The Relevance of Potential Indicators of External Load for Movement Evaluation in Elite Football Training

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ABSTRACT

Football is an intermittent (Bangsbo, 1994; Shephard, 1999; Reilly, 2005) and non-linear team sport. Coaches and practitioners must, therefore, prepare players to complete relatively large volumes of multidirectional activity that are short in duration due to frequent changes. One key aspect of ensuring the appropriateness of any training strategy is to develop and implement an effective training load monitoring strategy. Global Positioning Systems (GPS) incorporated into Micro-Electro-Mechanical Systems (MEMS) devices appear to be the technology that has been most widely adopted to determine activity (Akenhead & Nassis, 2016). The commonly used GPS technologies are regularly accompanied with tri-axial accelerometer within the MEMS hardware. It may be hypothesised that the progression of multiplanar MEMS accelerometer technologies may allow the frequent change of directions and velocities to be more accurately measured and, therefore, evaluate elite football training more effectively. There is, however, currently a lack of applied research, which has attempted to establish the utility of MEMS accelerometers to appropriately capture the movement requirements associated with elite football training. The overall aim of the research contained within the present thesis was, therefore, to investigate the relevance of indicators of external load for the evaluation of the movement requirements in elite football.

Study one (chapter three), therefore, attempted to evaluate if current external training load monitoring methods in Premier League football effectively differentiate between different coaching methods. The training load patterns

observed between different Premier League coaching groups within an in-season week were very similar. Differences were, however, present between the volume of TD, PL and TRIMP observed between the coaching groups. There was, however, little difference between the values of $m.min^{-1}$ observed between three of the four coaching groups. The observed training load patterns between the four coaching groups appear to suggest that the elite football training loads observed were largely modulated via duration. These findings suggest that the training load monitoring methods widely used within elite football may be ineffective in capturing the true differences in coaching methods, especially with reference to movement requirements.

Study two (chapter four) aimed to evaluate the effectiveness of MEMS accelerometers to describe differences in movement requirements between a range of football training activities. The PL and $PL.m^{-1}$ associated with different football training activities were compared. PL did not clearly distinguish between the movement requirements associated with the training activity. $PL.m^{-1}$, however, was found to be an effective external training load measure for describing differences in movement requirements between different training activities.

Study three (chapter five) then endeavoured to examine the sensitivity of MEMS accelerometer, GPS, heart rate and perceptually derived variables to changes in movement requirements in football specific activities. The systematic manipulation of movement requirements was completed via changing relative pitch dimensions in commonly completed training activities.

The findings suggest that PL.m^{-1} may effectively distinguish between changes in movement requirements modulated by relative pitch dimension. The measure was found to be greater when pitch dimensions were smaller, suggesting the variables may be sensitive to increases in multidirectional activity. M.min^{-1} also demonstrated sensitivity between movement requirements, however, conversely to PL.m^{-1}, the variable appeared to capture the greater locomotive activity associated with larger pitch dimensions. The other accelerometer, internal and perceptual based variables did not demonstrate the sufficient sensitivity to distinguish between the movement requirements associated with changes in relative pitch dimensions.

In summary, the findings and the relevant review the literature (chapter two), enable a conceptual monitoring model in football to be proposed. It appears that the volume component of training may typically be duplicated across traditional monitoring models and instead only one variable that captures this value should be used. Intensity is proposed as the second key component of the model. Due to the large variation in physiological response to intensity of different training modalities, it appears suitable to include both a locomotive and change of direction based measure for the component of training load. The final piece of the conceptual model includes a measure, which captures the movement requirement of the activity and, therefore, may inform the type of training load. PL.m^{-1}'s demonstrated utility now leads the researchers to propose the variable may suitably achieve this goal. The components of this conceptual model must, however, be challenged and further researched in the future.

Beyond the research outcomes from the current thesis, several professional development aims were also presented. It was hoped that the researcher’s research, related dissemination and networking, and management and leadership skills would all be developed. Throughout the thesis, these key themes of professional development are revisited throughout. It is suggested that these skills have all been significantly developed throughout the professional doctorate course. Evidence for this development is present within the investigations conducted in chapters three, four and five, the dissemination outlined in chapter six and throughout the reflective pauses. It is, however, suggested that there is certainly further room for improvement in each of these areas.

ACKNOWLEDGEMENTS

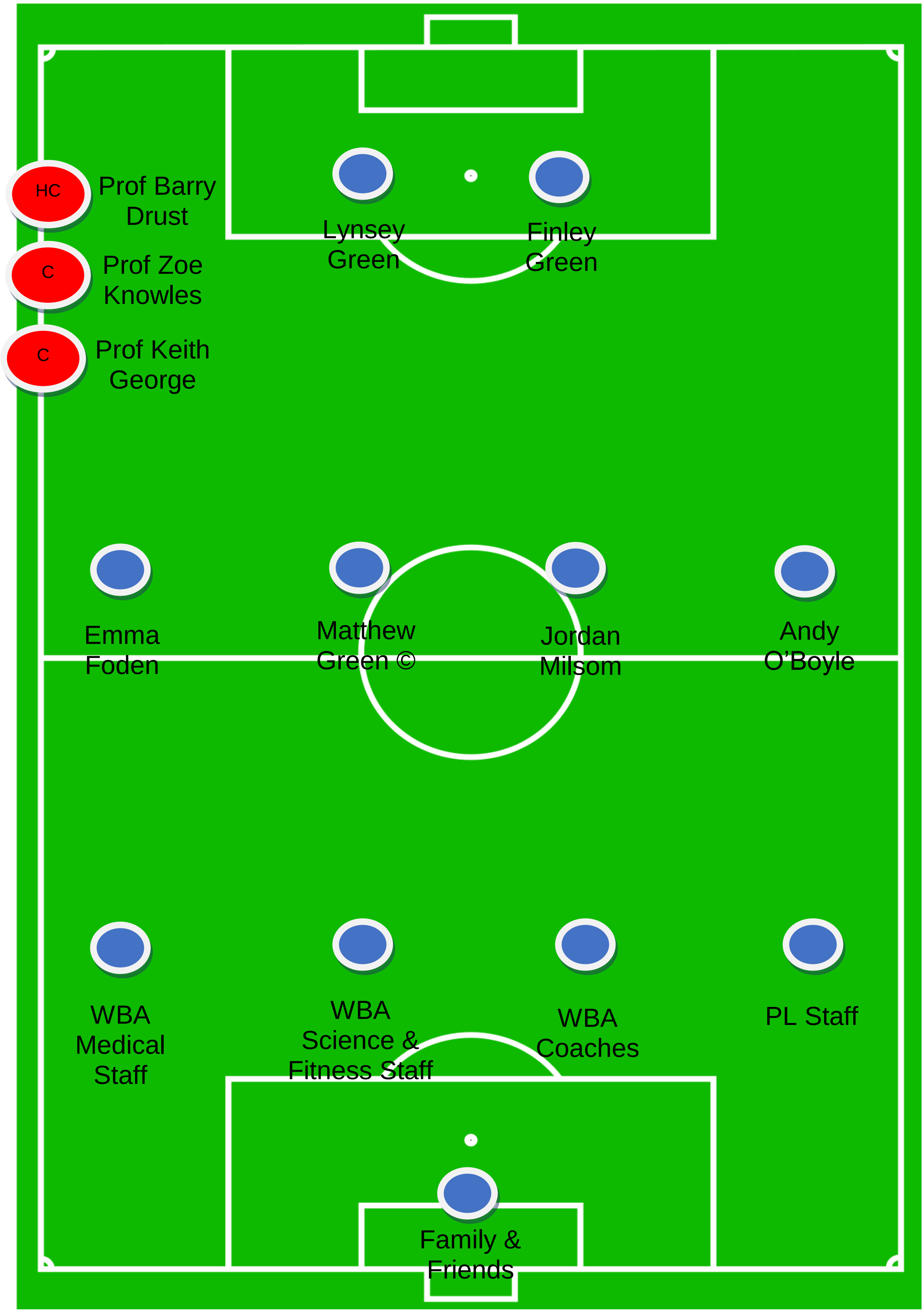


Figure 1. Acknowledged individuals in hypothetical football formation

Firstly, I would like to offer sincere thanks to head coach, director of studies Professor Barry Drust. The last 28-months has been an incredible season and I could not have asked for better guidance, support and challenge (tactical nous and man management). The role you have played throughout the current process and my academic and professional career long predating enrollment has surpassed the role of an academic supervisor. It will be your unwavering enthusiasm for personal development that will always stick with me.

