU, BST: 125.03 AU, Game: -9.78 AU. There was no significant effect of duration on CC load; F (1, 183) = 1.340, p = 0.26, η = 0.26. Estimated marginal means showed adjusted values; Hoff FET: 228.27 AU, YYIRL1: 213.15 AU, BST: 232.73 U, Game: -9.48 AU.

Amongst the YYIRL1, BST and game, the highest proportion (48, 50, 70 %) of AU events contributing to total PL were ranked 0-1. In, contrast 80 % of events in the Hoff FET were ranked 1 -2 AU (see Table 14).

Table 13: The PlayerLoad characteristics of each test condition and match-play (AU). Mean (SD).

Test	Total load	ML axis	ML %	AP axis	AP %	CC axis	CC %
Hoff FET	166.11 (23.95)	38.08 (6.19)	23	45.99 (11.06)	27	82.03 (11.65)	50
YYIRL1	205.51 (67.34)	51.89 (16.88)	26	53.27 (22.91)	25	100.35 (32.18)	49
BST	70.18 (10.79)	18.07 (3.03)	25	19.02 (5.02)	27	33.10 (4.53)	47
Game	912.62 (204.46)	225.47 (50.96)	25	257.53 (66.74)	28	429.59 (102.30)	47

Table 14: The proportional contributions (%) to total PL according to classification of AU events.

Test	0 -1 AU	1 - 2 AU	2 -3 AU	3 - 4 AU	4 - 6 AU	6 - 10 AU
Hoff FET	14	80	5	< 1	0	0
YYIRL1	48	34	16	1.5	< 1	0
BST	50	29	15	5	< 1	0
Game	70	23	5	1.5	< 1	0

4.3.2 Distance covered in different acceleration/deceleration zones

There was a significant effect of condition on distance covered in zone 1 after controlling for the effect of duration; $F(3, 166) = 29.085$, $p < 0.001$, $\eta = 0.35$. Estimated marginal means showed adjusted values; Hoff FET: 36.00 m; YYIRL1: 49.75 m; BST: 76.93 m; Game: -98.01 m. Follow up tests revealed significant differences between conditions; YYIRL1 > Hoff FET, $p = 0.03$, $d = 0.83$; BST > Hoff FET, $p < 0.001$, $d = 2.47$; BST > Game, $p = 0.04$, $d = -1.27$ (see Table 15, p.123).

There was a significant effect of condition on distance covered in zone 2, after controlling for the effect of duration; $F(3, 166) = 9.557$, $p < 0.001$, $\eta = 0.15$. Estimated marginal means showed adjusted values; Hoff FET: 162.99 m; YYIRL1: 193.134 m; BST: 169.43 m; Game: -263.22 m. Follow up tests revealed there were no significant differences between conditions.

There was a significant effect of condition on distance covered in zone 3, after controlling for the effect of duration; $F(3, 166) = 17.31$, $p < 0.001$, $\eta = 0.24$. Estimated marginal means showed adjusted values; Hoff FET: 974.16 m; YYIRL1: 896.93 m; BST: 736.02 m; Game: 716.50 m. Follow up tests revealed significant differences between conditions; Hoff FET > BST, $p = 0.01$, $d = 1.35$.

There was a significant effect of condition on distance covered in zone 4, after controlling for the effect of duration; $F(3,166) = 8.366$, $p < 0.001$, $\eta = 0.13$. Estimated marginal means showed adjusted values; Hoff FET: 1695.10 m; YYIRL1: 1543.30 m; BST:

1334.28 m; Game: 1514.29 m. Follow up tests revealed there were no significant differences between conditions (see Table 16, p.123).

There was a significant effect of condition on distance covered in zone 5, after controlling for the effect of duration; $F (3,166) = 219.648$, $p < 0.001$, $\eta = 0.80$. Estimated marginal means showed adjusted values; Hoff FET: 133.36 m; YYIRL1: 182.82 m; BST: 322.56 m; Game: -193.32 m. Follow up tests revealed significant differences between conditions; YYIRL1 > Hoff FET, $p < 0.001$, $d = 1.69$; YYIRL1 > Game, $p = 0.01$, $d = 0.35$; BST > Hoff FET, $p < 0.001$, $d = 6.47$; BST > YYIRL1, $p < 0.001$, $d = 4.78$; BST > Game, $p < 0.001$, $d = 4.42$.

There was a significant effect of condition on distance covered in zone 6, after controlling for the effect of duration; $F (3,166) = 78.475$, $p < 0.001$, $\eta = 0.59$. Estimated marginal means showed adjusted values; Hoff FET: 50.46 m; YYIRL1: 80.30 m; BST: 79.38 m; Game: -119.90 m. Follow up tests revealed significant differences between conditions; Hoff FET > Game, $p = 0.01$, $d = -5.49$; YYIRL1 > Hoff FET, $p < 0.001$, $d = 2.35$; YYIRL1 > Game, $p < 0.001$, $d = -3.20$; BST > Hoff FET, $p < 0.001$, $d = 2.28$; BST > Game, $p < 0.001$, $d = -3.19$.

Table 15: The distances (m) accumulated in each deceleration zone during each test condition and match-play. Mean (SD).

Test	Zone 1 (-20.00 to -4.00 m·s^{-2})		Zone 2 (-4.00 to -2.00 m·s^{-2})		Zone 3 (-2.00 to 0.00 m·s^{-2})	
	Dist. (SD)	Total %	Dist. (SD)	Total %	Dist. (SD)	Total %
Hoff FET	1.96 (3.16)	< 1	49.09 (127.21)	4	474.14[d] (120.27)	35
YYIRL1	25.67[a] (11.85)	2	102.59 (40.68)	6	543.33 (153.50)	31
BST	27.02[b,c] (41.78)	13	2.48 (2.18)	1	3.12 (1.95)	1
Match-play	23.37 (20.98)	< 1	204.39 (50.05)	3	2769.33 (340.91)	32

Sig: [a]: YYIRL1 > Hoff FET, $p = 0.03$, $d = 0.83$; [b]: BST > Hoff FET, $p < 0.001$, $d = 2.47$; [c]: BST > Game, $p = 0.04$, $d = -1.27$; [d]: Hoff FET > BST, $p = 0.01$, $d = 1.35$.

Table 16: The distances (m) accumulated in each acceleration zone during each test condition and match-play. Mean (SD).

Test	Zone 4 (0.00 to 2.00 m·s^{-2})		Zone 5 (2.00 to 4.00 m·s^{-2})		Zone 6 (4.00 to 20.00 m·s^{-2})	
	Dist. (SD)	Total %	Dist. (SD)	Total %	Dist. (SD)	Total %
Hoff FET	800.05 (227.01)	59	19.22 (9.45)	1	2.61[j] (3.29)	< 1
YYIRL1	910.36 (272.10)	53	102.103[e,f] (37.38)	5	46.46[k,l] (20.85)	3
BST	22.37 (6.18)	10	155.27[g,h,i] (20.06)	70	9.25[m,n] (2.90)	5
Match-play	5188.89 (698.23)	60	275.25 (49.95)	3	76.53 (19.49)	1

Sig: [e]: YYIRL1 > Hoff FET, $p < 0.001$, $d = 1.69$; [f]: YYIRL1 > Game, $p = 0.01$, $d = 0.35$; [g]: BST > Hoff FET, $p < 0.001$, $d = 6.47$; [h]: BST > YYIRL1, $p < 0.001$, $d = 4.78$; [i]: BST > Game, $p < 0.001$, $d = 4.42$; [j]: Hoff FET > Game, $p = 0.01$, $d = -5.49$; [k]: YYIRL1 > Hoff FET, $p < 0.001$, $d = 2.35$; [l]: YYIRL1 > Game, $p < 0.001$, $d = -3.20$; [m]: BST > Hoff FET, $p < 0.001$, $d = 2.28$; [n]: BST > Game, $p < 0.001$, $d = -3.19$.

4.3.3 Distance covered during high-speed activity

Comparison of HSA on an absolute basis demonstrates different characteristics between game and test values (see Table 17, p.125). HSA distance completed during the Hoff FET, YYIRL1, BST and in game, as measured by GPS were, 96.12 m (± 85.50), 826.68 m (± 304.73), 184.04 m (± 37.09) and 1167.41 m (± 387.76) respectively. A greater proportion of the TD was covered during HSR in the Hoff FET, and YYIRL1 compared to the game (90 %; 78 % vs. 52 %). Less distance was covered in LSS during the Hoff FET, and YYIRL1 compared to the game (9 %; 22 % vs. 24 %). The same pattern was evident in MSS activity >1 % vs. 14 %. HSS activity comprised 10 % of HSA in the game, but there was no activity in the Hoff FET or YYIRL1. Across the three tests, the BST test mirrored the HSA characteristics of the game the most closely.

There was a significant effect of condition on HSR distance after controlling for the effect of duration; $F(3, 166) = 149.278$, $p < 0.001$, $\eta = 0.73$. Estimated marginal means showed adjusted values; Hoff FET: 581.93 m; YYIRL1: 988.35 m; BST: 810.55 m; Game: -1426.50 m. Follow up tests revealed significant differences between conditions; Hoff FET > Game, $p = 0.001$, $d = 6.48$; YYIRL1 > Hoff FET, $p < 0.001$, $d = 3.11$; YYIRL1 > Game, $p < 0.001$, $d = 3.36$; BST > Hoff FET, $p < 0.001$, $d = 1.75$; BST > Game, $p < 0.001$, $d = -4.73$.

There was a significant effect of condition on LSS distance after controlling for the effect of duration; $F(3, 166) = 27.265$, $p < 0.001$, $\eta = 0.33$. Estimated marginal means showed adjusted values; Hoff FET: 433.30 m; YYIRL1: 482.29 m; BST: 695.60 m; Game: -1460.36 m. Follow up tests revealed significant differences between conditions; Hoff FET > Game, $p < 0.001$, $d = -10.34$; YYIRL1 > Hoff FET, $p < 0.001$, $d = 0.49$; YYIRL1 > Game, $p < 0.001$, $d = -9.84$; BST > Hoff FET, $p < 0.001$, $d = 2.64$; BST > YYIRL1, $p < 0.001$, $d = 2.45$; BST > Game, $p < 0.001$, $d = -7.69$.

There was a significant effect of condition on MSS distance after controlling for the effect of duration; $F(3, 166) = 9.204$, $p < 0.001$, $\eta = 0.14$. Estimated marginal means showed adjusted values; Hoff FET: -3.09 m; YYIRL1: 0.35 m; BST: 18.71 m; Game: 176.49 m. Follow up tests revealed no significant differences between conditions. Comparison of HSS was not possible because no distance was recorded during the Hoff FET or the YYIRL1.

YYIRL1 TD (1534 m ± 428) was correlated to in-game HSA $r = 0.43$, $p = 0.05$. The R^2 value is 0.18, meaning that the correlation value accounts for 18% of the variance. Hoff FET TD (1153 m ± 115) was correlated to in-game HSA $r = 0.06$, $p = 0.73$. The R^2 value is < 0.01, meaning that the correlation value accounts for < 1% of the variance.

Table 17: The high-speed activity (m) completed during each test condition and match-play. Mean (SD).

Test	HSR (15.1 to 18.0 km·hr^{-1})		LSS (18.1 to 21.0 km·hr^{-1})		MSS (21.1 to 24.0 km·hr^{-1})		HSS (>24.1 km·hr^{-1})	
	Dist. (SD)	%	Dist. (SD)	%	Dist. (SD)	%	Dist. (SD)	%
Hoff FET	87.00[a] (79.28)	90	8.77[f] (17.55)	9	0.35 (1.85)	> 1		
YYIRL1	638.36[b,c] (186.49)	78	182.08[g,h] (195.19)	22	2.07 (6.04)	> 1		
BST	85.12[d,e] (24.98)	46	73.34[i,j,k] (25.64)	40	23.73 (21.59)	13	1.85 (4.86)	1
Match-play	605.42 (216.01)	52	282.54 (115.49)	24	162.42 (92.27)	14	117.03 (90.67)	10

Sig: [a]: Hoff FET > Game, $p = 0.001$, $d = 6.48$; [b]: YYIRL1 > Hoff FET, $p < 0.001$, $d = 3.11$; [c]: YYIRL1 > Game, $p < 0.001$, $d = 3.36$; [d]: BST > Hoff FET, $p < 0.001$, $d = 1.75$; [e]: BST > Game, $p < 0.001$, $d = -4.73$; [f]: Hoff FET > Game, $p < 0.001$, $d = -10.34$; [g]: YYIRL1 > Hoff FET, $p < 0.001$, $d = 0.49$; [h]: YYIRL1 > Game, $p < 0.001$, $d = -9.84$; [i]: BST > Hoff FET, $p < 0.001$, $d = 2.64$; [j]: BST > YYIRL1, $p < 0.001$, $d = 2.45$; [k]: BST > Game, $p < 0.001$, $d = -7.69$.

4.3.4 Agreement between test performance and GPS distances

Mean YYIRL1 test performance (1534 m ± 428) and the GPS distance (1799 m ± 515) were strongly correlated ($r = 0.97$, $p < 0.001$). GPS distance demonstrated TE 117.50 m (CV 7.8 %). Mean Hoff FET test performance (1153 m ± 115) and GPS distance (1392 m ± 138), were strongly correlated ($r = 0.95$ $p < 0.001$) and GPS demonstrated TE 35.41 m (CV 2.9 %).

4.4 Discussion

This study intended to investigate the external load of three contemporary field tests in comparison the match play, with a focus on total PL, individual planar contributions and acceleration/deceleration activity. Secondary aims were to compare HSR, LSS, MSS and HSS during each condition. Key findings can be summarised as follows; there were no differences between either condition in total PL ($p = 0.46$, $\eta = 0.01$), AP load ($p = 0.80$, $\eta = 0.01$), ML load ($p = 0.46$, $\eta = 0.01$) or CC load ($p = 0.26$, $\eta = 0.26$). Differences in acceleration/deceleration activity were limited to zone 1 ($p < 0.001$, $\eta = 0.35$); Zone 3 ($p < 0.001$, $\eta = 0.24$); Hoff FET > BST, $p = 0.01$, $d = 1.35$; zone 5 ($p < 0.001$, $\eta = 0.80$, and zone 6 ($p < 0.001$, $\eta = 0.59$. Differences in HSA were limited to HSR ($p < 0.001$, $\eta = 0.73$) and LSS ($p < 0.001$, $\eta = 0.33$).

Advocates of the Hoff FET assert that it demonstrates strong ecological validity by replicating the motor actions of competition, specifically, accelerations/decelerations, jumping and changes in direction, unlike linear protocols (Chamari *et al.*, 2005; Hoff *et al.*, 2002; Kemi *et al.*, 2003; Zagatto *et al.*, 2015). It was interesting, therefore, that there were no differences in planar contributions to total PL after the effect of duration was controlled. That CC load contributed the greatest proportion to total PL was not unexpected, given the relationship with foot impact force (Boyd, Ball & Aughey, 2011; Scott *et al.*, 2013b; Wundersitz *et al.*, 2015a). Equally, each condition features, predominantly, forwards running and similarities in AP load are therefore not controversial. However, the lack of differences in ML load was unexpected, because the multi-directional construct of the Hoff FET was anticipated to evoke a greater ML load than the linear YYIRL1, but this was not the case.

Although total PL and planar PL were similar, the composition of accelerometer events on the AU scale was different between the tests and game data (see Table 14, p.120). Differences were mainly found between 1 - 3 AU, with the YYIRL1 and BST recording ~ 10 % more events in the 2 - 3 AU category, and it is suggested that these differences reflect the sharper directional changes, and associated rapid deceleration and re-acceleration (Millet, Candau, Faffori, Bignet & Varrav, 2003). In contrast, the higher proportion of 1-2 AU events in the Hoff FET may reflect a consistent running speed and lower magnitude acceleration/decelerations. While this discussion is speculative, practitioners would benefit from clarity about what type of event contributes to each category on the AU scale. When applied to an analysis of game data, it could help identify positional differences and inform training prescription.