Together with Barry, I would also like to thank the rest of the coaching team at Liverpool John Moores who have worked so tirelessly to establish the professional doctorate programme, specifically Prof Zoe Knowles and Prof Keith George. The programme of study has been so relevant for me and the work that the three of you have put in to establishing such a valuable programme of research and professional development is greatly appreciated.

One of the most beneficial elements of the professional doctorate programme is the incredible opportunity to share the experience with other like-minded professionals. Without my fellow midfielders Jordan Milsom, Emma Foden and Andy O’Boyle, the opponents faced would have looked far more fearsome – thank you.

During the professional doctorate process, the full-time whistle was blown on a period of nearly ten years employed by West Bromwich Albion FC. I will forever remember the great times and grateful for the incredible opportunities experienced at the club where the key performance problems and content of this thesis was formed. The support and input offered by performance staff past and present such as Mark Gillett, Nick Grantham, Fergus Ross, Fraser McKinney, Richie Rawlins, Andy Leaver, Paul Caldbeck, Matt Bickley, Lee Marsh, Darren Chesworth, Chris Barnes, Steve Wright and Paul Brice cannot be overplayed. They will always be the first names on the team sheet.

This project would not have been possible if not for the head coaches, assistant head coaches and academy coaches that I have worked with throughout my time at West Bromwich Albion Football Club. The coaching methods and principles that I have observed and supported throughout my time at the club has fundamentally driven the research question. Special mention is reserved for Keith Downing, whose regular discussions around the integration of coaching and science have always ensured I can articulate a lot of the scientific principles referenced within this thesis concisely and coherently in the language of the coach. Professional Development Phase coaches, Jimmy Shan and Jamie Smith have also been fantastic in their flexibility in allowing me access to the players for the research.

During the professional doctorate season, I made an exciting transfer window move into a new role at the Premier League. My new team mates there, namely Andy O’Boyle (again) and James McCarron have offered fantastic insight during the extra time period of the programme. I look forward to the exciting seasons of further collaboration ahead.

Away from my professional and academic support network I must thank my parents. Who continue to show unwavering faith and encouragement. As always, I am acutely aware that I am in safe hands.

Lastly, the greatest thanks are saved for the dynamic front two, the people who have demonstrated incredible support (and patience) to me over the last two and half years, my wife, Lynsey and son, Finley. The balance and perspective you have given me has been first class. Being married to someone completing a doctorate certainly has its challenges but being married to someone who is completing a doctorate and working full-time in football, while sharing the experience of bringing our little boy into the world demonstrates the strength, stability and understanding you bring. I look forward to providing the assists to many team goals in the future.

CONTENTS

THE SENSITIVITY OF EXTERNAL TRAINING LOAD TO DESCRIBE DIFFERENCES IN FOOTBALL SPECIFIC MOVEMENT

LESSONS FROM DISSEMINATION – SHAPING THE RELEVENT FINDINGS FOR DIFFERENT GROUPS

APPENDICES

LIST OF FIGURES

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 7

LIST OF TABLES

CHAPTER 2

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7

LIST OF ABBREVIATIONS

Acceleration	Acc
Acute Chronic Workload Ration	ACWR
Anteroposterior PlayerLoad™	PLap
Attacking	Att
Attacking Midfielder	AMF
Average Heart Rate	HRav
Bayesian Information Criterion	BIC
Breathlessness Rating of Exertion	RPE-B
Central Defender	CD
Central Forward	CF
Central Midfielder	CMA
Center of Mass	COM
Change of Direction	COD
Coefficient of Variation	CV
Comma Separated Values	CSV
Deceleration	Dec
Defending	Def
Defensive Midfielder	DMF
Double Leg Jump	DL Jump
Elite Coach Apprenticeship Scheme	ECAS
Full Back	FB
General Adaptation Syndrome Model	GAS
Global Positioning Systems	GPS

Goalkeeper	GK
Heart Rate	HR
High Speed Running (>19.8 km.h^{-1})	HSR
Horizontal Dilution of Precision	HDOP
Inertial Movement Analysis Efforts	IMA
Interclass Correlation Coefficient	ICC
Lactate	La^2
La Liga	LL
Large Possession	LPoss
Large Sided Games	LSG
Leg Rating of Exertion	RPE-L
Limit of Agreement	LoA
Long Dribbling	LDrib
Long Run	LRun
Low Speed Activity	LSA
Match Day	MD
Matchday Minus Four	MD-4
Matchday Minus One	MD-1
Matchday Minus Three	MD-3
Matchday Minus Two	MD-2
Matchday Plus One	MD+1
Matchday Plus Two	MD+2
Maximum Heart Rate	HRMax
Maximal Oxygen Uptake	$\dot{V}O_{2max}$
Maximum Sprinting Speed	MSS

Maximum Velocity	Max V
Mean Heart Rate	HRMean
Mediolateral PlayerLoad™	PLml
Metabolic Power	Met. Power
Micro-Electro-Mechanical Systems	MEMS
New Body Load	NBL
One Touch	1T
Oxygen Uptake	VO_2
Phosphocreatine	PCr
PlayerLoad™	PL
PlayerLoad™ per Meter	$PL.m^{-1}$
PlayerLoad™ per Minute	$PL.min^{-1}$
PlayerLoad™ Slow	PL_{slow}
Premier League	PL
Rating of Perceived Exertion	RPE
Repeated High Intensity Exercise	RHIE
Root Mean Square Error of Prediction	RMSEP
Scapulae	SCAP
Short Dribbling	SDrib
Short Run	SRun
Single Leg Jump	SL Jump
Smallest Worthwhile Difference	SWD
Small Possession	SPoss
Small Sided Game	SSG
Soccer Specific Aerobic Field Test	$SAFT^{90}$

Sprinting (>25.2 $km.h^{-1}$)	SPR
Standard Deviation	SD
Technical Rating of Exertion	RPE-T
Total Distance	TD
Total Distance per Minute	$m \cdot min^{-1}$
Training Impulse	TRIMP
Training Load	TL
Two Dimensional PlayerLoad^{TM}	2DPL
Two Touch	2T
Typical Error of Measurement	TEM
Vertical PlayerLoad^{TM}	PLv
Very High Intensity Distance (>21 $km.h^{-1}$)	VHID
Wide Midfielder	WM

CHAPTER 1

GENERAL INTRODUCTION

1. GENERAL INTRODUCTION

The objectives of any professional doctorate are to develop the capability of practitioners to work and research within their professional context (Fell *et al*., 2011). The following introduction is, therefore, split into two sections. One outlining the research background, aims and objectives and the other section outlining the professional background, aims and objectives. The two complimentary areas of research and practice development will be signposted throughout the thesis.

1.1 RESEARCH BACKGROUND

Football performance is characterised by a complex multifactorial blend of technical, tactical, cognitive and physical components. The specific physical requirements of football match play appears relatively well established, with elite players found to cover between 9672-11800m (Bradley *et al*., 2009; Bradley, *et al.,* 2011; Bradley, *et al.,* 2013; Dellal *et al*., 2011; Scott *et al*., 2016), a high intensity (>19.8kmph) distance of 534-1331m (Bradley *et al*., 2009; Bradley, *et al.,* 2011; Bradley, *et al.,* 2013; Scott *et al*., 2016) and sprint (>25.1kmph) distances of 133-451m (Bradley *et al*., 2009; Bradley, *et al.,* 2013; Dellal *et al*., 2011; Scott *et al*., 2016). Due to the unpredictable combination of these high-intensity activities interspersed with prolonged periods of lower intensity aerobic activities, football is classified as intermittent (Bangsbo, 1994; Shephard, 1999; Reilly, 2005). This activity is not only intermittent but also non-linear. It has been discussed that only 48.7 ± 9.2% of purposeful movements in match play are forwards (Bloomfield *et al.,* 2007). The remaining time is either spent not moving or moving backward, lateral, diagonal or in arced directions. These activities involved an average of 726 ± 203 turns during the match, with 609 ± 193 of these being of small magnitude (0° to 90°) (Bloomfield *et al.,* 2007). This evidence clearly informs coaches that players must be prepared for the large volume of intermittent, multidirectional activity that match play requires.