The majority of acceleration/deceleration distance (~ 84 - 94%) was completed within ± 0 - 2 $m \cdot s^{-2}$ in the Hoff FET and YYIRL1, which is similar to the game valves reported here (~ 93 %) and elsewhere (Akenhead *et al.*, 2013). In contrast, the differences in BST are consistent with its construct; the proportion of decelerations in zone 1 (12.5 %) and accelerations in zone 5 (71 %) reflect the frequent braking and re-acceleration. Rapid decelerations before turning are crucial for COD speed (Hader, Palazzi & Buchheit, 2015; Hewitt, Cronin, Button & Hume, 2010) and imply that a proportion of performance on the BST is dependent on the ability to decelerate efficiently. That performance on a COD correlated with eccentric hamstring strength (r = 0.63) (Jones, Bampouras & Marrin, 2009) serves to confirm this critical role (Chaouachi *et al.*, 2012). In contrast, there was far less activity < - 2.00 m·s^{-2} in the Hoff FET, YYIRL1 and game profile (~ 5 %, 4.5 % and ~ 3.5 %) respectively. Nevertheless, performance in each test procedure is dependent on the capacity to withstand the fatiguing effect of repeated concentric and eccentric muscular contraction (Clarkson & Sayer, 1999; Howatson & Milak, 2009; Lakomy & Haydon, 2004).

Significant differences in HSA were limited to HSR and LSS, whereby each test condition involved greater distance compared to the game when the effect of duration was controlled. Correlation between the YYIRL1 and in game HSA (r = 0.43, p = 0.04) was lower than young soccer players (r = 0.73) (Castagna *et al.*, 2010), young males (r = 0.77) (Castagna *et al.*, 2009) and adult males (r = 0.71) (Krustrup *et al,* 2003; 2005). The reasons for the lower correlation in this study are unclear, but the absence of HSS activity in the YYIRL1 compared to the game is a possible explanation. The average YYIRL1 performance was 1543 m (± 428), corresponding to volitional exhaustion around 16.0 km·hr^{-1} (Krustrup *et al.*, 2003), meaning many participants failed to record distance over the LSS threshold (>18.1 km·hr^{-1}). However, whether players genuinely reached volitional exhaustion is unclear in the absence of HR data, but it is feasible that, on this occasion, YYIRL1 performance was not a reliable indicator of their capacity to complete repeated HSA.

The inferior performance on the YYIRL1 compared to other groups is mirrored by a lower proportion of HSA distance covered during competition. In this study, total in-game HSA distance (1167.41 m) comprised ~ 13% of TD (8872 m), which is similar to young soccer players (15 – 16 %), but inferior to top-class European professionals (22 – 25 %) (Bradley *et al.*, 2009; Mohr, Krustrup & Bangsbo, 2003; Rampinini *et al.*, 2007b) and moderate level professionals (18 %) (Mohr, Krustrup & Bangsbo, 2003). Differences in game performance could be competition related because higher standard sides are shown to complete more HSA than lower standard sides (Mohr, Krustrup & Bangsbo, 2003). Also, amongst professionals, positive score lines were found to reduce HSA because there was no requirement to chase the ball (Lago *et al.*, 2010; Lago & Martin, 2007). The academy teams analysed are amongst the strongest in the region, and of the fixtures analysed, only one resulted in a loss, so it is feasible that the data reported does not represent the full physical potential of the players.

When interpreting the results obtained in this study, consideration is given to the limitations of the technology employed. Literature is unequivocal that high speed multi-directional activity limits the reliability of 5 Hz GPS when measuring distance (Jennings *et al.*, 2010b; Varley, Fairweather & Aughey, 2012; Vickery *et al.*, 2014). During a sport specific simulation course involving 45^{o}, 90^{o} and 180^{o} turns, the error of distance measurement was CV 3.71 - 3.78 %, 4.02 - 5.93 % and 5.33 - 6.11 % respectively (Portas *et al.*, 2010). In the present study, YYIRL1 test performance (1534 m ± 428) and the GPS distance (1799 m ± 515) were strongly correlated ($r = 0.97$, $p < 0.001$). GPS distance demonstrated TE 117.50 m (CV 7.8 %) which is higher than Portas *et al.* (2010), but these trials were conducted at 12.8 $km{\cdot}hr^{-1}$, whereas the YYIRL1 begins at 10 $km{\cdot}hr^{-1}$ and the majority of the test is performed > 13 $km{\cdot}hr^{-1}$ (Krustrup *et al.*, 2003). In addition, YYIRL1 test performance represents the cumulative 2x20 m distance (Bangsbo, 1996) whereas the edited GPS files represented distance throughout the entire procedure, and, therefore, included the 10 m rest interval at the end of each bout.

In contrast, average Hoff FET distance (1153 m ± 115) and GPS distance (1392 m ± 138), were strongly correlated (r = 0.95 $p < 0.001$) and GPS demonstrated TE 35.41 m (CV 2.9 %), which is slightly less than Portas *et al.* (2010). As discussed previously, alterations in body orientation during directional changes contribute to reliability issues (Barrett *et al.*, 2016b; Keller *et al.*, 1996; Tran *et al.*, 2010). Also, poor technical ability would negatively impact Hoff FET performance because players may spend time retrieving the ball, which would also accrue additional GPS distance. Finally, it is also noteworthy that Hoff FET distance was measured using a trundle wheel, which is susceptible to measurement error created by deviation from the marked course.

During competition, fatigue is shown to alter running mechanics by altering hip extension and knee flexion causing an increase in stride frequency (Small, McNaughton, Greig, Lohkamp & Lovell, 2008). This effect was suggested to explain the increase in total PL observed at the end of each playing half despite a reduction in activity (Barrett *et al.*, 2016a). Each of the procedures investigated in this study were maximal tests, and whether altered running mechanics contributed to the PL profiles is unclear. However, this seems unlikely because while there is a requirement to continue performing during competition when fatigued, test performance is limited by volitional exhaustion. It is also unlikely that participants reached the level of fatigue required to elicit the changes in running mechanics described above.

Finally, the BST incorporates seven repetitions. This number of trials has been used previously in soccer (Chaouachi *et al.* 2010; Wragg, Maxwell & Doust, 2000) and suggested to be appropriate for inducing fatigue while avoiding pacing (Chaouachi *et al.*, 2010). However, prior knowledge of the number of trials is associated with pacing during

RSA field tests (Billaut, Bishop. Schaerz & Noakes, 2011), which may have affected performance. In addition to encouraging a maximum effort in each repetition, participants in this study were also told that the sum of their repetitions would be their performance measure. Inadvertently, this may also have led some participants to regulate their efforts to avoid a decline in performance (Billaut *et al.*, 2011).

4.5 Summary

Differences in total PL, and tri-axial PL, between three field tests and competition, were minimal. Despite satisfying logical validity the multi-directional Hoff FET evoked a comparable tri-axial load to the YYIRL1, dispelling some of the criticisms leveled at linear shuttle running formats, and questioning the need for increasingly complex testing formats. Acceleration/deceleration activity within each test highlights that performance is reliant on the capacity to withstand repeated bouts and represents a large proportion of test activity.

4.6 Perspective

The evidence presented in this study reveals that HSA does not present as large a proportion of in-game TD, compared to other populations. This might be indicative of the competition tier or standard of competition within the tier, but, it questions whether HSA is as important at the sub-elite level. In comparison, the data reported in Chapter 3 demonstrated that acceleration underpins performance and, consequently, the capacity to accelerate repeatedly might be a more relevant focus for training and assessment.

Emergent research during the course of this thesis highlighted that the physical demands of soccer have evolved. Previously, superior HSR was widely reported amongst higher tiered sides (Andersson *et al.*, 2010; Bangsbo Nørregaard, & Thorsø, 1991; Ingebrigtsen *et al.*, 2012; Mohr, Krustrup & Bansgbo, 2003; Mohr *et al.*, 2008) presenting a high priority for training and testing. However, more recently, second and third tiered English sides completed more HSR than Premier League counterparts across a full season (Bradley, Carling, Gomez, Antonio, Barnes, Ade, Boddy, Krustrup & Mohr, 2013a). Similarly, position-specific changes in physical and technical performance in the English Premier League, point towards an evolution in the rigours of competition imposed by the modern strategic and tactical approach to competition (Bush *et al.*, 2015b).

In recent years professionals have become quicker (Haugen, Tønnessen & Seiler, 2013) and modern soccer is characterised by an increased number of sprints of shorter bout distance (Barnes *et al.*, 2014; Bush *et al.*, 2015b). Maximum accelerations occur at low velocity, and, are more frequent than maximum sprints, (Varley & Aughey, 2013) emphasising the integral role of acceleration during competition (Arruda, Carling, Zanetti, Aoki, Coutts & Moreira, 2015; Castellano & Casmichana, 2013). Importantly, acceleration and maximum sprinting speed, are separate qualities, based on their correlation (r = 0.56 - 0.87) (Buchheit, Glynn, Michael, Al Haddad, Mendez-Villanueva, Samozino & Morin, 2014; Little & Williams; Mendez-Villanueva, Buchheit, Kuitunen, Douglas, Peltola & Bourdon, 2011). Acceleration is determined by concentric force production (Dorn, Schache & Pandy, 2012), whereas maximum speed is related to the lower-limb stiffness, the stretch-shortening cycle and hip extension (Buchheit *et al.*, 2014b). Finally, the higher energetic cost of accelerating compared to steady state movement (di Prampero *et al.*, 2005) provides support for quantifying acceleration activity during competition. Although, current research reports the number of discreet acceleration efforts (Castellano & Casamichana, 2013; Bradley *et al.*, 2010; Dalen *et al.*, 2016; Ingebrigtsen *et al.*, 2015) and/or total acceleration distance during competition (Akenhead *et al.*, 2013; Dalen *et al.*, 2016), whether repeated bouts of acceleration feature during competition is unclear.

Chapter 5: Repeated acceleration profiles in soccer match-play

5.1 Introduction

Acceleration is integral within soccer and predicates athletic performance (Akenhead *et al.*, 2013; Ingebrigtsen *et al.*, 2015) and Chapter 3 adds to the growing body of knowledge by profiling the positional activity during competition. Recently, literature has reported that bouts of acceleration are increasingly frequent during competition (Barnes *et al.*, 2014; Bush *et al.*, 2015b) and is concurrent with an apparent decline in the importance of HSR. Previously superior HSR distance was reported amongst higher playing standards (Andersson *et al.*, 2010; Bangsbo Nørregaard, & Thorsø, 1991; Ingebrigtsen *et al.*, 2012; Mohr, Krustrup & Bangsbo, 2003; Mohr *et al.*, 2008) presenting a higher priority for training and testing. However, recently second and third tiered English sides completed more HSR than Premier League peers (Bradley *et al.*, 2013a) across a full season in direct contrast to previous research. It is difficult to explain this observation definitively because physical performance is subject to influence from a myriad of factors, including competitiveness (Rampinini *et al.*, 2009a), playing formation (Bradley *et al.*, 2011) and ball possession (Bradley *et al.*, 2013b). However, it is plausible that the move to compact formations, for example 4-2-3-1 and 4-1-4-1 (Bush *et al.*, 2015a; Wallace & Norton, 2014), and a higher priority on ball retention (Collet, 2013; Vogelbein, Nopp & Hökelmann, 2013) have facilitated a greater reliance on acceleration.

Research is unequivocal that maximal accelerations are more frequent than maximal sprints, and are completed at low velocities (Varley & Aughey, 2013), and they underpin performance (Arruda *et al.*, 2015; Castellano & Casmichana, 2013). Further, superior acceleration may present a competitive advantage, particularly in goal scoring situations (Davis, Brewer & Atkin, 1992; Faude, Koch & Meyer, 2012; Little & Williams, 2005; Lockie, Murphy, Knight & Janse de Jonge, 2011). Subsequently, any impairment in acceleration capacity would negatively affect a player's work rate affording competitive advantage to an opponent. Of concern to practitioners are the time dependent reductions in acceleration activity reported in the second half, both in Chapter 3, and in literature (Akenhead *et al*., 2013; Ingebrigtsen *et al*., 2015; Russell *et al*., 2016), and the temporary impairments in acceleration activity following the most intense period of match-play (Akenhead *et al*., 2013).

Reflecting on the above findings, the bias towards HSR both regarding conditioning and fitness assessment is somewhat contentious. On the basis of recent evidence the capacity to accelerate repeatedly during a game is crucial and evidence shows that acceleration activity declines during periods of fixture congestion (Arruda *et al*., 2015), despite no decline in HSR (Dellal, Lago-Peñas, Rey, Chamaria & Orhant, 2015; Djaoui, Wong, Pialoux, Hantier, Da Silva, Chamari & Dellal, 2014; Lago-Peñas *et al*., 2012; Rey *et al*., 2010). Accordingly, the focus should be on the capacity to accelerate repeatedly and this may be a more sensitive measure of physical performance (Arruda *et al*., 2015), but an investigation of activity during competition is lacking from literature.

To date, research into the acceleration activity in soccer has reported distance and frequency metrics without examining periods of repeated activity. Akenhead *et al*. (2013) examined the temporal patterns of acceleration during 18, 5 minute periods and defined peak activity in relation to the mean. Although insightful, TD was reported rather than the number of bouts and rest intervals. This provides convincing evidence of the impact of transient fatigue following elevated periods of activity and emphasises that this is an important physical component.

Repeated acceleration activity (RAA) was defined by Barberó-Álvarez, Boullosa, Naknamura, Andrín, & Weston (2014) as, as three consecutive accelerations (> 1.5 m•s^{-2}) interspersed with a maximum of 45 s. In the only study to date of referees and assistant referees, RAA distance constituted ~37 % and ~20 % respectively of total acceleration distance representing a sizeable proportion. Field referees completed 7 (± 3.9) RAA bouts across the game, and the mean number of accelerations per bout was 3.9 (± 1.5). The capacity to recover from repeated bouts is, therefore, an important element of performance for referees and allied with an absence of RSA during matches (Barberó-Álvarez *et al.*, 2014), presents a valid focus for referees' training programmes. Given the high prevalence of acceleration activity during match-play amongst outfield players, it is feasible that RAA is also an important component. Evidence of RAA, would support the inclusion of repeated acceleration training in conditioning programmes and highlights the need to evaluate an individual's capacity to complete this work.

The primary aim of this study was, therefore, to investigate positional RAA during competitive sub-elite youth competition. Secondary aims were to investigate the variability in RAA performance and differences in activity between playing halves. Hypothesis 3: The repeated acceleration activity during competitive sub-elite youth soccer will demonstrate positional differences.

5.2 Methodology

5.2.1 Participants

Sixty one well trained sub–elite youth soccer players (17.3 ± 0.9 yrs., 176.93 ± 4.31 cm, 63.96 ± 4.76 kg) volunteered for the study, and were classified by playing position (WD = 13, CD = 17, CMF = 11, WMF = 10, FW = 10). All participants were training in a high performance environment involving four, two hour field based sessions, two, sixty minute supervised strength and conditioning sessions and up to two competitive games per week. Players or parents/guardians provided informed consent where appropriate in accordance with the procedures outlines in the declaration of Helsinki. The experimental procedure was approved by the BuSH committee at the University of Central Lancashire.

5.2.2 Procedures

Fourteen home English College fixtures were monitored during the competitive phase of the 2014-2015 season. All games were played on a full sized synthetic 3G surface, a 4-2-3-1 formation was preferred and only players completing 90 minutes, in the same playing position, were included. Consequently, this produced uneven group numbers given the tendency for WD, WMF, and FW to be substituted more often. There were also periods of limited GPS unit availability and, therefore, WMF and FW were prioritised for data collection. Game activity was limited to 90 minutes and excluded additional time at the end of each playing half.

Portable GPS units (Catapult Sports, Minimax, 5 Hz) equipped with 100 Hz accelerometer were worn by players and located securely between the scapulae in a custom made harness. GPS units were switched on 10 minutes before use to allow satellite locking consistent with manufacturer's guidance. Horizontal dilution of precision (HDOP) indicated the accuracy of GPS in a horizontal plane (Catapult Sports) and optimum satellite availability (HDOP = 0) is where one satellite is directly overhead with a minimum of four spaced equally around the horizon. During these trials, HDOP ranged 0.8-1.6, which is a good signal.

The original definition of RAA (Barberó-Álvarez *et al.*, 2014) was adopted in order to facilitate comparison, but, also expanded to investigate RAA using thresholds of >1.0 $m \cdot s^{-2}$, > 2.0 $m \cdot s^{-2}$ and > 3.0 $m \cdot s^{-2}$.

5.2.3 Statistical analysis

Data was uploaded to Catapult Sprint software (version 5.1) and files were filtered to exclude non–game activity. All data were tested for normality using a Shapiro-Wilk's test, and Levene's test established homogeneity. Data are presented as Mean ± SD unless otherwise stated.