To effectively prepare players for these competitive demands it is important that the training processes within elite football are reflective of these characteristics. One key aspect of ensuring the appropriateness of any training strategy is to develop and implement an effective training load monitoring strategy. Impellizzeri *et al.,* (2005) proposes a conceptual model that outlines the important components of the training process, specifically highlighting that the external components of training load are modulated by an individual's characteristics, which result in the internal training response. The external training load referenced can be defined as the totality of mechanical or locomotive stress generated by an individual when undertaking a bout of activity (Barrett *et al.,* 2014). The use of technology has grown exponentially in professional sport in an attempt to accurately capture these external training loads (Malone *et al.,* 2015).

Global Positioning Systems (GPS) incorporated into Micro-Electro-Mechanical Systems (MEMS) devices are capable of accurately tracking an athlete's distance covered during team sport activity (Scott *et al*., 2016) and, therefore, appear to be the technology that has been most widely adopted to determine activity (Akenhead & Nassis, 2016). The commonly used GPS technologies are regularly accompanied with tri-axial accelerometer within the MEMS hardware. It may be hypothesised that the progression of multiplanar MEMS accelerometer technologies may allow the frequent change of directions and velocities to be more accurately measured and, therefore, evaluate elite football training more effectively. There is, however, currently a lack of applied research, which has attempted to establish the utility of MEMS accelerometers to appropriately capture the movement requirements associated with elite football training. It is, therefore, important to establish the sensitivity of these technologies in assessing the external demands within elite football, especially in reference to the movement requirements of training activities. This may then inform the appropriateness of current training load monitoring measures and ascertain a model of good practice for monitoring the football training process. A proposal may then be made, which may inform the effective prescription and organisation of training load.

N.B. Each chapter will be written as a distinct piece of work, therefore, there will be some repetition between methodology within the studies

1.2 RESEARCH AIMS AND OBJECTIVES

The overall aim of the research contained within the present thesis is;
To investigate the relevance of potential indicators of external load for the movement evaluation in elite football

This will be investigated through the fulfilment of the following objectives:

1 – To evaluate if current external training load monitoring methods in Premier League football effectively differentiate between different coaching methods

2 – To evaluate the effectiveness of MEMS accelerometers to describe differences in movement requirements between a range of football training activities

3 – To examine the sensitivity of MEMS accelerometer, GPS, heart rate and perceptually derived variables to changes in movement requirements in football specific activities

4 – To propose and disseminate an effective model of monitoring elite football training

1.3 PROFESSIONAL BACKGROUND

As an applied sport science practitioner, I have been extremely fortunate to be employed full time in elite football for the last 10-years. Figure 1 overviews my professional and academic journey during this period. The one principle that has guided my practice throughout these times is the attempt to effectively apply scientific theory and research to the applied football environment. Historically, it may have been suggested that the transient and unpredictable nature of football, combined with its rich traditions and conventions may have limited the potential impact of applied sport science. My career within the industry appears, however, to be aligned with an evolution of science in football where greater engagement and application has existed. This evolution has, therefore, ensured that most good intended, well rationalised proposals I have made to inform practice throughout my applied career have received suitable consideration from coaches, players and other support staff. My personal opinion is, however, that at times the term ‘science’ in football has become somewhat distorted and as a consequence the application of some overgeneralised and questionable methods have been implemented without a strong rationale or without facing enough professional challenge. It is my opinion that this is nowhere more apparent than in the prescription and monitoring of football training methods. It is this belief and observation that have led me to the research questions that I pose within the thesis and have motivated me to embark upon the professional development journey, which is the professional doctorate.

Figure 2. Timeline of academic and professional qualifications, experiences and roles.

1.4 PROFESSIONAL AIMS AND OBJECTIVES

In addition to the research aims and objectives the professional doctorate journey will allow me to develop a number of desirable professional skills that have been identified to be important to be successful in my chosen field. During the embryonic stages of my professional doctorate journey I completed a self-audit of these professional skills, which can be found in the training plan (appendix 9.1). This process helped clearly identify key areas of development that I would like to address during my professional doctorate journey. The development will be achieved through the fulfilment of the following aims:

1 – To develop relevant research skills

2 – To develop skills related to management and leadership

3 – To develop appropriate dissemination and networking skills

The successful completion of the above aims will ensure that I develop important and relevant professional skills that will benefit my future performance as a practitioner, researcher and manager. They will be accomplished by the following objectives:

1 – Further develop an understanding and application of different practical analytical and visualisation approaches relevant to the elite football environment

2 – Disseminate research findings via a broad dissemination approach. In turn, develop formal and informal research dissemination skills via regular engagement in scientific writing and the exploration of novel dissemination methods

3 – Develop a club research strategy along with formal academic collaboration

4 – Facilitate greater exposure to managerial, supervisory and mentorship responsibilities

5 – Engage in further reading and courses around important managerial and leadership skills

6 – Regular exposure to public speaking and presenting to a variety of different audiences

7 – Organisation and implementation of high standard scientific workshops, which aim to link research to practice in a variety of football specific areas

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

2.1 INTRODUCTION

Football training is relatively well researched within the scientific literature (Bangsbo, 2006; Hill-Haas *et al.,* 2011; Reilly, 2005). Despite this relatively large amount of research and the volume of practically orientated data that is available to clubs, the amount of research publicly available, which specifically investigates the training and monitoring processes in elite football is relatively scarce. Previous reviews have evaluated this body of football science research, however, without explicit reference to the change of direction and speed demands associated with the game. The current review, therefore, while considering all football research, specifically presents around the area of effective multidirectional training and monitoring methods utilising elite level players. The review will start broadly describing physical performance in football. The principles of traditional training periodisation will then be appraised ahead of examining the training processes. The later stages of the review will concentrate on the methods commonly utilised in monitoring the effectiveness of elite football training, with specific detail around the utility of accelerometers.

2.2 PHYSICAL PERFORMANCE IN FOOTBALL

Football is classified as intermittent (Bangsbo, 1994; Shephard, 1999; Reilly, 2005) due to the unpredictable combination of high-intensity activities interspersed with more prolonged periods of lower intensity aerobic activities. It is the occurrence of such high-intensity activities (sprints, accelerations, tackles, shots etc.), supported by the anaerobic energy system, which are the most critical actions to the match outcome (Wragg *et al.,* 2000; Hoff & Helgerud, 2004; Stolen *et al.,* 2005). Activity during football is also non-linear. Data shows that only 48.7 ± 9.2% of purposeful movements in match play is performed moving forwards (Bloomfield *et al.,* 2007). The remaining time is spent either static or moving in backwards, lateral, diagonal or in arched directions. The activity also involves an average of 726 ± 203 turns during the match, with 609 ± 193 of these being of small in angle (0° to 90°) (Bloomfield *et al.,* 2007). This type of evidence clearly informs practitioners that players must be prepared to complete relatively large volumes of multidirectional activities that are short in duration due to frequent changes.

Data on the demands of competitive football have been widely examined and reported for well over a decade (Bradley *et al*., 2009). Table 1 overviews this research, which illustrates large amounts of variability within the distances covered. This variation is thought to be a consequence of several contextual variables. Factors such as playing position (Bloomfield *et al.,* 2007; Di Mascio & Bradley, 2013; Ingebrigtsen *et al*., 2015; Bradley *et al.,* 2010; Bradley *et al.,* 2009; Buchheit *et al*., 2010; Carling, 2010; Di Salvo *et al.,* 2010; Di Salvo *et al*., 2007; Di Salvo *et al*., 2009; Gregson *et al*., 2010), level of competition (Bradley, *et al.,* 2013; Dellal *et al*., 2011), tactics (Bradley, *et al.,* 2011; Buchheit *et al.,* 2010; Carling & Bloomfield, 2010; Gregson *et al.,* 2010; Lago-Penas, 2009; Lago-Penas *et al*., 2010; Mendez-Villanueva *et al*., 2011), stage of the match (Bradley *et al*., 2009; Ingebrigtsen *et al*., 2015; Reilly *et al*., 2008) and the amount of possession (Bradley, *et al.,* 2011; Bradley, *et al.,* 2013) all impact players' physical match performance. The level of variability that is observed does not, however, appear to be equal across all of the variables that are used to describe the match activity. For example, the total sprint distance seems more variable than high-speed running and total distance (Carling *et al.,* 2016). It, therefore, appears that different variables offer different levels of sensitivity to the variety of contextual factors outlined. The appropriateness of the methods and variables examined should, therefore, be further investigated.

Table 1. Summary of the time-motion derived external demands associated with match play reported within the reviewed literature

Reference	Participants	Observations	Method	External Demands (mean ± SD)
Bradley *et al*., 2009	English Premier League players	320 players 28 games	Multi-camera computerised tracking system (Prozone)	TD CD – 9885 ± 555m FB – 10710 ± 589m CM – 11450 ± 608m WM – 11535 ± 933m CF – 10314 ± 1175m Very High Intensity Running (>19.8 $km{\cdot}h^{-1}$) CD – 603 ± 132m FB - 984 ± 195m CM – 927 ± 245m

				WM – 1214 ± 251m FW – 955 ± 239m SPR (>25.1 km·h^{-1}) CD – 152 ± 50m FB – 287 ± 98m CM – 204 ± 89m WM – 346 ± 115m CF – 264 ± 87m
Bradley *et al*., 2011	English Premier League players	153 players 20 games	Multi-camera computerised tracking system (Prozone)	TD 4-4-2 - 10697 ± 945m 4-3-3 - 10786 ± 1041m 4-5-1 - 10613 ± 1104m Very High Intensity Running (>19.8 km·h^{-1})

				4-4-2 - 956 ± 302m 4-3-3 - 924 ± 316m 4-5-1 - 901 ± 305m
Bradley *et al*., 2013	English Premier League players	810 Players 54 Matches	Multi-camera computerised tracking system (Prozone)	TD Low Possession - 10778 ± 979m High Possession - 10690 ± 996m High Intensity Running (>19.8 km·h^{-1}) Low Possession - 938 ± 311m High Possession - 931 ± 299m

				SPR (>25.1 km·h^{-1}) Low Possession - 246 ± 118m High Possession - 252 ± 120m
Carling *et al.*, 2016	French Ligue 1 players	12 players 31 matches	A multiple camera semi-automatic computerised player tracking system (AMISCO Pro)	HSR (>19.8 km·h^{-1}) FB - 995 ± 110m FB - 908 ± 158m FB - 933 ± 200m CD - 458 ± 118m CD - 502 ± 129m CD - 547 ± 135m CM - 745 ± 142m CM - 740 ± 110m

				CM - 599 ± 124m WM - 1091 ± 179m WM - 819 ± 196m CF - 899 ± 154m All - 770 ± 206m Total Sprint Distance (>25.2 $km \cdot h^{-1}$) FB - 252 ± 54m FB - 227 ± 71m FB - 270 ± 79m CD - 112 ± 62m CD - 104 ± 47m CD - 108 ± 63m CM - 116 ± 57m

				CM - 107 ± 29m CM - 93 ± 43m WM - 349 ± 100.9m WM - 223 ± 76m CF - 247 ± 48m All - 184 ± 87m
Dellal *et al.* 2011	English Premier League and Spanish La Liga players	5938 observations 600 matches	Multiple-camera match analysis system (Amisco Pro)	TD LL CD – 10496.1 ± 772.0m PL CD - 10617.3 ± 857.9m LL FB - 10649.7 ± 786.2m PL FB - 10775.3 ± 645.9m LL DMF - 11247.3 ± 913.8m PL DMF - 11555.6 ± 811.2m

				LL AMF - 11004.8 ± 1164.2m PL AMF - 11779.5 ± 705.9m LL WM - 11240.8 ± 761.8m PL WM - 11040.8 ± 757.0m LL CF - 10717.7 ± 901.4m PL CF - 10802.8 ± 991.8m High Intensity Running (21-24 $km \cdot h^{-1}$) LL CD – 226.1 ± 53.8m PL CD – 240.8 ± 63.9m LL FB – 284.8 ± 54.7m PL FB –270.1 ± 55.0m

				LL DMF –319.1 ± 67.7m PL DMF –278.0 ± 61.0m LL AMF – 334.0 ± 60.7m PL AMF – 310.6 ± 67.0m LL WM –298.0 ± 62.4m PL WM – 250.8 ± 71.5m LL CF – 288.6 ± 56.1m PL CF – 299.8 ± 63.7m SPR (>24 $km \cdot h^{-1}$) LL CD – 193.6 ± 64.6m PL CD – 208.5 ± 69.4m LL FB – 248.9 ± 77.4m PL FB – 279.6 ± 66.2m LL DMF – 263.0 ± 69.9m

				PL DMF – 203.3 ± 76.4m LL AMF – 245.8 ± 77.9m PL AMF – 222.2 ± 66.5m LL WM – 267.3 ± 64.2m PL WM – 259.2 ± 84.9m LL CF – 260.0 ± 72.6m PL CF – 278.2 ± 78.0m
Di Salvo *et al.*, 2007	Spanish La Liga and Champions League players	300 players 30 games	Multiple-camera match analyses system (Amisco Pro)	TD CD - 10627 ± 893m FB - 11410 ± 708m CM - 12072 ± 625m WM - 11990 ± 776m CF - 11254 ± 894m Sprint Distance (>23 $km{\cdot}h^{-1}$)

				CD - 215 ± 100m FB - 402 ± 165m CM - 248 ± 116m WM - 446 ± 161m CF - 404 ± 140m
Di Salvo *et al.*, 2009	English Premier League players	563 players 7355 observations	Computerised, semi-automated multi-camera image recognition system (Prozone)	Total High Intensity Running (>19.8 $km \cdot h^{-1}$) CD - 681 ± 128m FB - 911 ± 123m CM - 928 ± 124m WM - 1049 ± 106m CF - 968 ± 143m Total Sprint Distance (>25.2 $km \cdot h^{-1}$)

				CD - 167 ± 53m FB - 238 ± 55m CM - 217 ± 46m WM - 260 ± 47m A - 262 ± 63m
Di Salvo *et al.*, 2010	Elite Champions League and UEFA cup players	717 Players 67 Games 1325 Observations	Computerised, semi-automated, multi-camera image recognition system, provided by (ProZone)	Total Sprint Distance (>25.2 $km \cdot h^{-1}$) CD - 131 ± 66m FB - 233 ± 98m CM - 163 ± 85m WM - 285 ± 111m CF - 242 ± 106m
Gregson *et al.*, 2010	English Premier League players	485 players 7281 observations	computerised, semi-automated multi-	HSR (>19.8 $km \cdot h^{-1}$) CD - 604 ± 164m

			camera image recognition system (Prozone	FB - 951 ± 231m CM - 916 ± 253m WM - 1162 ± 247m FB - 941 ± 250m Total Sprint Distance (>25.2 $km \cdot h^{-1}$) CD - 145 ± 65m WD - 253 ± 96m CM - 198 ± 90m WM - 307 ± 109m CF - 272 ± 117m
Ingebrigtsen *et al*., 2015	Norwegian top league UEFA Europa league players	15 games 15 players 101 observations	Automatic tracking system based on microwave technology	TD CD - 10219 ± 381m FB - 11451 ± 673m