For normally distributed data, a one-way ANOVA was used to detect the main differences between playing positions. All significant main effects were investigated with a Bonferroni post hoc test, chosen to minimise the chance of a Type 1 error (Hopkins, 2000b). Eta^2 (η) determined the magnitude of the main effect; it was calculated using the formula; Sum of $Squares_{Effect}$ / Sum of $Squares_{Total}$ (Field, 2013) and interpreted using the scale 0.10 small; 0.30 medium and 0.50 large (Cohen, 1988). Cohen's *d* determined the magnitude of effect for pairwise comparisons, and was calculated using the formula; Mean group 1 - Mean group 2 / (SQRT mean squared error). It was interpreted using the scale outlined by Batterham & Hopkins (2006): trivial (< 0.2), small (> 0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0) or very large (>2.0-4.0).

For data violating the assumption of normality, a Kruskal-Wallis test was used to detect the main differences between playing positions. Effect size (ES) was calculated using the formula; r = Test statistic / (SQRT n), where n = the number of participants (Field, 2013).

Effect size was interpreted using the scale 0.10 small; 0.30 medium and 0.50 large (Cohen, 1988).

A paired T-Test established significant differences between playing halves for all variables. Cohens's *d* determined the magnitude of the effect and was calculated as above and interpreted using the scale outlined by Batterham & Hopkins (2006). Variability in performance was presented as CV %, calculated by (SD/mean) * 100. All statistical procedures were completed using SPSS 20.0 (SPSS Inc, Chicago, USA).

5.3 Results

5.3.1 RAA activity (> 1.0 m·s^{-2})

Across all positions, the mean total RAA bouts were 24.24 (± 5.23) and there was no significant main effect for playing position; F (4, 60) = 0.980, p = 0.43, η = 0.06. The mean number of efforts per RAA bout was 5.29 (± 0.90), there was no significant main effect for playing position; *H* (4, 61) = 6.551, p = 0.47, *r* = 0.45. The mean effort duration was 0.61 s (± 0.05), there was no significant main effect for playing position; *H* (4, 61) = 1.749, p = 0.78, *r* = 0.22. The mean recovery between efforts was 17.02 s (± 1.65) and there was a significant main effect of playing position; F (4, 60) = 3.042, p = 0.02, η = 0.18, although follow up tests revealed no positional differences. The mean recovery between bouts was 217.34 s (± 106.22) and there was no main effect of playing position; H (4, 61) = 7.367, p = 0.12, *r* = 0.94 (see Table 18, p.144).

On average, there were significantly more RAA bouts in the first half compared to the second (11.05 ± 2.81 vs. 9.95 ± 3.18); t (60) = 2.221, p = 0.03, *d* = 1.56. The mean number of efforts per bout were similar between playing halves (5.32 ± 1.34 vs. 5.26 ±

1.32), and were not significantly different; t (60) = 0.327, p = 0.75, *d* = 0.15. The mean duration of efforts showed no significant difference between playing halves (0.66 s ± 0.63 vs. 0.60 ± 0.07); t (60) = 0.702, p = 0.49, *d* = 0.20. The mean duration of recovery between efforts was not significantly different between playing halves (17.39 s ± 2.22 vs. 17.19 s ± 2.48); t (60) = 0.501, p = 0.62, *d* = 0.32. The mean recovery between RAA bouts was not significantly different between playing halves (169.86 s ± 70.92 vs. 189.19 ± 85.62); t (60) = -1.483, p = 0.14, *d* = -5.35.

5.3.2 RAA activity (> 1.5 $m{\cdot}s^{-2}$)

Across all positions, the mean for total RAA bouts was 7.09 (± 4.70). There was a significant main effect for playing position; F (4, 61) = 3.12, p = 0.02, η = 0.18, and post hoc testing revealed no significant positional differences. WMF vs. CD was approaching significance (p = 0.06, *d* = 0.88). The average number of efforts per RAA bout was 3.58 (± 0.81) and there was no effect of playing position; F (4, 61) = 1.09, p = 0.37, η = 0.07. The average recovery between efforts was 18.64 s (± 4.81 s) and there was no effect of playing position; F (4, 61) = 0.80, p = 0.53, η = 0.05. The average recovery per bout was 476.82 s (± 321.85 s), and there was no effect of playing position; F (4, 61) = 0.52, p = 0.72, η = 0.04. Average recovery per bout was 476.82 s (± 321.85) and there was not significant effect of playing position; F (4, 61) = 0.518, p = 0.72, η = 0.03 (see Table 18, p.144).

The mean number of RAA bouts per half was not significantly different (1.27 ± 1.20 vs. 1.16 ± 1.72); t (60) = 0.209, p 0.23, *d* = 0.23. The mean number of efforts per bout were similar between playing halves (2.52 ± 1.85 vs. 2.40 ± 1.97), and were not significantly different; t (60) = 0.413 p = 0.49, *d* = 0.91. The mean duration of efforts showed no significant difference between playing halves (0.37 s ± 0.26 vs. 0.33 s ± 0.26); t (60) = -0.06, p = 0.09, *d* = 0.24. The mean duration of recovery between efforts was not significantly different between playing halves (13.21 s ± 10.93 vs. 12.22 s ± 10.90); t (60) = -0.419, p = 0.33, *d* = 0.86. The mean recovery between RAA bouts was not significantly different between playing halves (87.46 s ± 140.16 vs. 42.08 ± 98.02); t (60) = -0.495, p = < 0.05, *d* = 5.34.

5.3.3 RAA activity (> 2.0 $m \cdot s^{-2}$)

Across all positions, the mean total for RAA bouts was 1.82 (± 2.00) and there was no significant main effect for playing position; *H* (4, 61) = 8.016, p = 0.09, ES = 1.02. The mean number of efforts per bout was 2.29 (± 1.72) and there was a significant main effect of playing position; *H* (4, 61) = 9.579, p = 0.04, ES = 1.23, although post hoc testing revealed no positional differences. The average duration of efforts was 0.33 s (± 0.52) and there was no significant main effect of playing position; *H* (4, 61) = 8.533, p = 0.07, ES = 1.09. The mean recovery between efforts was 13.56 s (± 10.76) and there was no significant main effect of playing position; *H* (4, 61) = 8.558, p = 0.07, ES = 1.09. The mean recovery between bouts was 728.23 s (± 1079.80) and there was no significant main effect of playing position; *H* (4, 61) = 4.077, p = 0.39, ES = 0.53.

The mean number of RAA bouts playing halves was not significantly different (0.62 ± 0.92 vs. 0.65 ± 0.97); t (60) = -0.231, p = 0.82, *d* = 0.09. The mean number of efforts per bout were not significantly different between playing halves (1.38 ± 1.75 vs. 1.39 ± 1.76); t (60) = -0.030, p = 0.98, *d* = -0.01. The mean duration of efforts was not significantly different between playing halves (0.29 s ± 0.64 vs. 0.21 s ± 0.27); t (60) = 1.032, p = 0.31, *d* = 0.31. The mean duration of recovery between efforts was not significantly different between playing halves (7.55 s ± 10.68 vs. 10.08 s ± 17.23); t (60) = -1.149, p = 0.26, *d* = -1.71. The mean duration of recovery between RAA bout was not significantly different between playing halves (135.45 s ± 341.31 vs. 175.00 ± 429.30); t (60) = -8.13, p = 0.42, *d* = -5.67 (see Table 18, p.144).

5.3.4 RAA activity (> 3.0 $m \cdot s^{-2}$)

Across all positions, the mean total for RAA bouts was 0.08 (± 0.42) and there was no significant main effect for playing position; *H* (4, 61) = 2.554, p = 0.63, ES = 0.33. The mean number of efforts per bout was 0.15 (± 0.65) and there was a significant main effect of playing position; *H* (4, 61) = 2.530, p = 0.63, ES = 0.32, although post hoc testing revealed no positional differences. The average duration of efforts was 0.02 s (± 0.10) and there was no significant main effect of playing position; *H* (4, 61) = 2.510, p = 0.64, ES = 0.32. The mean recovery between efforts was 0.99 s (± 4.86) and there was no significant main effect of playing position; *H* (4, 61) = 2.513, p = 0.64, ES = 0.32. The mean recovery between bouts was 0.99 s (± 4.85) a lack of data meant it was not possible to complete inferential analysis (see Table 15, p.144).

Given the very low incidence of RAA bouts within this category, differences between playing halves were not examined.

Table 18: The RAA for all playing positions. Mean (SD).

	RAA bouts			Efforts per bout		Effort duration (s)		Recovery per effort (s)		Recovery per bout (s)	
	Mean (SD)	CV (%)	95 % CI	Mean (SD)	95 % CI	Mean (SD)	95 % CI	Mean (SD)	95 % CI	Mean (SD)	95 % CI
	RAA threshold: > 1.0 m·s^{-2}										
WD	27.79 (2.49)	9.12	25.26 - 28.27	5.38 (0.75)	4.93 - 5.83	0.61 (0.03)	0.59 - 0.62	16.45 (1.21)	15.72 - 17.18	168.92 16.17)	159.15 - 178.69
CD	23.70 (6.19)	26.11	20.52 - 26.89	5.00 (0.67)	4.66 - 5.34	0.60 (0.06)	0.57 - 0.63	17.64 (1.83)	16.70 - 18.58	247.43 (169.33)	160.37 - 334.49
CMF	23.18 (6.88)	29.70	18.55 - 27.80	5.30 (0.87)	4.71 - 5.89	0.60 (0.00)	0.60 - 0.60	17.95 (1.92)	16.66 - 19.24	236.28 (82.52)	180.85 - 291.72
WMF	23.60 (4.69)	19.90	20.24 - 26.96	5.78 (1.48)	4.72 - 6.83	0.63 (0.07)	0.58 - 0.67	16.44 (1.05)	15.69 - 17.19	204.55 (75.05)	150.86 - 258.25
FW	23.70 (4.39)	18.50	20.55 - 26.84	5.18 (0.65)	4.71 - 5.65)	0.61 (0.05)	0.59 - 0.62	16.29 (1.33)	15.33 - 17.23	221.09 (70.40)	170.73 - 271.45
All positions	24.24 (5.23)	21.60	22.90 - 25.59	5.29 (0.90)	5.06 - 5.52	0.61 (0.05)	0.60 - 0.62	17.02 (1.65)	16.59 - 17.44	217.34 (106.22)	190.14 - 244.54
	RAA threshold: > 1.5 m·s^{-2}										
WD	9.15 (3.71)	40.55	6.90 – 11.39	3.78 (0.50)	3.47 - 4.08	0.55 (0.60)	0.50 – 0.59	19.75 (2.63)	18.16 – 21.35	477.09 (353.72)	263.34 – 690.84
CD	5.56 (3.32)	59.71	3.89 – 7.21	3.52 (0.98)	3.03 - 4.01	0.49 (0.14)	0.43 – 0.56	19.23 (5.85)	16.32 – 22.15	515.34 (394.45)	319.19 – 711.50
CMF	5.46 (3.86)	70.70	2.86 – 8.04	3.16 (1.09)	2.42 - 3.90	0.47 (0.16)	0.36 – 0.58	18.58 (6.97)	13.90 – 23.26	418.71 (323.55)	201.35 – 636.07
WMF	10.50 (7.16)	68.20	5.37 – 15.63	3.68 (0.54)	3.29 - 2.42	0.54 (0.07)	0.49 – 0.59	18.48 (2.01)	17.03 – 19.92	385.15 (184.37)	253.26 – 517.04
FW	6.80 (3.94)	57.94	3.98 – 9.61	3.75 (0.95)	3.33 - 4.18	0.50 (0.07)	0.45 – 0.55	16.35 (4.01)	13.47 – 19.22	562.74 (257.78)	253.26 – 517.04
All positions	7.29 (4.70)	64.47	6.09 – 8.48	3.58 (0.81)	3.36 - 3.78	0.51 (0.11)	0.48 – 0.54	18.64 (4.80)	17.42 – 19.86	476.82 (321.85)	395.08 – 558.56
	RAA threshold: > 2.0 m·s^{-2}										
WD	2.84 (2.44)	85.92	1.37 - 4.33	3.10 (1.04)	2.47 - 3.72	0.46 (0.15)	0.37 - 0.55	19.28 (7.82)	14.56 - 24.00	725.98 (902.97)	179.65 - 1270.98
CD	1.00 (1.73)	173.00	0.11 - 1.89	1.19 (1.67)	0.33 - 2.05	0.18 (0.26)	0.05 - 0.32	7.14 (10.23)	1.87 - 12.40	340.08 (590.59)	36.42 - 643.74
CMF	1.63 (1.50)	92.02	0.63 - 2.65	2.20 (1.80)	0.98 - 3.41	0.30 (0.25)	0.14 - 0.48	15.00 (12.16)	6.84 - 23.18	1123.99 (1214.13)	308.33 - 1939.65
WMF	2.10 (2.37)	112.86	0.39 - 3.80	2.50 (1.78)	1.23 - 3.77	0.32 (0.27)	0.12 - 0.50	14.90 (10.80)	7.18 - 22.62	434.45 (596.17)	7.98 - 860.82
FW	1.80 (1.55)	86.11	0.69 - 2.91	2.95 (1.60)	1.80 - 4.09	0.42 (0.25)	0.24 - 0.59	14.05 (9.66)	7.14 - 20.96	1250.32 (1788.25)	- 0.28 - 2529.56
All positions	1.82 (2.00)	109.89	1.30 - 2.33	2.29 (1.72)	1.85 - 2.72	0.33 (0.52)	0.26 - 0.39	13.56 (10.76)	10.79 - 16.30	728.23 (1079.80)	451.68 - 1004.78
	RAA threshold: > 3.0 m·s^{-2}										
WD	0.07 (0.28)	400.00	-0.09 - 0.24	0.23 (0.83)	-0.27 - 0.74	0.04 (0.14)	- 0.45 - 0.12	2.54 (9.15)	- 2.99 - 8.06	2.53 (9.15)	- 2.99 - 8.06
CD	0.00 (0.00)	N/A	0.00 - 0.00	0.00 (0.00)	0.00 - 0.00	0.00 (0.00)	0.00 - 0.00	0.00 (0.00)	0.00 - 0.00	0.00 (0.00)	0.00 - 0.00
CMF	0.09 (0.30)	333.33	-0.12 - 0.29	0.27 (0.90)	-0.33 - 0.88	0.05 (0.15)	- 0.06 - 0.15	1.20 (3.97)	- 1.47 - 3.87	1.20 (3.97)	- 1.47 - 3.87
WMF	0.30 (0.95)	316.67	-0.38 - 0.98	0.30 (0.95)	-0.38 - 0.97	0.04 (0.13)	- 0.05 - 0.13	1.46 (4.62)	- 1.84 - 4.77	1.46 (4.61)	- 1.84 - 4.77
FW	0.00 (0.00)	N/A	0.00 - 0.00	0.00 (0.00)	0.00 - 0.00	0.00 (0.00)	0.00 - 0.00	0.00 (0.00)	0.00 - 0.00	0.00 (0.00)	0.00 - 0.00
All positions	0.08 (0.42)	525.00	-0.03 - 0.19	0.15 (0.65)	-0.20 - 0.32	0.02 (0.10)	- 0.03 - 0.05	0.99 (4.86)	- 0.25 - 2.24	0.99 (4.85)	- 0.254 - 2.24

5.4 Discussion

The current study is the first to profile RAA during competition and findings demonstrate that bouts frequently occur during youth soccer. Wide players tended to complete the most RAA bouts, and the most efforts per bout on average, however, the lack of significant differences suggest RAA is a generic feature of competition, and, it may be an important physical component to develop at this level.

The uneven distribution of workload during competition (Carling & Dupont, 2011; Impellizzeri *et al.*, 2008; Withers *et al.*, 1982) has led to a focus on repeated sprint activity, yet the absence of evidence reported in Chapter 3 and elsewhere (Carling, Le Gall & Dupont, 2012; Gabbett & Mulvey, 2008; Gabbett, Wiig & Spencer, 2013; Schimpchen *et al.*, 2016), suggests RAA could be a more appropriate focus for analysis. While RSA is a valid modality for developing game related fitness (Taylor, Macpherson, Spears & Weston, 2016), it is not recommended as a valid method of assessing fitness or physical performance (Taylor, Macpherson, Spears & Weston, 2016).