			(RadioEye)	CM - 11546 ± 1024m WM - 12320 ± 979m CF - 10584 ± 461m SPR (>25.2 km·h^{-1}) CD – 123 ± 48m FB – 284 ± 123m CM – 174 ± 89m WM – 294 ± 76m CF - 181 ± 111m Accelerations (>2m ·s^{-2}) CD – 86.9 ± 18.0 FB – 95.4 ± 19.4 CM – 85.2 ± 23.6 WM – 105.5 ± 22.2

				CF - 83.7 ± 13.8
Lago-Peñas *et al.*, 2009	Spanish Premier League players	18 Matches 127 Players	Multiple-camera match analyses system (Amisco)	TD CD -10070 ± 534m FB - 11056 ± 619m CM - 11541 ± 594m WM - 11659 ± 935m CF - 10626 ± 1242m SPR (>23 km·h^{-1}) CD – 184 ± 100m FB – 304 ± 124m CM – 219 ± 122m WM – 490 ± 172m CF – 340 ± 129m

The common conceptual approach to the quantification of match demands has traditionally been to use velocity based locomotive focused activity categories to describe the intensities performed by players. This approach of using distances in specific speed thresholds may not adequately represent the physical demands that elite football players are exposed to. A wide variety of energetically demanding activities seem to be present within football competition that this generalised analytical approach would seem to neglect. For example, it has been proposed that players completed an 8-fold greater number of maximal accelerations than sprints per game. Of these accelerations, 85% did not reach specific velocities that would enable them to be characterised as high-speed running distance (Varley & Aughley, 2012). Similarly, a much greater volume of accelerations (91 ± 21) than sprints (16.6 ± 7.9), has been observed (Ingebrigtsen *et al*., 2015), suggesting that these types of actions may be quantitatively more important (Barnes *et al*., 2014). It therefore, seems reasonable to suggest that the physiological demands that are associated with these activities may be underestimated when using a more traditional velocity-based quantification method. It, therefore, appears intuitive to further investigate if the training and monitoring processes, which occur in elite football suitably prepare players for these activities and capture the demands appropriately.

2.3 THE SUITABILITY OF TRADITIONAL TRAINING PERIODISATION PRINCIPLES FOOTBALL

With a suitable definition of training absent from the literature, the authors suggest training may be defined as the multifactorial preparation and advancement of skills, behaviours and capacities important for performance in competition. There are many elements to consider when designing suitable and effective training (e.g. technical, tactical, physical, cognitive etc.). It has been proposed that the physical dynamics of training primarily involve the manipulation of three key variables; intensity, duration and frequency (Issurin, 2010). The subtle manipulation of any of these three training load variables can have large implications for the demands placed on the physiological systems and subsequently the key component of fitness being conditioned. The extent to which these variables are modulated should be informed by the training load that the athlete has previously been exposed to and the expected future training load.

From a conceptual basis, each training ‘stress’ provides a similar response pattern that includes adaptability and resistance. This conceptual model is known as the general adaptation syndrome (GAS) model (Seyle, 1951). This model has since been modified to specifically translate the important concepts to the training process including supercompensation principle (Harre, 1982), which is displayed in Figure 1. The model suggests that for a desired adaptation to occur, physiological homeostasis must first be disturbed by the required initial stimulus. In the current context this would be a planned training dose. When this disruption is then followed by a sufficient period of relevant recovery, the desired super-compensation will occur, therefore, improving performance and/or adaptation (Kentta & Rassmen, 1998). It is, therefore, important that for the desired outcome to be achieved, the appropriate training and recovery dose are suitably understood, planned and delivered. The proposed model does not, however, accurately describe how the cumulative programming of multifactorial training sessions may impact upon desired training outcomes. It may be suggested, that to get a clearer understanding of how the physiological system responds to training stimuli, three key training principles must be understood.

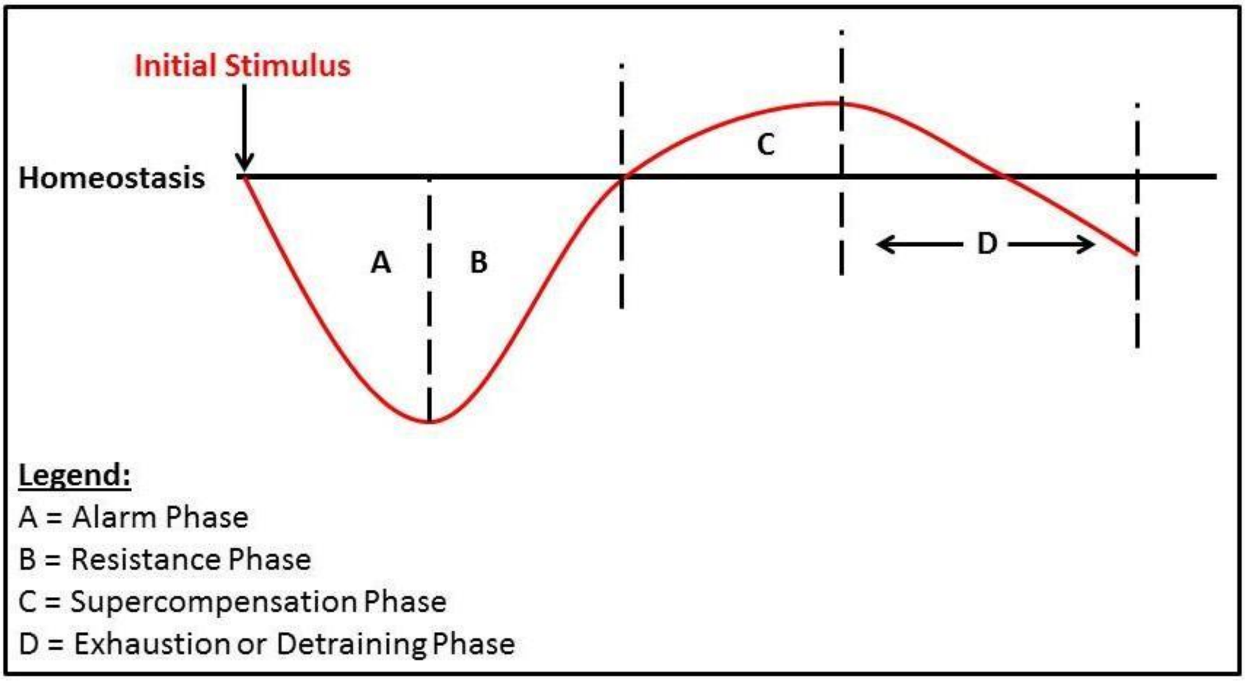


Figure 3. The Stress-Response Model based on Selye's GAS (Seyle, 1951). The 'alarm phase' represents the application of an intense training stress/ load. The resultant adaptation of the biological system to resist the stress/ load more efficiently is termed the 'resistance phase'. When this adaptation rises above baseline/ homeostasis level ensuring biological system is better suited to resist stress/ load it is referred to as the 'supercompensation phase'. If an inappropriate application of stress/ load occurs an 'exhaustion/ detraining phase' causes a reduction to below the body's baseline/ homeostasis level

The three key training principles are described as progressive overload, reversibility and specificity (Reilly, 2007). All three of these principles will have significant impact upon the stress-response model proposed above. Progressive overload specifies that training adaptations will only take place if the magnitude of the training load is above the habitual level completed (Zatsiorsky & Kraemer, 2006). It would, therefore, be inappropriate to prescribe the same training stimulus repeatedly over a prolonged period and still expect the same level of adaptation to which originally occurred. The concept of reversibility is not only concerned with the magnitude of the training stimulus but also the appropriate frequency. It is highlighted within seminal research that found that following 21-days of training cessation, endurance trained athletes' $\dot{V}O_{2max}$ reduced by 7% and 16%, following 56-days (Coyle *et al*., 1984). In addition to an effective magnitude and frequency of training stimulus, the type of load needs to be considered. The principle of specificity identifies that adaptation only occurs in the tissues and systems that are overloaded during the training exposure (Reilly, 2007). The three highlighted principles, therefore, appear to be important considerations during the planning, delivery and monitoring stages of the training process in elite football.

It is, however, too over simplistic to assume that an individual's physiological response is only modified by these three principles (Kiely, 2017). Instead, a complex interaction of internal factors such as genetic inheritance, personal predispositions and traits, stress history and resilience, prior training and injury history and current stress status are important considerations for training design (Kiely, 2017). A process of incorporating these considerations along with key training principles into a systematic plan that enables the application of loads and recovery has been proposed as ‘periodisation’ (Issurin, 2010). Periodisation is described as the micromanagement of the training process, a blueprint, which allows the coach to allocate time towards the acquisition and realisation of specific fitness characteristics (Cunanan *et al.,* 2017). Periodisation is considered as an important model to maximise performance gains and minimise the potential for overtraining (Afonso *et al.,* 2017). One key principle that may underpin this key proposal is the variation of training load. Periodisation promotes training load variation via the prescription of a framework of several structural units that each intends to achieve the specific training objective (Cissik, 2012). Each of these units differ regarding their specific terminology and associated duration as outlined in Table 2.

Table 2. The hierarchical structure of periodised training cycles (adapted from Issurin, 2010). Each of these units differs regarding their specific terminology and associated duration

Structural Unit	Duration	Content
Multiyear cycle	Years	Long lasting systematic athlete training composed of 2-4-year cycles
Macrocycle	Months	Large size training cycle (frequently annual cycle), which includes preparatory (preseason), competitive (in-

		season) and transition (offseason) periods
Mesocycle	Weeks	Medium size training cycle, which consists of several microcycles
Microcycle	Days	Small size training cycle, which consists of several days (frequently one week)
Training session	Hours & seconds	A single training exposure as group or individual

Traditional periodisation was originally developed to support preparation for a major championship such as the Olympics (Reilly, 2007). Within such controlled longitudinal plans, training can often be prospectively programmed due to an ability to mitigate against unpredictable external factors. The appropriate flexibility of the traditional approach to support the application to training plans in an unpredictable, dynamic environment such as elite football has, therefore, been questioned (Issurin, 2010; Kiely, 2012). There are several different models of periodisation proposed in practice and research; for example, nonlinear, block, fractal and conjugate sequence (Kiely, 2012). Each of these models utilise different approaches to vary training load prescription (Morgans *et al*., 2014). The intentional variety in training load that each of the models provide is clearly desirable in football training, as monotony should be avoided. Practitioners and coaches should, however, consider the appropriateness of the models with care. For example, the consecutive development of the motor abilities and skills using concentrated loads, with a resultant cumulative and residual effect in block periodisation (Issurin, 2010) may not be ideally suited to an elite professional football environment where a coach may have short term priorities due to the impending fixture and result dependent nature of the business.

Periodisation as a training model has, therefore, been recently been modified from its traditional structures and applied in a team sports setting where intentional peaking for matches occurs much more frequently throughout a competitive season (Robertson & Joyce, 2015) than for a single competition. The frequent nature of these regular match day peaks (every 4-7 days) and the unpredictable physiological cost and associated recovery period will make structured prospective training programs difficult to adhere to in elite football. It does, however, appear that the adherence to a structured prospective model of perioidsation may be less important than originally thought. In a study, which organised different interval training sessions in a specific mesocycle order or mixed distribution found little or no effect on training adaptations over 12-week period of the same training load (Sylta *et al*., 2016). It, therefore, appears that variety and novelty in training are the important factors, whereas the specific type of periodisation may not (Afonso *et al*., 2017).

The evidence that there are limited benefits to organising training into traditional predetermined periodised training structures is likely welcome news for football coaches and practitioners. This is because it appears apparent that periodisation, in its traditional sense, is inappropriate for the elite football context. Football possesses a highly complex challenge to those responsible for training design. The sport is truly multidimensional with technical, tactical, psychological and physical elements performed in combination, each of which possesses several more intricate components. Training, therefore, needs to be planned and delivered in a holistic approach within a team setting. Throughout football training, all the body's physiological energy systems must continually work in combination, switching in priority at an instant. These challenges are only accentuated as inter-individual differences, where players have their own specific response to prepared stimuli, interventions etc. These elements together with the fact that the competitive fixture schedule requires multiple (~40-50) peaks across many months (~10) (Morgans *et al*., 2014), where all matches have similar importance (Loturco & Nakamura, 2016) and often involve travel, guarantee that traditional training periodisation concepts may not be suitably applied. Instead, it appears that a fluid programming process, which incorporates the ongoing monitoring appears to be the most appropriate methodology, promoting individualisation, preparedness and responsiveness of the player (Cunanan *et al*., 2017; DeWeese *et al.,* 2013).

2.4 THE TRAINING PROCESS IN FOOTBALL

It is widely established that differences within the level of play (Casamichana *et al.,* 2013), age of players (Wigley *et al*., 2012), gender of players (Alexiou & Coutts, 2008) and country of the team (Manzi *et* al., 2013) will affect the training strategies that are used in football. Table 3 below outlines some of the variation that is present from the literature. It appears that the training load may be dependent upon specific contextual factors of the club such as coach/ manager philosophy, physical condition of players, number of players, fixture schedule etc. Regarding fixture schedule, it has been recognised that when comparing 7-day periods including one, two and three fixtures, the volume of high speed and high intensity distance completed is greater when more games are played (Anderson *et al.,* 2016). The total distance, however, was greatest in the two and three fixture weeks and duration greatest in the two-fixture week (Anderson *et al.,* 2016). The fact that elite football teams are not subjected to the same frequency of matches as each other, therefore, has large implications on their training volumes and intensities. The observed reduction in weekly work volume present when more fixtures are played appears to be a result of the additional taper and recovery stages required at the expense of the loading stage. This, therefore, has implications on the total work completed within training outside of the competitive fixtures.

Table 3. Summary of the elite football external training loads reported within the reviewed literature

	In-season Training Session TD	In-season Training Session HSR	Match HSR	Weekly TD	Weekly HSR	Weekly SPR
Morgans *et al*., 2014	508m-5780m	0-133m				
Owen *et al*., 2014	2200m-11800m	0-553m				
Thorpe *et*		0-750m	1250-			

al., 2015			1800m			
Anderson *et al.,* 2016				25-35km	1.00-2.25km	300-1000m

Numerous studies have reported a taper of training load in preparation for a fixture (Akenhead *et al*., 2015; Anderson *et al*., 2016; Malone *et* al., 2015; Los Arcos *et* al., 2017; Thorpe *et al.,* 2015). This training technique is widely accepted as a taper can have a beneficial effect upon performance (Mujika, 1998). It does appear, however, that the specific duration of the taper within Premier League football is reliant upon the subjective philosophy of specific key decision makers such as managers and coaches rather than a theoretical consideration. One-day (Malone *et* al., 2015; Thorpe *et al.,* 2015), two-day (Anderson *et al*., 2016) and four-day tapers (Akenhead *et al*., 2015) have all been observed prior to matches. This taper seems limited to training volume as training intensity seems to be maintained throughout the training week (Akenhead *et al*., 2015). The method of tapering observed in these approaches (i.e. tapering training volume, while maintaining intensity) appears to fit with the recommendations within the periodisation literature (Mujika, 1998). The optimal prescription for a taper within an elite football in-season microcycle has not yet been investigated scientifically. This may partially explain why there is a variation in the practice that is carried out between clubs.

It is so far unestablished if the variation in practice that occurs within a microcycle between clubs, similarly occurs across a macrocycle. Only one study is available that has assessed long-term periodisation strategies in elite football by examining the external training load across a whole season (Malone *et al.,* 2015). The findings of the study suggest that there was limited variation in the training loads completed by players across the season. This data also been reflected elsewhere when using RPE as an indicator of training load (Los Arcos *et al*., 2017). The only difference observed in the training prescription was a change in volume (i.e. the total distance covered) between the first and last mesocycles of the Premier League season. This difference may be explained by the change in the objectives of the training plan at these different periods (i.e. an early season focus on developing the players' physical capacity of players and a recovery and preparation focus during the final mesocycle). The heart rate (HR) response (as indicated by %HRmax), was also greater midseason than those in the first mesocycle of the season. This may be due to greater amounts of multifactorial (physical, travel, psychological) stress associated with the congested fixture schedule. Such increased stresses may lead to players reaching an elevated state of fatigue at this stage of the season (Morgans *et al*., 2014). It has been previously hypothesised that an uncoupling or divergence of the relationship between external and internal loads may differentiate between fresh and fatigued athletes (Halson, 2004). This may be a potential explanation for the change in the heart rate response at this time as the training load completed was not observed to be different. This limited variability in training load suggests that there may not be a periodisation strategy employed in developing the training load throughout a season and between training cycles. While useful this data is however limited due to its focus on a single team.