The lack of RAA studies makes comparison impossible, but the RAA > 1.5 $m \cdot s^{-2}$ data reported here is similar to elite referees (Barberó-Álvarez *et al.*, 2014), who completed 7.0 (± 3.9) bouts, and 3.9 (± 1.5) efforts per bout. Given the varied roles of referees and players, any direct comparison is tentative, yet, it appears RAA might be worth developing for both groups. Unlike Barberó-Álvarez *et al.* (2014) this study analysed RAA across a range of acceleration thresholds (> 1.0 $m \cdot s^{-2}$ to > 3.0 $m \cdot s^{-2}$), and the mean number of RAA bouts decreased as the rate of acceleration increased (see Table 18, p.144). Although no significant differences were found between playing positions in the number of RAA bouts, wide players tended to complete more bouts, and moderate effect sizes suggest meaningful differences. Similarly, 95 % CI data highlights that wide players complete more bouts of RAA than suggested by the mean. These profiles are consistent with the positional differences reported in chapter 3, and literature reporting greater sprint and acceleration activity amongst wide players compared to central positions (Bradley *et al.*, 2009; Di Salvo *et al.*, 2009; Ingebrigtsen *et al.*, 2015; Varley & Aughey, 2013).

Interestingly, at the professional level the tendency towards compact playing formations (4-2-3-1, 4-1-4-1), and, the tactical requirement for WMF to occupy more central positions (Bush *et al.*, 2015a) to promote compactness, increases player density in central areas (Wallace & Norton, 2014). Given the commonality in playing formation between this study and the aforementioned, central players within this study could have been expected to complete more RAA in order to navigate congested areas effectively, but this was not the case. Rather, wide players completed more RAA, and this may be associated with their combined offensive and defensive roles. At the professional level, WD and WMF are required to press forwards to participate in offensive play, and then track back when possession is lost, (Bush *et al.*, 2015a; Di Salvo *et al.*, 2007).

Further insight into the frequency of RAA is provided by examining the recovery periods. In each category of RAA, there were no significant positional differences in the duration of recovery between efforts or bouts. However, analysis of consecutive sprints amongst professionals highlights that recovery is significantly influenced by playing position (Carling, Le Gall & Dupont, 2012; Schimpchen *et al.*, 2016). Recovery between efforts for RAA > 1.0 $m{\cdot}s^{-2}$ and 1.5 $m{\cdot}s^{-2}$ was 17.02 s (± 1.65) and 18.64 s (± 4.80) respectively, which is longer than the mean interval between 3, 4 and 5 consecutive sprints in a single bout of RSA during international football (8.1 s ± 7.6; 6.1 s ± 5.4; 3.2 s ± 3.1)

(Schimpchen *et al.*, 2016). In contrast, recovery times between efforts for RAA > 2.0 m·s^{-2} was shortest (13.56 s ± 10.76) but disproportionally affected by a single bout of RAA completed by a CD. Recovery between bouts for RAA > 1.0 m·s^{-2} and > 1.5 m·s^{-2} was also shorter than the average for RSA amongst internationals (217.34 s ± 106.22; 476.82 s ± 321.85) vs. 2743.3 s ± 287.4) (Schimpchen *et al.*, 2016).

Examining the consistency in physical performance is important to evaluate the impact of training interventions (Bush *et al.*, 2015a). Understanding the natural variation in game to game performance can also be used to identify a decline in physical work attributable to factors other than contextual. The between match variation in RAA (1.0 – 1.5 m·s^{-2}) was CV ~ 22 – 65 %, which is greater than the CV 14.4 – 24.8 % reported for high speed running (> 19.8 km·hr^{-1}) (Bush *et al.*, 2015a; Carling, Bradley, McCall & Dupont, 2016; Rampinini *et al.*, 2007b; Mohr *et al.*, 2003). Higher variation is found for sprint activity compared to HSR (CV 22.6 – 32.3 %) (Bush *et al.*, 2015a) which is similar to the variability in RAA > 1.0 m·s^{-2} (CV 21.60 %) but less than > 1.5 m·s^{-2} (CV 64.47 %). High levels of variability within a physical performance measure may question the appropriateness for evaluating work rate (Carling *et al.*, 2016), casting doubt on the usefulness of RAA. But, the impact of contextual factors should be considered. Perhaps the greatest influence on work rate this level is the standard of opposition, which can be markedly inconsistent leading to a varied physical work rate between games. Although not analysed in this study, against stronger opposition CD exhibited lower CV for HSR compared to a similar, or weaker, standard opponent, whereas WMF produced lower variation against weaker opponents (Bush *et al.*, 2015a).

The trend for central players to exhibit greater variability in high speed running and sprinting (Bush *et al.*, 2015a; Carling *et al.*, 2016; Gregson *et al.*, 2010), is similar to variation in RAA reported here; RAA (> 1.0 m·s^{-2}) central players: CV 18.50 – 29.70 %; wide players: CV 9.12 – 19.90 %; RAA (> 1.5 m·s^{-2}) central players: CV 40.55 – 68.20 %; wide players: 57.94 – 72.53 %. Given the consistency in game venue, playing surface, playing formation, tactics, and strategy, the high variation in RAA is perhaps surprising. Also, the broader tactical role of wide players could have been expected to lead to greater variation in RAA performance, but this was not the case. Rather, greater variability amongst central players is suggested to reflect higher player density in central areas (Bush *et al.*, 2015a) and suggests that central players are more sensitive to the tactical and strategic decisions during competition (Gregson *et al.*, 2010). However, this might also be reflective of the varied roles of central midfielders in the modern game. In recent years several sub-categories have been defined, including holding midfielders, man-markers, box-box midfielders and playmakers, and these varied roles would evoke different physical work profiles as a consequence of the tactical restrictions imposed, but were not separated in this study.

After collapsing data, only the greater number of RAA bouts > 1.0 m·s^{-2} in the first half reached statistical significance (p = 0.03, *d* = 1.56). The lack of differences between playing halves seems at odds with the reduction of acceleration activity (0.0 – 4.0 m·s^{-2}) reported in chapter 3. Reductions in the number and distance of accelerations are widely reported, and it is interesting that RAA did not show a similar decline (Dalen *et al.*, 2016; Ingebrigtsen *et al.*, 2015; Russell *et al.*, 2016). On reflection, analysis of 45 minute periods may not illustrate the fluctuation in work rate throughout the half and be insensitive to the reduction in activity following an intense period (Akenhead *et al.*, 2013). Temporal reductions in activity could be supposed to impact on an individual's functional role by negatively affecting their ability to react to the changing configurations of competition (Gréhaigne, Bouthier & Godbout, 1999; Folgado, Fernandes, Duarte & Sampaio, 2014). Future research could explore the temporal characteristics of RAA, and, the interaction with the technical and tactical elements of competition.

Despite the lack of statistical significance, moderate and large effect sizes suggest meaningful differences in the duration of recovery intervals, at > 1.5 $m \cdot s^{-2}$ (13.21 s ± 10.93 vs. 12.22 s ± 10.90, $d = 0.86$) and > 2.0 $m \cdot s^{-2}$ (7.55 s ± 10.68 vs. 10.08 s ± 17.23, $d = -1.71$), and, recovery between RAA bouts at > 1.0 $m \cdot s^{-2}$ (169.86 s ± 70.92 vs. 189.19 s ± 85.62, $d = -5.35$), > 1.5 $m \cdot s^{-2}$ (87.46 s ± 140.16 vs. 42.08 s ± 98.02, $d = -5.34$); > 2.0 $m \cdot s^{-2}$ (135.45 s ± 341.31 vs. 175.00 s ± 429.30, $d = -5.67$). A lack of uniform trend between playing halves suggests RAA might not exhibit the same temporal characteristics as locomotor activities and recovery intervals between HSR, which generally decline in the second half (Bangsbo, Nørregaard & Thorsø, 1991; Bradley *et al.*, 2009; Carling & Dupont, 2011; Mohr, Krustrup & Bangsbo, 2003).

Importantly acceleration occurs from varied movement velocities and a limitation of this study is that the starting velocity of RAA bouts was not considered. Greater inaccuracies occur in the measurement of instantaneous velocity when acceleration commences from a lower starting speed (Varley, Fairweather & Aughey, 2012), and the impact on the RAA profile is unclear. Conceivably central players might commence more RAA bouts from lower starting speeds, compared to wide players, due to the limited space in which they patrol. When interpreting the findings from this study, it is noteworthy that RAA was assessed using absolute thresholds and this may have underestimated the work rate of players during concentrated periods of activity. Future research could investigate RAA using individualised thresholds determined from peak velocity achieved during 5 or 10 m linear sprints. The impact of the 0.6 s event threshold on positional profiles is also unclear, but could feasibly impact on the positional profile. Finally, the limitations relating to the acceleration dependent validity of the 5 Hz GPS employed suggest that the data reported is the minimum RAA completed during competition.

5.5 Summary

This is the first study to report the RAA of sub-elite youth competitive soccer. Evidence shows that RAA is a generic attribute at this level, although wide players tend to complete more bouts. Time dependent changes between playing halves were minimal, but moderate and large effect sizes suggest meaningful differences in the duration of recovery between efforts, and bouts.

5.6 Perspective

This thesis has added to the understanding of the external load of competitive sub – elite youth soccer, and this study provides insight in to periods of elevated acceleration activity. Clarifying this activity is an important step, and these findings will be useful to practitioners seeking to prescribe interventions to limit the decrements in performance found peak activity (Akenhead *et al.*, 2013).

As described previously literature has long proposed that superior HSA is desirable, and consequently training and testing protocols have focussed on this component. However, the evidence provided in this thesis, and contemporary research, demonstrate that acceleration is increasingly central to performance warranting a change of emphasis. Further, the reliance on RSA field tests to assess the most intense periods of match-play are misguided in light of the low incidence of RSA during games. By comparison, RAA bouts are more frequent and may be a more relevant focus given the reductions in acceleration activity found following peak activity (Akenhead *et al*., 2013) and during periods of fixture congestion (Arruda *et al*., 2015), despite no concurrent decline in HSA (Dellal *et al*., 2015; Djaoui *et al*., 2014; Lago-Peñas *et al*., 2012; Rey *et al*., 2010). In light of these findings the derivation of a valid and reliable field test of RAA is a necessary step and would address the absence in literature.

Chapter 6: The validity and reliability of the Repeated Acceleration Performance test (RAPT)

6.1 Introduction

The preceding chapters of this thesis support the standpoint that HSA is central to competitive soccer, but asserts that the focus on HSR and RSA within literature is misaligned with the demands of the modern game. Compelling evidence of the longitudinal changes within soccer demonstrates the increasing reliance on acceleration during match-play (Barnes *et al.*, 2014; Bush *et al.*, 2015b) and a shift in the physical rigours of the game. Chapter 5 evidences that repeated efforts constitute an important proportion of acceleration activity warranting a special focus, particularly in the light of limited evidence of RSA. The review of existing literature revealed a valid and reliable procedure for the assessment of RAA is lacking, and this is an important omission.

During running, the acceleration phase is divided into the starting acceleration and the main acceleration when peak velocity is achieved (Maćkala, Fostiak & Kowalski, 2015). The frequency and magnitude of these actions during three contemporary field tests are reported in Chapter 4 (p.96) emphasising their crucial role in athletic performance. Although each procedure is a valid and reliable assessment of the respective fitness component, there is sufficient evidence to question whether they remain crucial to the modern game.

Acceleration and maximal speed are separate skills (Little & Williams, 2005) and the prevalence of short sprints during soccer supports their separate assessment. Despite soccer being multi-directional, linear assessment of acceleration prevails with 0-10 m trials most common (Buchheit *et al.*, 2014b; Little & Williams, 2005). Alternatively, COD trials incorporate several turns but are single trials and assess peak speed with no consideration for the repeated efforts abundant in soccer (Dellal *et al*., 2010a; Wong, Chan & Smith, 2012).

Dellal *et al.* (2010a) recognised that soccer is characterised by repeated COD necessitating consecutive accelerations and decelerations, but these do not feature in linear RSA protocols prompting researchers to distinguish between RSA and RCOD (Wong, Chan & Smith, 2012). RCOD is defined as "repeated COD with minimal recovery between bouts" (Wong, Chan & Smith, 2012. p.2325) and assessed via the RCOD test, a 6x20 m format adapted from the Change of Direction Performance Test (CODT) (Beckett, Schneiker, Wallman, Dawson & Guelfi, 2009). The RCOD incorporates four 100° turns every 4 m and trials are separated by 25 s active recovery (Wong, Hjelde, Cheng & Ngo, 2015) (see Figure 5).

Figure 5: The structure and dimensions of the Repeated Change of Direction Test (RCOD) (Wong, Chan & Smith, 2012) (m).

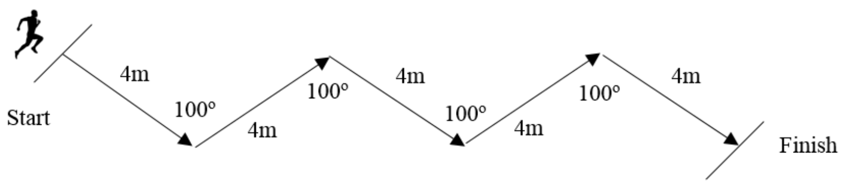
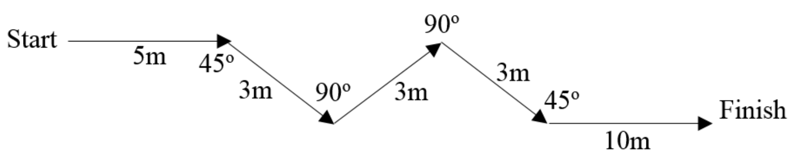


Figure 6: The structure and dimensions of the Change of Direction and Acceleration test (CODAT) (Lockie *et al*., 2013) (m).



The RCOD can be differentiated from the range of COD tests used in soccer because the derivation of the CODT was informed by in game analysis of AFL (Dawson, Hopkinson, Appelby, Stewart & Roberts, 2004) and field hockey (Keogh, Weber & Dalton, 2003). In contrast, the 505 (Maio Alves, Rebelo, Abrantes & Sampaio, 2010), the Illinois agility run (Vescovi, Brown & Murray, 2006), the T-Test (Sporis *et al.*, 2010) and the CODAT (Lockie *et al.*, 2013) (see Figure 6) seek to replicate general athletic movement rather than a specific sport. Repeating any of the former tests a designated number of times would not produce a valid assessment of RAA, because specificity is achieved by replicating the movement patterns and energetics of the activity accurately (Balsom, 1994; Bangsbo, Mohr, Poulsen, Perez-Gomez & Krustrup, 2006). The CODT, and therefore RCOD, reflect the rigours of AFL and hockey, but, not soccer because the 100^{o} turns do not mimic the 0-90^{o} turns most common in soccer (Bloomfield, Polman & O'Donoghue, 2007). This is a significant discrepancy because sprint speed and fatigue development are angle dependent (Buchheit *et al.*, 2012) requiring different footwork patterns and force reduction/development (Young, Hawken & McDonald, 1996). Therefore a valid RAA procedure should be informed by the RAA characteristics of soccer.

The construct of the RCOD and CODAT are reflective of the sprint distances found in soccer. A high proportion of sprints are 5 m (Barnes *et al.*, 2014; Di Salvo *et al.*, 2010; Haugen *et al.*, 2014; Vigne *et al.*, 2010) and the total distances are 20 and 24 m respectively, similar to the longer sprints in soccer (Haugen *et al.*, 2014; Vigne *et al.*, 2010). However, there is a paucity of information relating to the validity of each procedure. Physical assessment is also reliant on the ability of a test to separate random error, or "noise", and reliably reflect the actual performance (Hopkins, 2000a). Similarly, tests are required to be sensitive, or able to identify changes in performance, seasonal variation or differences between groups. At this time, the lack of information means neither could be adopted confidently in soccer and further work is required to support their use.

In summary, the preceding chapter highlighted the prevalence of RAA during competitive soccer accentuating its importance as a training and testing priority. To evaluate the efficacy of training interventions a measurement of the capacity to complete RAA is necessary. However, a valid and reliable procedure is lacking, and literature remains biased towards the YYIR and RSA protocols. The aims of this study were threefold. Firstly, to examine the test-rest reliability of the Repeated Acceleration Performance Test (RAPT), secondly to determine the sensitivity of the RAPT to changes in performance following a training intervention. Finally, to determine the validity of the RAPT through comparison with acceleration/deceleration activity and RAA during match-play.

6.2 Methodology

6.2.1 Participants

All participants were training in a high performance environment involving four, two hour field based sessions, two, sixty minute supervised strength and conditioning sessions and up to two competitive games per week. A precise breakdown of participants in each element of the study is provided below. Players or parents/guardians provided informed consent where appropriate in accordance with the procedures outlines in the declaration of Helsinki. The experimental procedure was approved by the BuSH committee at the University of Central Lancashire.

Portable GPS units (Catapult Sports, Minimax, 5 Hz) equipped with 100 Hz accelerometer were worn by players during the trials and located securely between the scapulae in a custom made harness. GPS units were switched on 10 minutes before use to allow satellite locking consistent with manufacturer's guidance. Horizontal dilution of precision (HDOP) indicated the accuracy of GPS in a horizontal plane (Catapult Sports) and optimum satellite availability (HDOP = 0) is where one satellite is directly overhead with a minimum of four spaced equally around the horizon. During these trials, HDOP ranged 0.8-1.6, which is a good signal.

6.2.2 Procedures

There were three separate elements to this study, and these are detailed below.

6.2.2.1 Short term reliability

Participants (n = 28, 17.4 ± 0.7 yrs, 177.1 ± 3.8 cm, 65.1 ± 5.4 kg) completed the RAPT during two scheduled field based training sessions separated by 24 hours. Before the test, participants completed the regular 15 minute group warm up, comprising ball work and dynamic flexibility, followed by two submaximal attempts, although players were already familiar with the procedure.

6.2.2.2 Sensitivity

Participants (n = 26, 17.4 ± 0.7 yrs, 176.8 ± 3.4 cm, 66.0 ± 4.8 kg) completed the RAPT either side of a 6 week training intervention designed to improve repeated acceleration. Each session comprised of two drills varied to progress the training stimulus and maintain motivation. Two sessions were completed each week immediately after the regular group warm up and in the presence of the coaching team. Each drill was typically < 10 s in duration and adhered to a 1:5 work/rest ratio to ensure adequate recovery (Reilly & Williams, 2003). Poles/mannequins marked the drills in preference to cones because they evoke a more sport specific cutting action (McLean, Lipfert & Van Der Bogert, 2004). The content of the programme can be found in Table 19 and detail about each drill in Appendix 2.

To be considered for analysis, participants were required to complete 85 % of the training sessions, meaning nine were withdrawn (Young & Rogers, 2014). Also, five were unavailable for re-testing due to injury or absence reducing the sample size further. However, the final total was comparable with studies examining the reliability of RSA (Chelly, Fathloum, Cherif, Ben Amar, Tabka & Van Praagh, 2009; Impellizzeri *et al.*, 2008; Meylan, McMaster, Cronin, Mohammed, Rogers & DeKlerk, 2009; Pettersen & Mathien, 2012; Tønnessen, Shalfawi, Haugen & Enoksen, 2011) and COD tests (Jullien, Bisch, Largouet, Manouvrier, Carling & Amiard, 2008; Lockie *et al.*, 2013; Mujika, Santiseban, Castagna, 2009; Pettersen & Mathien, 2012; Thomas, French & Hayes, 2009) incorporating a training intervention.

Table 19: The structure of the 6 week training intervention implemented during the sensitivity study.

	No. of accelerations	Total accelerations	% Change	Content (drill/reps)
Week 1	Session 1: (30+20) = 50 Session 2: (25+20) = 45	95	N/A	Drill 1 & Drill 2 (x5) Drill 3 & Drill 4 (x5)
Week 2	Session 1: (30+25) = 55 Session 2: (25+24) = 49	104	+10%	CODAT (x6) & Drill 6 (x5) Drill 5 (x5) & Drill 7 (x6).
Week 3	Session 1: (30+30) = 60 Session 2: (25+30) = 55	115	+10%	Drill 1 (x6) & Drill 2 (x6) Drill 3 (x5) & Drill 5 (x5)
Week 4	Session 1: (30+25) = 55 Session 2: (25+24) = 49	104	-10%	CODAT (x6) & Drill 6 (x5) Drill 5 (x5) & Drill 7 (x6)
Week 5	Session 1: (30+30) = 60 Session 2: (24+30) = 55	114	+10%	Drill 1 (x6) & Drill 2 (x6) Drill 4 (x6) & Drill 5 (x5)
Week 6	Session 1: (35+28) = 63 Session 2: (35+28) = 63	126	+10%	Drill 3 (x7) & Drill 4 (x7) Drill 6 (x7) & Drill 7 (x7)

6.2.2.3 Validity

Acceleration/deceleration and RAA data for the RAPT was collected during trials within the short term reliability and sensitivity stages of the study, and then pooled for analysis. Firstly, comparison of RAPT external load data was made with external load data from match-play reported in Chapter 3. Specifically, acceleration/deceleration distance was categorised as; zone 1: -20.0 to -4.0 $m{\cdot}s^{-2}$; zone 2: -4.0 to -2.0 $m{\cdot}s^{-2}$; zone 3: -2.0 to 0.0 $m{\cdot}s^{-2}$; zone 4: 0.0 to 2.0 $m{\cdot}s^{-2}$; zone 5: 2.0 to 4.0 $m{\cdot}s^{-2}$; zone 6: 4.0 to 20.0 $m{\cdot}s^{-2}$. Secondly, RAA (> 1.5 $m{\cdot}s^{-2}$) data reported during match-play in Chapter 5 was compared to RAPT data. Specifically, the number of RAA bouts, efforts per RAA bout, duration of each RAA effort, recovery per RAA effort and recovery between each RAA bout. Finally, to establish that acceleration was an integral element of the RAPT test, correlation was measured between linear speed performance (5 m, 10 m and 20 m), and, the duration of the fastest RAPT repetition ($RAPT_{Best}$), the total duration of the RAPT trial (sum of six repetitions) ($RAPT_{Total}$), and, the performance decrement across the RAPT trial ($RAPT_{Dec}$). Performance decrement was calculated using the formula; $RAPT_{Dec}$ = 100 *

(1 - [Rep1 +Rep2+…Rep6) / Rep1 * 6]) as per Bishop et al. (2001), Fitzsimmons, Dawson, Ward & Wilkinson (1993), McGawley & Bishop (2006), Spencer *et al.* (2005) and Wragg, Maxwell & Doust (2000).

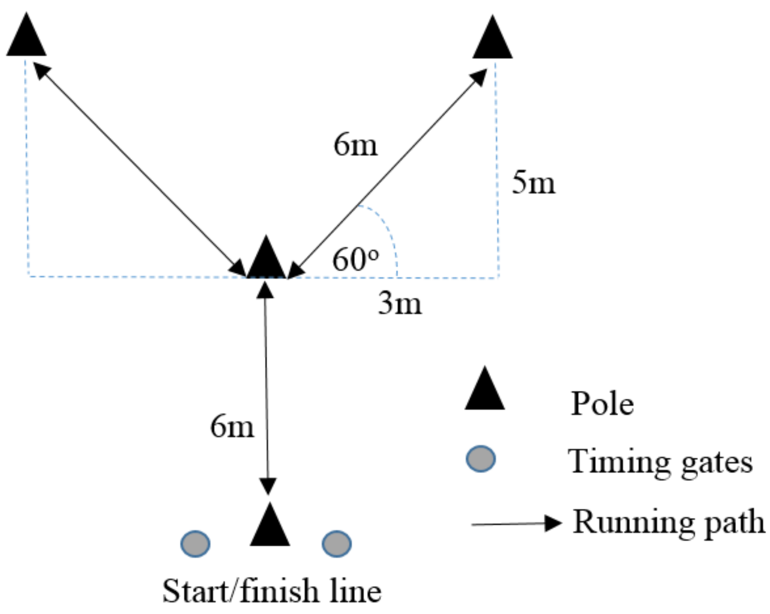
6.2.2.4 Derivation of the Repeated Acceleration Performance Test.

The RAPT was adapted from the reactive agility test proposed by Young & Rogers (2014) and the dimensions are shown in Figure 7 (p.161). To begin the test, participants adopt a stationary athletic stance 0.3 m behind the start line and each trial begins with a 3, 2, 1 countdown. Sprinting forwards to the centre pole, they turn 60^{o} left towards pole 2 and then turn 180^{o}. On reaching the centre pole for the second time, they turn left 60^{o} towards pole 3 and turn 180^{o}. On reaching the centre pole for the final time, they turn 60^{o} left before sprinting through the finish line. The full procedure consists of six maximal repetitions, separated by 20 s of active rest, alternating between left and right first turns. Chapter 2, and literature informed the dimensions and turning angles adopted, and represents the activity of players (Barnes *et al.*, 2014; Bloomfield, Polman & O'Donoghue, 2007). The TD of one repetition is 36 m and the number of repetitions, and rest periods, was informed by the RAA data presented in Chapter 5.

Before assessment, participants completed the regular group warm up of ~15 minutes, comprising ball work and dynamic flexibility, and two submaximal repetitions were completed before assessment, regardless whether participants were familiar with the procedure. To discourage a pacing strategy, participants were instructed that the performance measure would be the sum of their six repetitions. No technical advice was given about the most efficient movement technique. All trials were completed in the presence of a coach, and strong verbal encouragement was given throughout to discourage pacing. All trials were completed during a scheduled training session, on the same artificial 3G surface and participants were required to wear appropriate footwear.

Electronic timing gates (Smartspeed, Cardiff, UK), positioned at the start/finish line measured performance to the nearest tenth of a second. During the test, participants wore portable GPS units (Catapult Sports. Minimax, 5 Hz) equipped with 100 Hz accelerometer, during the trials, HDOP ranged 0.9-1.4, which is a good signal (Catapult Sports).

Figure 7: The structure and dimensions of the Repeated Acceleration Performance Test (RAPT) (m).



6.2.3 Statistical analysis

Data was uploaded to Catapult Sprint software (version 5.1) and files were manually edited to exclude non-test activity. All data was tested for normality using a Shapiro-

Wilk's test and Levene's established homogeneity. All statistical procedures were completed using SPSS 20.0 (SPSS Inc., Chicago, USA). Data is presented as Mean ±SD unless otherwise stated.

6.2.3.1 Short term reliability

Relative and absolute reliability, were examined. Relative reliability being the degree to which individuals maintain their position in a sample with repeat measure, and absolute reliability, being the degree to which repeat measures vary for individuals (Impellizzeri *et al.*, 2008). Relative reliability was assessed using inter-class correlation (ICC), whereby > 0.90 was high, 0.90-0.80 was moderate and < 0.80 was low (Vincent & Weir, 2012), although above 0.70 was acceptable (Lockie *et al.*, 2013). Paired T-Test compared performance between trial 1 and trial 2. Cohen's *d* measured the size of the effect and was calculated using the formula; *d* = Mean group 1 - Mean group 2 / SD pooled, where SD pooled = SQRT [(SD^2 group 1 + SD^2 group2) / 2]. Cohens *d* was interpreted using the scale outlined by Batterham & Hopkins (2006): trivial (< 0.2), small (> 0.2-0.6), moderate (> 0.6-1.2), large (> 1.2-2.0) or very large (> 2.0-4.0). Absolute reliability was assessed using the total error of the measure (TEM) and expressed as a percentage using the coefficient of variation (CV). Calculations were made using a custom designed spreadsheet (Hopkins, 2000c).

6.2.3.2 Sensitivity

ICC determined the relative reliability of test scores before and after the intervention. A Paired T-Test compared RAPT test performance either side of the training intervention. Cohen's *d* measured the size of the effect and was interpreted according to Batterham & Hopkins (2006) (see p.131). Absolute reliability was assessed using TEM and expressed as a percentage using CV, and calculations were made using a custom designed spreadsheet (Hopkins, 2000c). Smallest Worthwhile Change (SWC) was determined by multiplying the combined mean SD of both trials by 0.2, which is a small effect, and 0.5, which is a large effect (Hopkins, 2015a). If the SWC was greater than TEM the test was rated as good, if the TEM was similar it was rated OK and if the TEM was higher, the test was rated marginal (Hopkins, 2004) (see p.131).

6.2.3.3 Validity

Distances completed in each acceleration zone during the RAPT and game were compared using ANCOVA with duration selected as the covariate. Post hoc analysis was completed using a Bonferroni correction chosen to reduce the chance of a Type one error (Hopkins, 2000b). Eta^2 (η) determined the magnitude of the main effect; it was calculated using the formula; Sum of Squares$_{\text{Effect}}$ / Sum of Squares$_{\text{Total}}$ (Field, 2013) and interpreted using the scale 0.10 small; 0.30 medium and 0.50 large (Cohen, 1988). Cohen's *d* determined the magnitude of effect for pairwise comparisons, and was calculated using the formula; Mean group 1 - Mean group 2 / (SQRT mean squared error). It was interpreted using the scale outlined by Batterham & Hopkins (2006).

The number of RAA bouts, efforts per RAA bout, duration of each RAA effort, duration of recovery per RAA effort and recovery between each RAA bout, within the game and RAPT test, was compared using an independent Mann-Whitney U test. Effect size (ES) was calculated using the formula; *r* = Test statistic / (SQRT n), where n = the number of participants (Field, 2013). Effect size was interpreted using the scale 0.10 small; 0.30 medium and 0.50 large (Cohen, 1988).

Pearson's correlation coefficient measured the strength of the relationship between linear sprint performance (5 m, 10 m and 20 m) and RAPT performance. Across three sprint trials the fastest repetition (m_{Best}) and mean time (m_{Mean}) were correlated with $RAPT_{Best}$, $RAPT_{Total}$ and $RAPT_{Dec}$. According to Hopkins (2015a), the magnitude of correlation coefficients was considered as trivial (r = 0.1), small (r = 0.1 - 0.3) moderate (r = 0.3 - 0.5), large (r = 0.5 - 0.7), very large (r = 0.7 - 0.9) nearly perfect (r = 0.9 - 9.9), and perfect (r = 1.0).

6.3 Results

6.3.1 Short term reliability

$RAPT_{Best}$ showed significant differences between test and retest performance (p = 0.03, d = 0.09), but there were no differences between $RAPT_{Total}$ and $RAPT_{Dec}$ (see Table 20). Relative reliability was high for $RAPT_{Best}$ and $RAPT_{Total}$ (ICC 0.94-0.95), but low for $RAPT_{Dec}$ (ICC 0.35). Absolute reliability was high for $RAPT_{Best}$ and $RAPT_{Total}$ (TE: 0.10-0.53 s, CV 1.2-1.0 %) and poor for $RAPT_{Dec}$ (TE 1.09 %, CV 46.4 %).

Table 20: The short term test, and re-test, descriptive and inferential data for the $RAPT_{Best}$, $RAPT_{Total}$ and $RAPT_{Dec}$ performance measures. Mean (SD).

				Relative reliability			Absolute reliability	
	Test	Re-test	Mean (SD)	Sig.	*d*	ICC	TEM	CV
$RAPT_{Best}$ (s)	8.40 (0.43)	8.36 (0.39)	8.38 (0.40)	p = 0.03	0.09	0.94	0.10 s	1.2 %
$RAPT_{Total}$ (s)	52.02 (2.37)	51.69 (2.19)	51.86 (2.27)	p = 0.11	0.23	0.95	0.53 s	1.0 %
$RAPT_{Dec}$ (%)	3.15 (1.38)	3.04 (0.31)	3.10 (1.38)	p = 0.70	0.10	0.35	1.09 %	46.4 %

6.3.2 Sensitivity

$RAPT_{Best}$, $RAPT_{Total}$ and $RAPT_{Dec}$ all showed significant differences between trials ($p < 0.05$, d = -2.11 - 0.69), and ICC was low (0.15-0.25), demonstrating poor relative reliability (see Table 21). As a measure of absolute reliability, TE ranged between 0.32-1.94 s (CV 4.0 %) for $RAPT_{Best}$ and $RAPT_{Total}$, whereas $RAPT_{Dec}$ was TE 1.30 (CV 44.2 %). TE was greater than $SWC_{0.2}$ and $SWC_{0.5}$ representing a marginal rating.

Table 21: The test, and re-test, descriptive and inferential data for the sensitivity study. Mean (SD).