The limited variation observed in the seasonal study may suggests that training in elite football is monotonous (Malone *et al*., 2015). This approach, from a theoretical standpoint, may be inappropriate as research suggests that training load should be varied to best negate the effects of fatigue and to promote training adaptations (Issurin, 2010). Recent literature, however, may provide a rationale for the effectiveness of training loads that are similar throughout the season. Significant changes in training load may be potential predictors of non-contact soft tissue injury (Ehrmann *et al.,* 2016) with significant increases in external training load ($m \cdot min^{-1}$ & NBL) increasing the likelihood of time loss from activity. These ideas are supported by the growing volume of multi-sport research on the acute: chronic workload ratio (ACWR) (Bowen *et al.,* 2016; Hulin *et al.,* 2015; Malone *et al*., 2016). This theoretical framework suggests that athletes are at increased risk of injury if acute training load is disproportionately increased (1.5 times greater) than their chronic training load (average weekly load for this week and the previous three weeks). There appears, therefore, to be a potential contradiction for prescription whereby both highly varied training loads that avoid monotony or very consistent training loads with limited variation are both potentially ineffective. A difference in focus with respect to the specific outcome of training may help explain this as the goal of traditional periodisation methods are to promote optimal training adaptation, while the recently proposed ACWR and similar methods appear to propose training load management to minimise the risk of injury. Both outcomes would seem advantageous for practitioners in the field. It may, therefore, be suggested that variation in training load while important to incorporate should be carefully managed to be small and incremental.

Not only the training load variation present between teams but also between players within a team is an important consideration of the training process. The two key contributory factors to this are match day playing status and the position of the player. A key challenge for all coaches and practitioners in elite football is managing these differing individual workloads within the constraints of the team setting. It is, therefore, firstly imperative that the staff responsible for prescribing training have a clear understanding of how these modifying factors specifically affect different types of training load variation within a team. The impact of the playing status of an individual has been reported to have a large impact upon their weekly RPE (Los Arcos *et* al., 2017), high-speed running and sprint volume of a player, however, not total distance (Anderson *et al.,* 2016). This suggests the volume of work is not affected by a player's selection, however, the intensity of the work completed is. It, therefore, appears that the additional training that is prescribed for non-selected players is insufficient in matching workloads to those who played in the fixture. This is a key point for practitioners responsible for physically preparing players within clubs. It appears that if it is important that each player should to be subjected to similar volumes and intensities of training load, then additional high intensity distance and sprint work is required for the players not selected for competitive fixtures. Training load throughout a week should, therefore, be considered and programmed on an individual basis rather than a 'one boot fits all' approach.

The other factor than has been widely reported to affect within team training load differences is individuals' playing positions (Akenhead *et al*., 2015; Gaudino *et* al., 2013; Malone *et al*., 2015). The level of within team training load variation attributed to playing position may once again be dependent upon club context, because of coach led training design. Training should prepare players for match demands. As positional differences are present in match loads (Bloomfield *et* al., 2007), positional differences are expected and acceptable in training when they mirror the different physical match play demands. The magnitude of these differences will be a result of the type of training drills completed. If a greater volume of position specific tactical work is completed the differences may be pronounced, however, if training is typically generic technical or non-positional possession-based drills the differences may be limited. These suggestions are supported within the literature where small sided (4v4) and large sided (9v9 & 10v10) games were investigated (Owen *et al*., 2016). The authors found that positional differences in training load were present in large sided games but were absent from small-sided games.

2.5 SMALL SIDED GAMES

Small-sided games (SSGs) are commonly used as a football training tool of choice throughout all levels the game. The frequency of their implementation appears to be once again related to the training preferences of the coach. Their appeal relates to their multifactorial and holistic nature, where physical, technical, tactical and psychological components of the game can be trained in combination in a football specific context at the same time as effectively maintaining (Los Arcos *et al*., 2015) or improving (Dellal *et al.,* 2012b; Impellizzeri *et al*., 2006) aerobic fitness and player enjoyment (Los Arcos *et al*., 2015). Practical findings suggest that subtle manipulations in SSG drill design variables can influence these physiological, perceptual and time-motion responses in football players (Hill-Haas *et al.,* 2010). The challenge that practitioners face in the field is ensuring that appropriate methods are available and used to monitor these varying demands effectively. Table 4 overviews the wide range of research around SSGs presented within the literature over recent years. These findings appear to suggest that a variety of design factors may influence drill outcomes. These factors, which should be carefully considered are number of players (Castellano *et al.,* 2013; Dellal *et al*., 2012a; Djaoui *et al.,* 2017; Rampinini *et al.,* 2007), pitch size (Djaoui *et al.,* 2017; Gaudino *et al*., 2014; Kelly & Drust, 2008; Owen *et al*., 2016), game format (Castellano *et al.,* 2013; Gaudino *et al*., 2014), bout duration (Fanchini *et al*., 2011; Hill-Haas *et al.,* 2010), rule changes (Hill-Haas *et al.,* 2010), coach interaction (Rampinini *et al.,* 2007), number of touches restrictions (Dellal *et* al., 2012a) and under/ overloading of team numbers (Hill-Haas *et al.,* 2010).

Table 4. Summary of the reported SSG findings within the reviewed literature

Reference	Participants	Independent Variables	Dependent Variables	Key Findings
Castellano *et al.,* 2013	Fourteen semiprofessional male soccer players	Game formats - Possession, SSG (GK), SSG (target goals). Number of players - 7v7, 5v5 and 3v3. Pitch area per player ($210m^2$) was controlled.	TD, THSR, HSR, VHSR, SD, PL, Acc, Max V and %HRMean, %HRMax (10 Hz GPS)	3v3 v 5v5 = ↑%HRMean 7v7 & 5v5 v 3v3 = ↑Max V Possession v SSG (GK) & SSG (target goals) = ↑%HRMean Possession v SSG (target goals) = ↑%HRMax, ↓Max V 7v7 = HR in diff. game formats 7v7 SSG (target goals)

				v 7v7 Possession = ↑SD 7v7 SSG (target goals) v 7v7 SSG (GK) = ↑VHID 5v5 Possession v 5v5 SSG (GK) & 5v5 SSG (target goals) = ↑%HRMean 3v3 Possession & 3v3 SSG (GK) v 3v3 SSG (target goals) = ↑%HRMean 3v3 SSG (GK) v 3v3 Possession = ↑VHID 7v7 SSG (target goals)

				v 3v3 SSG (target goals) =↑%HRMax, SD, VHID 7v7 Possession v 3v3 Possession =↑SD 7v7 Possession & 5v5 Possession v 3v3 Possession =↑VHID 3v3 SSG (GK) v 5v5 SSG (GK) = ↑%HRMean 7v7 SSG (GK) & 5v5 SSG (GK) v 3v3 SSG (GK) =↑SD