				Relative reliability			Absolute reliability			
	Pre-test	Post-test	Mean (SD)	Sig.	*d*	ICC	TEM	$SWC_{0.2}$	$SWC_{0.5}$	CV
$RAPT_{Best}$ (s)	7.84 (0.37)	8.25 (0.36)	8.04 (0.42)	p < 0.001	0.69	0.25	0.32 s	0.08	0.21	4.0 %
$RAPT_{Total}$ (s)	48.50 (2.22)	51.64 (2.16)	50.07 (2.68)	p < 0.001	-2.11	0.22	1.94 s	0.54	1.34	4.0 %
$RAPT_{Dec}$ (%)	3.17 (1.27)	4.32 (1.52)	3.75 (1.51)	p < 0.01	-0.98	0.15	1.30 %	0.30	0.76	44.2 %

6.3.3 Validity

Distances accumulated in each acceleration/deceleration zone is presented in Tables 22 & 23 (p.167). The majority of distance was covered ± 2.00 $m \cdot s^{-2}$ in the RAPT and match-play (76 % vs. 93 %. Greater activity was reported during the RAPT compared to match-play in zone 2 (7 % vs. 2.38 %), zone 5 (8.77 % vs. 3.22 %) and 6 zone (4.84 % vs. 0.89 %). There was a non-significant effect of duration on distance covered in zone 1 after controlling for the effect of duration; $F(2, 81) = 0.062$, $p = 0.80$, $\eta = 0.001$. Estimated marginal means showed adjusted values; RAPT: 460.10 m; Game: -562.88 m. There was a non-significant effect of duration on distance covered in zone 2 after controlling for the effect of duration; $F(2, 81) = 0.002$, $p = 0.97$, $\eta = < 0.001$. Estimated marginal means showed adjusted values; RAPT: -224.51 m; Game: 523.37 m. There was a non-significant effect of duration on distance covered in zone 3 after controlling for the effect of duration; $F(2, 81) = 0.005$, $p = 0.94$, $\eta = <0.001$. Estimated marginal means showed adjusted vales; RAPT: -2626.93 m; Game: 6333.11 m. There was a non-significant effect of duration on distance covered in zone 4 after controlling for the effect of duration; $F(2, 81) = 0.00$, $p = 0.98$, $\eta = < 0.001$. Estimated marginal means showed adjusted values; RAPT: 146.00 m; Game: 5147.94 m. There was a non-significant effect of duration on distance covered in zone 5 after controlling for the effect of duration; $F(2, 81) = 0.00$, $p = 0.98$, $\eta = < 0.001$. Estimated marginal means showed adjusted values; RAPT: 134.84 m; Game: 120.18 m. There was a non-significant effect of duration on distance covered in zone 6 after controlling for the effect of duration; $F(2, 81) = 0.002$, $p = 0.96$, $\eta = <0.001$. Estimated marginal means showed corrected values; RAPT: 115.45; Game: -63.87 m.

RAA demands of the RAPT are displayed in Table 25 (p.169). Average efforts during the RAPT was 7.70 (± 2.65), average effort duration was 0.58 (± 0.01 s) and average recovery per effort was 17.60 (± 4.10 s). The mean number of efforts per bout was significantly different between match-play and RAPT, $U = 7.25$, $p < 0.001$, $ES = 0.69$. The mean effort duration was significantly different between match-play and RAPT, $U = 3.706$, $p < 0.001$, $ES = 0.35$. The mean effort recovery duration was significantly different between match-play and RAPT, $U = -2.101$, $p = 0.04$, $ES = -0.81$. The mean bout recovery was significantly different between match-play and RAPT, $U = -8.480$, $p < 0.001$, $ES = 0.20$.

Table 22: The distances (m) accumulated in each deceleration zone during the RAPT and match-play. Mean (SD)

	Zone 1 (-20.00 to -4.00 m·s^{-2})			Zone 2 (-4.00 to -2.00 m·s^{-2})			Zone 3 (-2.00 to 0.00 m·s^{-2})		
	Dist. (SD)	CI 95%	%	Dist. (SD)	CI 95%	%	Dist. (SD)	CI 95%	%
RAPT	6.60 (2.34)	5.92 - 7.28	3.12	14.79 (4.12)	13.53 - 15.93	7.00	45.89 (11.74)	42.87 - 49.30	21.71
Match-play	41.78 (10.09)	36.33 - 47.22	0.48	204.38 (50.04)	187.75 - 222.02	2.38	2769.33 (340.91)	2655.11 - 2873.27	32.37

Table 23: The distances (m) accumulated in each acceleration zone during the RAPT and match-play. Mean (SD).

	Zone 4 (0.00 to -2.00 m·s^{-2})			Zone 5 2.00 to 4.00 m·s^{-2})			Zone 6 (4.00 to 20.00 m·s^{-2})		
	Dist. (SD)	CI 95%	%	Dist. (SD)	CI 95%	%	Dist. (SD)	CI 95%	%
RAPT	115.29 (23.22)	108.55 - 122.03	54.56	18.54 (5.08)	17.06 - 20.01	8.77	10.17 (3.20)	9.24 - 11.10	4.84
Match-play	5188.89 (698.23)	4933.04 - 5428.57	60.65	275.25 (49.96)	258.35 - 292.15	3.22	76.53 (19.49)	69.93 - 83.12	0.89

Correlations between RAPT performance and sprint times are reported in Table 24. $RAPT_{Best}$ showed the strongest correlation with $10m_{Mean}$ (r = 0.62) and $10m_{Best}$ (r = 0.61). The weakest correlations were found with $5m_{Mean}$ (r = 0.51). $RAPT_{Total}$ showed the strongest correlation with $10m_{Best}$ (r = 0.69 very large), the weakest correlation was with $10m_{Mean}$ (r = 0.34). $RAPT_{Dec}$ showed the strongest correlation with $5m_{Best}$ (r = 0.48) and the weakest correlation was with $20m_{mean}$ (r = 0.44).

Table 24: The descriptive data for 0 - 20 m linear sprint tests (s) and correlation with RAPT (r). Mean (SD).

	$5m_{Best}$	$5m_{Mean}$	$10m_{Best}$	$10m_{Mean}$	$20m_{Best}$	$20m_{Mean}$
Duration of sprint trial (s)	0.97 (0.05)	1.01 (0.09)	1.69 (0.09)	1.72 (0.07)	3.00 (0.11)	3.03 (0.11)
$RAPT_{Best}$ (r)	0.51	0.48	0.67	0.61	0.58	0.55
$RAPT_{Total}$ (r)	0.56	0.53	0.69	0.62	0.54	0.54
$RAPT_{Dec}$ (r)	0.48	0.38	0.35	0.34	0.49	0.44

Table 25: The RAA characteristics of the RAPT and positional activity during match-play. Mean (SD).

Position	Total bouts		Average efforts per bout		Average effort duration (s)		Average recovery per effort (s)		Average recovery per bout (s)	
	Mean (SD)	CI 95 %	Mean (SD)	CI 95 %	Mean (SD)	CI 95 %	Mean (SD)	CI 95 %	Mean (SD)	CI 95 %
WD	9.15 (3.71)	6.90 – 11.39	3.78 (0.50)	3.47 – 4.08	0.55 (0.60)	0.50 – 0.59	19.75 (2.63)	18.16 – 21.35	477.09 (353.72)	263.34 – 690.84
CD	5.56 (3.32)	3.89 – 7.21	3.52 (0.98)	3.03 – 4.01	0.49 (0.14)	0.43 – 0.56	19.23 (5.85)	16.32 – 22.15	515.34 (394.45)	319.19 – 711.50
CMF	5.46 (3.86)	2.86 – 8.04	3.16 (1.09)	2.42 – 3.90	0.47 (0.16)	0.36 – 0.58	18.58 (6.97)	13.90 – 23.26	418.71 (323.55)	201.35 – 636.07
WMF	10.50 (7.16)	5.37 – 15.63	3.68 (0.54)	3.29 – 2.42	0.54 (0.07)	0.49 – 0.59	18.48 (2.01)	17.03 – 19.92	385.15 (184.37)	253.26 – 517.04
FW	6.80 (3.94)	3.98 – 9.61	3.75 (0.95)	3.33 – 4.18	0.50 (0.07)	0.45 – 0.55	16.35 (4.01)	13.47 – 19.22	562.74 (257.78)	253.26 – 517.04
All positions	7.29 (4.70)	6.09 – 8.48	3.58[a] (0.81)	3.36 – 3.78	0.51[b] (0.11)	0.48 – 0.54	18.64[c] (4.80)	17.42 – 19.86	476.82[d] (321.85)	395.08 – 558.56
RAPT	1.06 (0.24)	0.99 - 1.13	7.70 (2.65)	6.93 - 8.47	0.58 (0.01)	0.55 - 0.61	17.60 (4.10)	16.40 - 18.79	4.70 (18.73)	-0.73 - 10.13

Sig. [a]: vs. RAPT $p < 0.001$, ES = 0.69; [b]: vs. RAPT $p < 0.001$, ES = 0.35; [c]: vs. RAPT $p = 0.04$, ES = -0.20, [d]: vs. RAPT $p < 0.001$, ES = -0.81.

6.4 Discussion

This study aimed to address the absence of a valid and reliable field test for the assessment of RAA within literature, and the data presented demonstrate the suitability of the RAPT to assess this important component. Validity and reliability were strong, and the RAPT provides a suitable low cost and simple measure of the capacity to accelerate repeatedly.

The RAPT reported large correlations between $RAPT_{Best}$ and $RAPT_{Total}$ and 10 m_{Best} and 10 m_{Mean} (r = 0.61 – 0.69). Values are not available for the RCOD (Wong, Chan & Smith, 2012), but are comparable with the CODAT and 10 m_{Mean} (r = 0.76) and the Illinois Agility Run (r = 0.71) (Lockie *et al.*, 2013). 10 m sprint times are widely used to assess acceleration in soccer players (Buchheit *et al.*, 2014b; Köklü, Alemdaroglu, Özkan, Koz, Ersöz, 2015; Little & Williams, 2005; Nikolaidis, Dellal, Torres-Luque & Ingebrigtsen, 2015, Sporis *et al.*, 2010) and the strength of the correlation confirms acceleration is a central feature of the RAPT. The small differences between the protocols may be explained by the increased frequency, and acute turns in the RAPT, which increases deceleration time. Acceleration is crucial following a change of direction (Wheeler & Sayers, 2010; Wong, Chan & Smith, 2012) and the frequent COD in the RAPT elicit repeated efforts mimicking elements of soccer match-play. To assess the extent to which COD speed contributes to RAPT performance it would have been useful to compare with the CODAT or similar procedure.

Inferential analysis revealed that the acceleration/deceleration activity in the RAPT was not significantly different to match-play after the effect of duration was controlled. This demonstrates strong construct validity serving to differentiate the RAPT from the RCOD (Wong, Chan & Smith, 2012). In contrast, the RCOD and CODAT (Lockie *et al.*, 2013) also involve a prominent acceleration component, yet whether they mirror match-play is unclear.

The RAA data reported in Chapter 5 informed the construct of the RAPT, yet there were significant differences between the two. The RAPT featured an average of 7.70 (± 2.65) efforts per bout compared to 3.58 (± 0.81) ($p < 0.001$, ES = 0.69) during competition, which is an apparent shortcoming. However, work rate periods are unevenly distributed during match-play (Akenhead *et al.*, 2013), and during intense periods consecutive RAA may be completed. It would, therefore, be useful for future work to examine the occurrence of RAA in relation to game events, such as scoring, or conceding, a goal.

On reflection, the RAPT is better suited to assessing the capacity to complete consecutive RAA bouts because it exposes players to prolonged intense periods of activity. WMF and WD are required to complete a greater number of RAA bouts (CI 95 % 6.90-11.90; 5.37-15.63) increasing the likelihood of consecutive bouts.

The findings of the short term reliability study showed that $RAPT_{Total}$ was the measure with the greatest absolute and relative reliability, and $RAPT_{Dec}$ was the least reliable. $RAPT_{Best}$ performance was not significantly different between the trials, yet a trivial effect size ($p = 0.03$, $d = 0.05$) renders the strength of these findings questionable. ICC for both $RAPT_{Best}$ and $RAPT_{Total}$ (ICC 0.94; 0.95) is similar to the Illinois Agility Run (ICC 0.91) and superior to the CODAT (ICC 0.84) (Lockie *et al.*, 2013). CV ranged 1.0 % - 1.2 % for $RAPT_{Best}$ and $RAPT_{Total}$. In contrast, $RAPT_{Dec}$ reported poor reliability (ICC 0.35, CV 46.4 %), and the large CV is greater than reported for from RSA assessments (CV 14.9 % - 36.7 %), (Bishop *et al.*, 2001; Fitzsimmons *et al.*, 1993;

Impellizeri *et al.*, 2008; McGawley & Bishop, 2006). The limitations with this metric may be methodological because the calculation incorporates each repetition, and variation in a single trial will affect the overall measure (McGawley & Bishop, 2006). Therefore, these findings support the cautious use of decrement calculations in soccer (Impellizzeri *et al.*, 2008).

The results from the sensitivity study highlighted that measured performance declined significantly from trial one to trial two, across all variables ($p < 0.01$, $d = 0.15\text{-}0.25$ moderate/large, ICC 0.15 – 0.25). CV 4 % for the $RAPT_{Best}$ and $RAPT_{Total}$ represents an acceptable level of absolute reliability (Hopkins, 2004), which was greater than the short term study, but not unexpected because fitness levels are subject to fluctuation during a longer period. Also, the demonstrable short term reliability of $RAPT_{Best}$ and $RAPT_{Total}$, imply that the findings of the sensitivity study reflect a real decline in performance.

A possible contributor to performance decline may be a change in the fatigue status of the group. The 6 week progressive training intervention incorporated drills to improve the capacity to accelerate repeatedly. This exposed the group to an increased training load that was compounded by the accommodation of rearranged fixtures into the programme. The accumulation of external load during this period is likely to have increased neuromuscular fatigue, which has been shown to impact negatively on acceleration (Cormack *et al.*, 2013). Also, the absence of structured recovery interventions may also have contributed to the decline in RAPT performance.

The length of the training intervention may also have been too short to produce a meaningful change in performance. Amongst Youth AFL players, 6 weeks of COD training did not improve performance in a COD field test (8.65 s ± 0.45 vs. 8.64 s ± 0.32) (Young & Rogers, 2014). However, unlike the present study, this group was already exposed to regular COD training. Therefore, an improvement in performance would require a larger increase in the volume, and intensity, of training. The specificity of the training intervention was also criticised because it replicated the demands of AFL, but not necessarily, the COD used. In contrast, the training intervention in the present study incorporated a range of turning angles, and distances, found in the RAPT and competition and was sport specific.

In each variable, TEM was greater than the SWC, indicating that the RAPT was not able to detect a small or moderate, worthwhile change in performance. However, the relatively small number of participants drawn from the same demographic influences these findings. Limited homogeneity of an athletic group produces a narrow SD and therefore a lower SWC, however by increasing the number, and heterogeneity of the group, the SD would increase, as would the SWC, leading to a change in the sensitivity of the RAPT (Lockie *et al.*, 2013).

There were a number of withdrawals during the study, reflecting the limitations working in an applied environment, yet, final totals were comparable with similar research (Jullien *et al.*, 2008; Lockie *et al.*, 2013; Mujika, Santisteban, Castagna, 2009; Pettersen & Mathisen, 2012; Thomas, French & Hayes, 2009; Young & Rogers, 2014). The short term study reported good relative reliability, and a change in participant number is unlikely to modify the results (Buchheit, Lefebvre, Laursen &Ahmaidi, 2011; Young & Rogers, 2014). However, the sensitivity study may have benefitted from a larger, and more heterogeneous, group (Lockie *et al.*, 2013).

In addition to the limitations mentioned above, there are other factors relating to the test procedure worthy of discussion. Firstly, the RAPT commences from a standing start, unlike a large proportion of accelerations within match-play that commence from a variety of movement velocities. Replicating the myriad of accelerations, and situations in which they occur within competition is fundamentally impossible given the stochastic nature of the sport. However, a standing start does, at least, standardise the procedure.

Establishing the validity of the RAPT against metrics measured during competition also presents issues because of the inherent variability of physical performance during match-play (Drust, Atkinson & Reilly, 2007). Chapter 5 reported CV ~ 65 % for the number of RAA bouts (> 1.5 $m \cdot s^{-2}$), emphasising the difficulty measuring validity against game data. These CV values would, therefore, partly account for the significant differences reported between the RAPT and game activity for RAA metrics.

6.5 Summary

In conclusion, the RAPT is a valid measure of RAA based on the demonstrable relationships with linear acceleration, and acceleration activity reported during match-play. The differences in RAA between the RAPT and competition suggested a lack of validity but also emphasises the difficulty validating a procedure based on match-play given its inherent variability. $RAPT_{Best}$ and $RAPT_{Total}$ are the most reliable measures of performance while the use of $RAPT_{Dec}$ should be avoided. Short term reliability was strong demonstrating the RAPT provides a reproducible measure of RAA, however, the sensitivity study was likely compromised by a number circumstantial factors, most notably the fatigue status of the group.

6.6 Perspective

Soccer performance is predicated on the ability to accelerate, and accelerate repeatedly without fatigue, and this is increasingly important in the modern game (Barnes *et al.*, 2014; Bush *et al.*, 2015b). Therefore, it is important that provision is made for the reliable assessment of RAA so that physical preparation can be optimized and readiness to compete determined. The RAPT is the first reliable field test for the evaluation of RAA.

Common obstacles to the incorporation of regular fitness testing into the applied setting are often time related and the perception that assessment is time wasted. A counter argument to this standpoint is that as the physical demands of soccer increase, along with demands of the fixture list, it is prudent to focus on the most relevant elements of performance. Measurement of the capacity to repeatedly accelerate would, therefore, inform the development of an important physical component. When resistance is met from coaches and players, they should be reminded that changes to coaching strategy cause the physical demands of the sport to evolve, not the other way around. The priority placed on aerobic capacity evolved to focus on HSR, and now the modern game has shifted again to be reliant on the capacity to accelerate repeatedly.

Chapter 7: Synthesis of findings

7.1 Introduction

The overall aim of this thesis was to evaluate the positional physical demands of sub-elite youth football using acceleration/deceleration profiles, and accelerometer derived metrics, to inform the derivation of a field based testing protocol.

At the outset of this project, portable GPS technology was a relatively new concept in soccer and publications about the external load of competition were limited to the elite population (Boyd *et al.*, 2013; Scott *et al.*, 2013a). Insight into the positional demands of match-play at the sub-elite level was absent, and, given the size of this demographic, presented a significant shortcoming. Moreover, my employer at this time had a large football academy allied to a Further Education (16 - 19 years old) academic programme. Students train in a high-performance environment, comprising four, two hour field based sessions, two, sixty minute strength and conditioning sessions, and, up to two competitive games per week. I determined that understanding the positional physical demands of competition in greater detail, would support the physical training programme, and optimise readiness to compete. Finally, the findings from this analysis were intended to inform the design and implementation of an innovative field test used to monitor and evaluate the fitness status of the academy players.

7.2 Summary of results

The aims of this research were first met using 5 Hz Minimax GPS and accelerometer technology to quantify the positional demands of match-play. The findings showed that total PL and AP load was greatest in CMF compared to CD ($p < 0.04$, $d = 1.26 - 1.56$), and that the acceleration/deceleration demands of competition were higher for WMF and FW compared to other positions (Chapter 3).

Chapter 4 compared the external load of three contemporary field tests with match-play data from Chapter 3. After controlling for the effect of duration, comparison between the YYIRL1 and multi-directional Hoff FET showed no significant differences in total PL or individual contributory planes. The analysis also highlighted that field test performance is reliant on the capacity to accelerate/decelerate repeatedly.

Analysis of RAA during competition (Chapter 5) found non-significant differences between playing positions suggesting it is a generic requirement. However, wide players tended to complete more bouts compared to central players. Finally, Chapter 6 established the validity of the RAPT as a field test of RAA, through correlation with 10 m sprint time (r = 0.61 - 0.69). Also, acceleration/deceleration activity within the field tests was comparable with competition, after the effect of duration was controlled. The number of RAA efforts per bout, effort duration, average recovery per effort, and recovery per bout, were higher in the RAPT than the game, suggesting the RAPT is more suited to assessing consecutive RAA bouts. Short term reliability was strongest for $RAPT_{Total}$ measured 24 hours apart ($p = 0.11$, $d = 0.23$, ICC 0.95, TE 0.53 s, CV 1.0 %). However, sensitivity of $RAPT_{Total}$ was poor either side of a six week training intervention ($p < 0.001$, $d = -2.11$, ICC 0.22, TE 1.94 s, CV 4.0 %).

7.3 Review of hypotheses

During this course of investigations, a series of hypotheses were formulated, and it is appropriate to review whether the findings led to their acceptance or rejection;

Hypothesis 1: *Positional differences in tri-axial external load will be exhibited and will demonstrate time dependent changes.*

This hypothesis was accepted. WMF completed greater distance during accelerations and decelerations $\pm$ 2.0 m·s^{-2}. MF reported higher CC load consistent with greater TD covered, which was and significantly more than CD. Acceleration/deceleration activity $< \pm$ 4.0 m·s^{-2} was significantly higher in the opening 15 minute period of the first half (P1), compared to all other periods.

Hypothesis 2: *The tri-axial external load of three contemporary field tests will be different in comparison to competitive sub-elite youth soccer.*

The hypothesis was partially accepted. Differences in total PL, and tri-axial PL, between the tests and match-play, were minimal and did not reach statistical significance. Acceleration activity in zone 5 (2.00 - 4.0 m·s^{-2}) and zone 6 (> 4.00 m·s^{-2}) during the field tests was higher than match-play.

Hypothesis 3: *The repeated acceleration activity during competitive sub-elite youth soccer will demonstrate positional differences.*

The hypothesis was rejected. Within the four categories of RAA, there were no significant differences between positions in terms of the number of RAA bouts, efforts per RAA bout, effort duration, recovery per effort and recovery per bout.

7.4 Examination of results in relation to existing literature

The ability to accelerate and overcome inertia is integral to soccer performance (Lockie, Murphy, Callaghan & Jeffriess, 2011) and the elevated energetic cost of changing movement velocity frequently is suggested to contribute to fatigue (Osgnach *et al.*, 2010; Russell *et al.*, 2016). Accordingly, research into the acceleration/deceleration demands of competition has increased substantially in recent years, to inform athlete preparation. Chapter 3 highlighted the positional differences in acceleration/deceleration activity at the sub-elite youth level, reporting greater activity amongst WMF. A tendency for wide players to complete more acceleration/deceleration activity has been reported elsewhere, albeit in different populations (Akenhead *et al.*, 2013; Dalen *et al.*, 2016; Ingebrigtsen *et al.*, 2015; Varley & Aughey, 2013), and is likely explained by their combined offensive and defensive roles within the team. However, any direct comparison between studies is made cautiously, given the differences in physical maturity between the participants, and methodological differences. This study quantified accelerations > 1.0 $m{\cdot}s^{-2}$ similar to Akenhead *et al.* (2013), whereas Dalen *et al.*, (2016) and Ingebrigtsen *et al.* (2015) opted for 2.0 $m{\cdot}s^{-2}$, and, Bradley *et al.* (2010) 2.5 $m{\cdot}s^{-2}$. Given the majority of accelerations/decelerations occur < ± 2.0 $m{\cdot}s^{-2}$, as reported in Chapter 3 and elsewhere (Akenhead *et al.*, 2013), omitting this category omits a large proportion of activity. The explanation for the contrasting approaches is unclear, but reflects a lack of consensus within literature about a uniform system of classification.

An apparent shortcoming within literature is that acceleration/deceleration activity is not categorised according to the starting velocity. Importantly, an acceleration of 1.0 $m{\cdot}s^{-2}$ is fundamentally different when commencing from an initial velocity of 0.0 $km.hr^{-1}$, 10.0 $km.hr^{-1}$ or 19.8 $km.hr^{-1}$, and would, therefore, require a different approach to training. Considering the different movement profiles of playing positions, it is speculated that CD may accelerate more frequently from a lower starting velocity compared to wide players who have a greater tendency to be on the move. Recently sprints have been delineated into leading sprints or explosive sprints based on the prior movement velocity (Barnes *et al.*, 2014; Di Salvo *et al.*, 2009) providing an evidence based approach for the enhancement of training interventions.

As a measure of external load, tri-axial accelerometers are used widely in an applied setting to monitor workload, and a common method of summarising this information is termed Playerload. Playerload has demonstrated acceptable test-retest reliability during treadmill running (CV 5.3 - 14.8 %) (Barrett, Midgley & Lovell, 2014), Australian football (CV 1.9 %) (Boyd, Ball & Aughey, 2011) and soccer (CV 6.4 ± 2.4 %) (Barrett *et al.*, 2016). However, published information about the rigours of team sports is scarce and limited to a handful of studies (Barrett *et al.*, 2016; Boyd, Ball & Aughey, 2013; Scott *et al.*, 2013a). A unique contribution of Chapter 3 was, therefore, a quantification of the positional total PL and planar contributions during competitive youth football. CMF accumulated significantly higher total PL than CD, and this is linked to the greater total distance covered during the game, and associated increased footfall, supporting the use of PL as a proxy measure of workload.

Information about the planar contributions to PL during team sports is also scarce. Barrett and colleagues (2016) detailed the temporal characteristics of planar contributions during soccer, reporting within-match variability (CV 7.3 - 9.0 %) linked to changes in locomotor efficiency. However, the same study did not differentiate between playing positions. Chapter 5 reported a lack of significant differences in planar contributions to PL between playing positions, and this was surprising given the differences in positional activity profiles (Bloomfield, Polman & O'Donoghue, 2007).

On reflection, a normalised version of PL, either PL per minute ($PL \cdot min^{-1}$) or PL per metre of TD ($PL \cdot m$), and equivalent planar versions might have been more sensitive to positional differences. Recently, Dalen *et al.* (2016) reported significantly higher $PL \cdot m$ for CD than all other positions, despite significantly lower TD, suggesting PL is accumulated differently according to each playing position. A second possible explanation for the lack of differences might be the sub-optimal location of the accelerometer unit. The centre of mass is the recommended location for an accelerometer (Halsey *et al.*, 2011) unlike the standard practice within sport that seeks to ensure player safety and maintain the GPS signal, by locating the unit between the scapula. In contrast to the centre of mass, a scapula mounted accelerometer underestimated ML load, due to reduced sensitivity to hip rotation, and increased CC load, due to forward lean of the upper body, during treadmill running (Barrett, Midgley & Lovell, 2014). Differences in tri-axial load between playing positions are likely, therefore, to reflect the varied running mechanics of individual participants to some degree, questioning the efficacy of between-participant comparisons (Barrett, Midgley & Lovell, 2014).

The chaotic nature of match-play dictates that work efforts are often condensed into intense periods (Dawson, 2012) and historically RSA has been purported to replicate these periods providing a tool for training and testing. However, the limited evidence of RSA during competition reported in Chapter 3 and elsewhere (Carling, Le Gall, Dupont, 2012; Gabbett & Mulvey, 2008; Gabbett, Wiig & Spencer, 2013; Schimpchen *et al.*, 2016) renders the importance of RSA contentious. Considering the temporal reductions of acceleration activity following intense periods (Akenhead *et al.*, 2013), it was surprising that repeated acceleration activity has not been investigated previously. The evidence reported in Chapter 5 demonstrates RAA is prevalent during competition and suggests it is a general requirement for all playing positions. The tendency for wide players to complete more RAA bouts was similar, but not identical, to the pattern of acceleration activity reported in Chapter 3, suggesting wide players might benefit from developing this physical capacity.

Presently there is no comparable research about RAA during competition, but an improved tolerance to repeated bouts of acceleration might be advantageous during match-play. Tactical synchronisation is reliant on the ability of players to continually adjust their position in relation to their teammates and opponents (Folgado *et al.*, 2014). The higher amount of time spent in synchronisation against better teams (Folgado *et al.*, 2014) is consistent with a higher work rate produced by higher standard opponents (Lago-Penas, 2012), suggesting that the RAA demands of competition may be dependent on the level of competition.

Unlike Barberó-Álvarez *et al.* (2014) this study profiled RAA at four thresholds ranging > 1.0 to > 3.0 $m{\cdot}s^{-2}$, and the greatest differences between playing positions were observed at > 1.5 $m{\cdot}s^{-2}$. However, RAA was quantified on an absolute basis and a relative threshold, perhaps based on individual 5 or 10 m sprint time, may change the interpretation of physical performance (Lovell & Abt, 2013). However, there are significant practical limitations to this approach, including, the need to re-evaluate each individuals threshold periodically. Clarity about the starting velocity of each RAA effort would have also provided greater insight and might have helped to differentiate between playing positions.

Variability measures the consistency of physical performance over time, and variation in RAA (> 1.5 $m{\cdot}s^{-2}$) for all positions was CV ~ 65 %, which is higher than total HSR (~ 14 - 25 %) (Bush *et al.*, 2015; Carling *et al.*, 2016; Gregson *et al.*, 2010: Mohr *et al.*, 2003: Rampinini *et al.*, 2007b). Although this is a large difference, acceleration is more sensitive to fatigue (Akenhead *et al.*, 2013; Arruda *et al.*, 2015) and may be expected to exhibit greater variability, unlike HSR that remains more stable (Dellal *et al.*, 2015;

Djaoui *et al.*, 2014; Lago-Peñas *et al.*, 2012; Rey *et al.*, 2010). This study reported less variability for WD (CV 40.55 %) compared to FW (CV 57.94 %), CD (59.71 %), WMF (CV 68.20 %) and CMF (CV 70.70 %) which is similar, but not identical, to the tendency for wide players to report less variation in locomotor activity versus central players (Carling *et al.*, 2016; Gregson *et al.*, 2010). The range of variability may be explained by a small sample size that magnified the SD of the mean and contributes to a greater CV. Also, the number of unique contributors to each position was unequal and would introduce bias into the data set. As such, the data reported for CMF and WMF might reflect differences in the execution of positional roles between individuals. This emphasises that variability should be interpreted on a case-wise basis to monitor an individual's physical performance. Finally, the broad CV may suggest that RAA is not appropriate for monitoring physical performance over time (Carling *et al.*, 2016), but further research is required to establish how the variation reported here, compares to different groups.

Speed is considered an important prerequisite for soccer performance (Lockie *et al.*, 2011) and a defining quality in game changing scenarios (Buchheit *et al.*, 2014; Faude, Koch & Meyer, 2012; Macadam, Simperingham & Cronin, 2016). The evolutionary trend in English Premier League soccer describes an increased frequency of sprint bouts over shorter distances (Barnes *et al.*, 2014; Bush *et al.*, 2014) emphasising the importance of developing this capacity. Importantly, the majority of sprints in soccer are < 20 m, so players do not reach maximum velocity (Macadam, Simperingham & Cronin, 2016) and the capacity to accelerate is, therefore, paramount. Speed and acceleration are separate qualities evidenced by the magnitude of their correlation (r = 0.56 - 0.87) (Little & Williams, 2005; Mendez-Villanueva *et al.*, 2011; Vescovi & McGuigan, 2008). Speed is suggested to be related to muscular-tendon stiffness, the stretch-shortening cycle and hip extensor activity (Buchheit *et al.*, 2014; Murphy, Lockie & Coutts, 2003), whereas acceleration is reliant on the concentric extension of the knee and hip (Dorn, Schache & Pandy, 2012). Subsequently, speed and acceleration need a different approach to training and assessment.

Within soccer, acceleration ability is often determined using 5 m and/or 10 m split times during longer sprint trials (Lockie, Moreno, Lazar, Orjalo, Giuliano, Risso, Davis, Crelling, Lockwood, Jalivand, 2016; Manson, Brughelli & Harris, 2014), without consideration for the repeated efforts featuring in match-play. In response, Chapter 6 aimed to validate a procedure to assess the capacity to complete repeated accelerations. In relation to logical validity, correlation with 5 m and 10 m sprint times (r = 0.67 - 0.69) confirmed acceleration is an integral element of the RAPT, and, acceleration/deceleration activity between the RAPT and match-play showed no significant differences. However, the RAPT featured more accelerations per RAA bout (7.70 ± 2.65) than match-play (3.58 ± 0.81, $p < 0.001$, ES = 0.35) suggesting it reflects consecutive bouts of RAA. The construct of the RAPT aimed to reflect the common turning angles reported in match-play (Bloomfield, Polman & O'Donoghue, 2007) and the distances of shorter sprints (Barnes *et al.*, 2014). However, this introduced a change of direction element to the procedure which might have added measurement error. Other important considerations for fitness assessment are test re-test reliability and sensitivity. Reliability was strong for $RAPT_{Total}$ ($p = 0.11$, $d = 0.23$, ICC 0.95, TE 0.53 s, CV 1.0 %), however TE (1.94 s) was greater than SWC (0.54 - 1.34 s) suggesting the RAPT was unable to detect systematic changes in performance. The decline in RAPT performance after the training intervention seems at odds with the observation that fitness levels of professionals tend to remain relatively stable during the season (Impellizzeri *et al.*, 2008). However, it is plausible that the congested fixture period, on top of the training intervention, increased the training load leading to residual fatigue explaining this finding.

7.5 Implications for applied practice

This study has highlighted that acceleration/deceleration activity is integral to sub-elite youth competition, with wide players, in particular, exposed to higher demands than central players. While the cost implications and administrator burden, present significant limitations to the adoption of GPS at the sub-elite level, the evidence within this thesis justify the incorporation of a structured training programme to develop these qualities.

Explosive sprinting activities over short distances (< 20 m) would, in time, improve acceleration (Lockie *et al.*, 2014; Rumpf, Lockie, Cronin & Jalilvand, 2015) but should commence from a variety of initial movement velocities, and incorporate a multi-directional stimulus, to achieve specificity. Further, evidence of repeated acceleration presented in this thesis highlights that activity is condensed into intense periods. Players would benefit from enhancing their immunity to the fatiguing effects of repeated accelerations, and this seems particularly important for wide players who complete more RAA. The number of efforts per RAA bout, rest periods between efforts and bouts, presented in Table 25 (p.169) provide guidance for structuring these sessions.

In relation to strength training, key elements would be, firstly, the development of the hip, knee and ankle extensors to increase force development improving acceleration. Lower body strength, assessed by back squat performance, is strongly associated with superior sprint performance over shorter distances (Comfort, Bullock & Pearson, 2012; Wisløff, Castagna, Helgerud, Jones & Hoff, 2004). However, access to gym equipment at the sub-elite level may be limited. Instead, plyometric exercises comprising body weight exercises could be incorporated into field based training sessions after the warm up. Examples of exercises shown to significantly improve sprint performance, include: maximal bilateral, or unilateral, countermovement jumps, depth jumps, horizontal/lateral hopping and skipping, (Buchheit, Mendez-Villanueva, Delhomel, Brughelli & Ahmaidi, 2010; Ozbar, Ates & Agopyan, 2014; Sáez de Villarreal, Suarez-Arrones, Requena, Haff & Ferrete, 2015).

The second area of focus would be the development of eccentric strength in the knee flexors to minimise the risk of injury during the terminal swing phase of sprinting (Rey, Paz-Dominguez, Porcel-Almendral, Paredes-Hernández, Barcala-Furelos & Abelairas-Gómez, 2017). In the absence of conventional gym based strength training equipment, the implementation of field based techniques may prove advantageous. Nordic hamstring exercises have shown to reduce injury incidence amongst footballers, and would be a straightforward addition to a warm up, or cool down, period (Arnason, Andersen, Holme, Engebretsen & Bahr, 2008; Rey *et al.*, 2017).

7.6 Research limitations

The following section outlines limitations associated with the research process and is divided into broad themes for simplicity.

1. Technological limitations

   This study used 5 Hz GPS to measure acceleration/deceleration activity during competition, but this system exhibits its greatest limitations during these activities. For example, the error when measuring distance during sprinting and tight changes of direction (Jennings *et al.*, 2010b), and, underestimations of movement velocity (Varley, Fairweather & Aughey, 2012) are significant. Finally, interunit reliability also presents limitations for the interpretation of data. Moderate reliability was found when measuring distance during walking, jogging and sprinting through a course with gradual changes of direction (CV 7.9 - 10.0 %) and tight changes of direction (CV 8.6 - 9.7 %) (Jennings *et al.*, 2010a). Also, poorer values are found during linear, and shuttle running, over 10 - 40 m (CV 13.6 - 30.0 %) (Petersen *et al.*, 2009). Between unit agreement when measuring peak speed (CV 7.5%, ICC = 0.52) has also led authors to conclude that 5 Hz GPS in unsuited to the quantification of movement during intermittent team sports (Scott, Scott & Kelly, 2016).

In contrast, the latest 10 and 15 Hz systems demonstrate improved accuracy, validity and reliability. During linear shuttle running measurement error of distance, ranged 2.95 - 3.16 % for walking, jogging, running and sprinting for 15 Hz GPS (Rawstorm *et al.*, 2014). Measurement of velocity during a 15 m sprint (CV 8.4 %) reaffirms that suggest 15 Hz is superior to 5 Hz (Vickery *et al.*, 2014). However, the assumption that increased sampling frequency is preferable is contradicted by findings during a team sports simulation circuit. 15 Hz GPS showed moderate interunit reliability (TEM = 8.1 %, ICC = - 0.14), but significantly, this was poorer than 10 Hz GPS (TEM 1.6 %, ICC = 0.97) (Johnston *et al.*, 2014).

During the course of the study the GPS units were subject to periodic software updates, and, on reflection, it would have been prudent to check the impact of these updates on the data collected. Following routine software updates, Buchheit and colleagues (2014a) reported significant decreases in the number of accelerations (> 1.5 m·s^{-2}: -29.48 %; > 3.0 m·s^{-2}: - 24.06 %; > 4.0 m·s^{-2}: - 48.0 %) and decelerations (> - 1.5 m·s^{-2}: - 14.71 %; > - 3.0 m·s^{-2}: - 14.70 %; > - 4.0 m·s^{-2}: - 22.22 %). Acceleration/deceleration data from match-play obtained during the 2012-2013 playing season (Chapter 3) was used for comparison in Chapter 4, and Chapter 6, but the effect of software updates occurring between these studies is unknown.

Integral to this study was the use of GPS housed accelerometers to report Playerload and individual planar contributions. During team sports activity between device reliability was acceptable (CV 1.9 %), and, the noise (< 2.0 %) was below the SWD (5.88 %) demonstrating that tri-axial accelerometers can detect differences in team sports activity (Boyd, Ball & Aughey, 2011). Players were issued with the same unit wherever possible to minimise between device reliability issues. However, this was not always possible due to equipment availability. Finally, players were fitted with an appropriate custom made harness to minimise the noise within the data arising from unit artefact.

2. Generalisability

The studies within this thesis were completed on one FA chartered football Academy presenting limitations with the generalisability of the findings. As such, the data reported is specific to this tier of competition and reflects the particular combination of strategy and tactics employed. The Academy studied is amongst the strongest in the region, and during the period of analysis, game losses were few. Positive score lines are linked to reductions in HSR because there is no need to try and regain a foothold in the game (Lago *et al.*, 2010; Lago & Martin, 2007), and, therefore, the data presented may not reflect the full physical potential of the players. As such, the acceleration/deceleration and RAA data could be considered to be the minimum achieved by the players, effectively emphasising that RAA is more prevalent than suggested.

Analysing soccer performance is problematic because of the myriad of situational variables that can influence match-play. The 4-2-3-1 playing formation remained consistent throughout the study, but, the impact of the opposing team's approach was not examined. However, research suggests that the formation of the reference team, and the opponents, has minimal impact on work rate (Bradley *et al.*, 2011; Carling, 2011). Significantly, in this thesis, only home games were monitored and, while this can be viewed as a limitation, it helped to reduce the variability in physical performance because, playing surface (Nédélec *et al.*, 2012), pitch dimensions, and, the advantage of playing at home (Lago-Pénas, 2009) were all consistent (Morgans *et al.*, 2014). The effect of player interchange during games introduced some bias into the data set because WMF and FW tended to be substituted most often, according to the academy policy of sharing field time. In response, these positions were prioritised for data collection during periods of limited GPS unit availability, to try and ensure they were equally represented in the final analysis.

The outcome of this thesis was the RAPT which aims to evaluate the capacity to complete repeated accelerations. Football performance is multifaceted and reliant on the complicated combination of physical, technical and strategic components (Drust, Atkinson & Reilly, 2007), and, therefore, it is acknowledged that any improvement in RAPT performance, or capacity to complete repeated accelerations, does not necessarily translate into enhanced football performance. Rather, the RAPT intends to evaluate a physical element that is prevalent during match-play, at this level, in order to inform training prescription.

The RAPT was validated against the acceleration/deceleration activity, RAA and accelerometer metrics, during match-play. However, on reflection, this approach presents limitations, given the variability in RAA (> 1.5 $m \cdot s^{-2}$) (CV 64.47 %), reported in Chapter 5. The amount of variation might have been reduced by increasing the number of participants significantly. However, this would have distorted the data and reduced the usefulness of findings for the reference academy (Carling *et al.*, 2016).

Finally, the training intervention within the sensitivity study (Chapter 6) presents two key issues. Firstly, fitness is typically maintained during the competitive phase, due to difficulties scheduling developmental work during periods of fixture congestion (Reilly & Williams, 2003). In reality, the intervention coincided with a re-arranged games programme and residual fatigue may have contributed to the decline in RAPT performance. Secondly, the intervention was six weeks in duration, which may have been too short to elicit a training effect. However, the duration was governed by the time constraints of the academic calendar and was, unfortunately, unavoidable.

7.7 Recommendations for future research.

The present study has highlighted several areas for future research, and these include;

1. Expanding the current research on RAA to provide a comparison with higher tiers of competition.

2. Investigating the impact of normalised thresholds, based on 5 m or 10 m sprint times, on RAA activity during competition.
3. Exploring the interaction between RAA and game related variables. For example, score line, ball possession and playing position.
4. Investigating the impact of a range of minimum event durations, for example, 0.3 s, 0.4 s, 0.3 s, rather than the default 0.6 s, on RAA performance during competition.
5. Providing greater clarity about how physical actions are categorised and contribute to PL according to the AU scale.

7.8 Conclusions

Based on this series of studies it is concluded that acceleration/deceleration is central to sub-elite youth soccer and that repeated bouts of acceleration (RAA) are prevalent during competition. Positional differences highlight that wide players are exposed to higher demands than central players, suggesting these players, in particular, might benefit from developing these capacities. Finally, the RAPT presents a valid and reliable field test for the assessment of the capacity to accelerate repeatedly within the sub-elite youth tier.

7.9 Personal reflection

Doing a PhD has been described as an experience in learning (Hanrahan, Cooper & Burroughs-Lange, 1999) but this was not at the forefront of my mind when deciding to undertake one. Instead, the desire to test myself and see whether I was equal to the challenge of study at this level was strong, and, I was mindful that as a HE lecturer, a PhD was a vehicle to advance my academic career. I was also keen to complete applied research within soccer to positively impact the preparation of players at the home academy, and, more broadly, to learn more about the game I have loved since childhood. The existing research about "soccer science," and that which emerged during this six year period, required voluminous reading. In addition to adding to my academic knowledge about this topic, this process made me more mindful about the depth of reasoning required to critically analyse published material. Pleasingly this is something I have improved significantly, and I am now more proficient in presenting a discussion about academic material in an objective, and coherent, manner.

Although perhaps not appreciated at the time, throughout the process of this study I have become more proficient in the research process (Hanhrahan, Cooper & Burroughs-Lange, 1999). Specifically, an increased understanding of research methodologies, the complexities of analysing data and, concluding findings. Wider skills also include managing time, resources and large data sets effectively, and, importantly when completing applied research, organising and communicating with participants, and coaches. The publication of two peer reviewed academic papers were important landmarks and provided useful reviewer feedback enabling me to refine how I prepare academic papers, and the final thesis.

In relation to the final thesis, the overall aim was to evaluate the positional physical demands of sub-elite youth football using acceleration/deceleration profiles, and accelerometer derived metrics, to inform the derivation of a field based testing protocol. Accordingly, the first step (Chapter 3) was to establish the acceleration/deceleration characteristics of competition, and, Chapter 4, determined the extent these were replicated in contemporary field tests.

The commencement of Chapter 5, around 2013/2014, saw a slight change in the direction of the study. At this time the importance of acceleration/deceleration activity during competition was apparent (Barnes *et al.*, 2014; Bradley *et al.*, 2010; Varley & Aughey, 2013), along with the fatigue related decline in activity (Akenhead *et al.* 2013). Emergent work by Barberó-Álvarez *et al.* (2014) concerning repeated acceleration activity, highlighted a gap in literature and led me to explore this topic in my home academy. While Chapter 5 presents evidence of RAA the impact of situational variables was not considered and given the complexity of soccer performance (Carling, 2013) this is something that would, in hindsight, provide greater depth to this chapter. Implementing a validity, reliability and sensitivity study (Chapter 6) was challenging and presented several logistical issues. Scheduling quality time with the playing squads and collecting data in a time constrained environment was difficult. Consequently, this led to the training intervention being six weeks long and limited to two training sessions per week for each group of players.

In summary, while I have been able to satisfy my reasons for undertaking a PhD, I have benefitted to a greater extent by the process of learning I have undergone during this period of study. Reflecting on the process has highlighted some limitations, and a range of decisions that I would take differently now I have acquired a greater understanding of both the research process, and, the complexities of applied research in soccer. Completing this PhD is an important first step, and I look forwards to conducting future research in applied sport.

Chapter 8: References

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Chapter 10: Appendices

10.1: APPENDIX 1: Informed consent

University of Central Lancashire

School of Psychology

Informed Consent Form

Investigation:

Investigator: David Barron

Participant No:

Full Name ____

I have read the participant information sheet and discussed the project with the investigator. The nature, demands and the risks associated with the project have been explained to me. I knowingly accept the risks involved and feel confident that I can undertake the requirements of the test without undue strain. As such I agree to participate in the above named study. I understand that I may withdraw my consent and discontinue participation at any time without having to give an explanation.

Participant's signature: ------------ Date:

____

Parent's signature in the case of a minor Date:

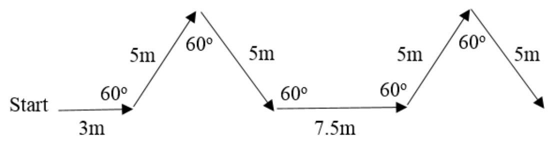
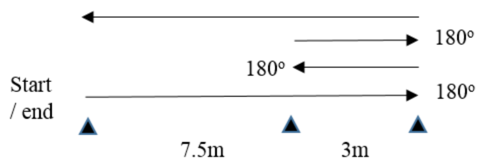
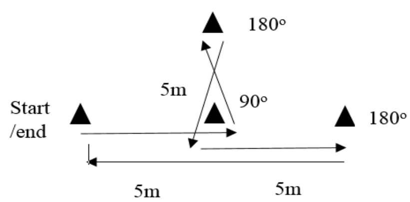
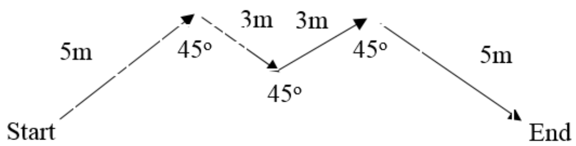
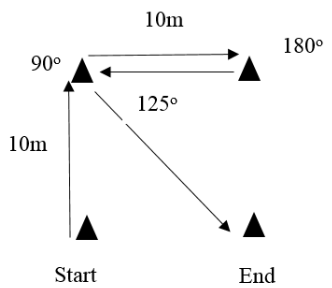
____

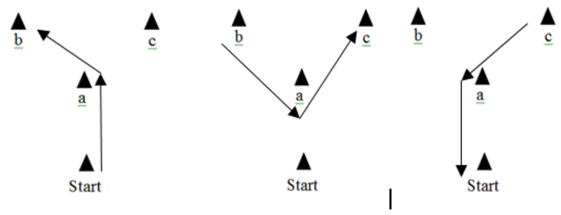
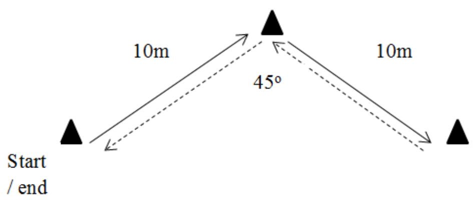
I certify that I have explained to the above individual the nature, purpose and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature

Signature of ------------------------- investigator: Date:

____

10.2: APPENDIX 2: Structure of training intervention

<table>
<tr><th>No.</th><th>Diagram</th><th>Instructions</th></tr>
<tr><td>1</td><td>
</td><td>From an athletic stance, the participant accelerates towards the first turn and proceeds to zig zag through the course sprinting through the finish point.</td></tr>
<tr><td>2</td><td>
</td><td>From an athletic stance, the participant accelerates to the first pole and checks before sprinting to pole two. Two more 180° turns are completed at poles two and three before a sprint through the finish line.</td></tr>
<tr><td>3</td><td>
</td><td>From an athletic stance, the participant sprints towards pole one and turns left to reach pole two. Turning 180° at pole two before sprinting towards pole two and turning left again to reach the finish line. This exercise would also be completed in the opposite direction to balance left and right turns.</td></tr>
<tr><td>4</td><td>
</td><td>From an athletic stance, the participant accelerates to the first pole and proceeds to zig zag through the course sprinting through the finish point. This exercise would be completed in the opposite direction to balance left and right turns.</td></tr>
<tr><td>5</td><td>
</td><td>From an athletic stance, the participant accelerates to pole one where they turn right. At pole two they turn 180° before sprinting towards pole two where they turn 125° and sprint through the finish line.</td></tr>
</table>

6		From an athletic stance, the participant accelerates to pole a and turns left (45°) towards pole b. At pole b they turn 180° before turning left (75°) at pole a, and reaching pole c. At pole c they turn 180° and sprint around pole a (40°), towards the finish line.
7		From an athletic stance, the participant accelerates to the first pole and turns right (45°) toward the second pole. Turning 180° the participant runs the reverse route back to the finish line.