Dellal *et al*., 2012a	Forty outfield international soccer players	Game formats – 4v4 (1 touch), 4v4 (2 touch), 4v4 (free play) and 11v11 (friendly) Pitch area for 4v4 (30x20m) and duration (4x4-min, 3-min recovery) was controlled.	%HRMax, RPE, Blood La^2, TD, HSR, SD (5 Hz GPS for 4v4 and semi-automatic multiple camera system for 11v11)	4v4 v 11v11 = ↑ HSR, SD, m·min^{-1} ↓ Blood La^2 ↑ duels, lost balls ↓ % successful passes 4v4 (1T & 2T) v 4v4 (free play) = ↑ m·min^{-1}
Djaoui *et al.,* 2017	Twenty-four elite professional French first league and twenty-four elite amateur French fourth league soccer	Standard of players – Professional v Elite Amateur Number of players – 11v11, 10v10, 9v9, 8v8,	Maximum sprinting speed (MSS)	Professional v Elite Amateur = MSS Ball conservation v GK and mini-goal = ↓ MSS 11v11 v SSG = ↑ MSS

	players	7v7, 6v6, 5v5, 4v4 Pitch size – 34x38 to 102x66 Pitch area per player – 92 – 306m^2 Rules changes – GK, mini-goals, ball-conservation		↑ Pitch area = ↑ MSS ↑ Length of pitch = ↑ MSS ↑ Number of players = ↑ MSS
Fanchini *et al*., 2011	Nineteen male amateur and professional soccer players	Game duration – 2, 4, 6-minute bouts. Number of players (3v3), recovery (4-min), number of bouts (3), pitch area per player	HR, RPE, technical actions (pass, successful pass, unsuccessful pass, tackle, header, turn, interception, dribbling,	6-min v 4-min = ↓HR 6-min v 4-min v 2-min = RPE 6-min v 4-min v 2-min = Technical actions WM & WD v CM & CD =

		(191m^2) and rules (GKs, 2-touch) was controlled between durations.	shoot, and shoot on target)	↑ MSS
Gaudino *et al*., 2014	Twenty-six soccer players competing in the English Premier League and UEFA Champions League	Game formats - Possession, SSG (GK). Number of players – 10v10, 7v7 and 5v5. Pitch area per player was controlled between formats.	TD, THSR, HSR, VHSR, SD, Acc, Dec, Max V., Met. Power (5 Hz GPS)	↑Number of players & pitch size = ↑ TD, THSR, HSR, VHSR, Max V., Max Acc & Max Dec, ↑ Energy cost, Met Power 10v10 v 7v7 & 5v5 = ↑SD SSG v Possession = ↑ VHSR, SD, Max V., Max Acc, Max Dec

				↓ TD, Energy cost, Met Power ↓ Number of players & pitch size = ↑ Mod. Acc, Mod. Dec, changes in V.,
Hill-Haas *et al*., 2009	Sixteen male youth soccer players	Game duration – Continuous (24-min), Intermittent (4x6-min, 90-sec recovery) Number of players and pitch area per player was controlled.	%HRMax, RPE, Blood La^2, TD, HSR (1 Hz GPS)	Cont. TD = Int. TD Int. v Cont. = ↑ HSR distance & number, ↓RPE, %HRMax
Hill-Haas *et al*., 2010	Sixteen male youth	Number of players –	%HRMax, RPE, Blood	Rules 4 = ↑ TD & HSR

	soccer players	3v4, 3v3+1, 5v6, 5v5+1. Rules changes – 1 = offside and kick ins; 2 = as rules 1 + all in att 2/3 for goal; 3 = as rules 2 + two flankers; 4 = as rules 3 + one player from each team running pitch laps (sprint width, jog length)	La[2], TD, HSR (1 Hz GPS)	Rules 1 & 2 v Rules 3 = ↑ RPE Rules 2 = ↑ %HRMax Matched teams (3v3+1 & 5v5+1) v Overload teams (4 & 6) = ↑ TD Underload teams (3 & 5) v Overload teams (4 & 6) = ↑ RPE Floater v 4 player team = ↑ TD Floater v 5 and 6 player team = ↑ HSR number 3 player team v 4 player team = ↑ RPE

Kelly & Drust, 2008	Eight full-time professional male soccer players from an English Championship club	Pitch size – small (30m×20m), medium (40m×30m), large (50m×40m). Duration of 4×4min (2min recovery) was controlled	HR, technical actions (pass, receive, turn, dribble, interception, tackle, shot, header)	Small v medium v large = HR, passing, receiving, turning, dribbling, interceptions, heading Small v large = ↑tackles Small v medium & large = ↑shots
Owen *et al.*, 2011	Fifteen elite male professional soccer players from a Scottish Premier League team who were competing at	Pitch size and number of players - small (3v3 + GK; 30x25m = 125m^2 per player), large (9v9 + GK; 60x50m =	HRmean, HRmax, %HRzones, technical actions (block, pass, receive, turn, dribble, interception, tackle,	Small v large = ↑HR, dribbles, shots, tackles, ball contacts per player ↓blocks, headers, intercepts, passes,

	UEFA Champions League level	166.6 m^2 per player) Duration of 3x5min (4min recovery) was controlled	shot, header, ball contacts)	receives, total ball contacts
Owen *et al*., 2016	Twenty-two male European professional soccer players	Game format – SSG (4v4+GKs, 30x25m = 750m^2, 7x3 (2min recovery)), LSG, (10v10+GKs, 90x68m = 6120 m^2, 3x8 (2min recovery)), sLSG (9v9+GKs, 45x38m, 1710m^2, 4x5 (2min recovery).	RPE	sLSG v SSG & LSG = ↑RPE sLSG WF v sLSG CF = ↑RPE

		Positional differences were analysed		
Rampinini *et al.,* 2007	Twenty amateur soccer players	Pitch size and number of players - 3v3 (12x20m, 15x25m, 18x30m), 4v4 (16x24m, 20x30m, 24x36m), 5v5 (20x28m, 25x35m, 30x42m) and 6v6 (24x32m, 30x40m, 36x48m). Coach encouragement – With and without.	%HRmean, RPE, Blood La^2,	3v3 = ↑%HRmean, Blood La^2, RPE 4v4 v 5v5 = % HRmean, Blood La^2, RPE 6v6 = ↓%HRmean, Blood La^2, RPE Large v medium & small = ↑%HRmean, Blood La^2 Small v medium & large = ↓RPE With v without coach

				encouragement = ↑%HRmean, Blood La[2], RPE

As referenced one of the key drill design factors that can be manipulated to affect training load and, therefore, physiological response is the number of players. It has been found that as the number of players on each team reduces, the internal and perceptual responses (heart rate, blood lactate concentration and rating of perceived exertion (RPE)) increase (Castellano *et al.,* 2013; Dellal *et al*., 2012a; Rampinini *et al.,* 2007). These internal responses are not, however, always reflected in the external loads reported. The same study reported that peak speed and number of accelerations per player increased as player numbers increased (3v3, 5v5, 7v7) (Castellano *et al.,* 2013). These differences in external demands are, however, not reflected when SSGs (4v4) were compared to large sided games (LSGs) (11v11) as the former was exposed to greater total distance per minute, high-intensity running activities (sprinting and high-intensity runs) and total numbers of duels (Dellal *et al*., 2012a). The manipulation of player numbers has also been found to affect the technical and tactical outcomes with increased difficulty observed in small-sided games. SSGs exposed players to greater turnovers in possession, lower pass completion percentage and lower number of ball possessions when compared to match-play (Dellal *et al*., 2012a). Some of the physical and technical observations within the literature may appear counter intuitive as less players may be perceived to mean more space and, therefore, time. This is not, however, how training design typically occurs in practice and, therefore, in the research presented. It is often the case that when SSG player numbers are restricted so are the pitch dimensions.

It appears that it is the interaction between player number and pitch area rather than solely player number, which plays an important role in affecting the demands of SSGs. The relative pitch size, therefore, appears a more important drill design consideration. It may be hypothesised that this is because the relative space that a player has on a football pitch is a major differentiating factor in establishing both their physical and technical demands. Theoretically, the less relative area a player is exposed to the greater the change of direction load as opposed to opportunities to run in long linear patterns. This theoretical proposal is supporting within the literature where an increased volume of accelerations, decelerations and total number of changes in velocity was observed in pitches sizes that had a relatively smaller area per player (Gaudino *et al*., 2014). As hypothesised these external demands are, however, not reflected across all variables, as total distance and high speed distance along with the opportunity to reach higher peak velocities, accelerations and decelerations increased as relative pitch size increased (Gaudino *et al*., 2014). The interpretation of how these differing external demands impact upon the internal load a player is exposed to is, therefore, complex. It has been demonstrated that no difference between RPE was present between LSGs and SSGs (Owen *et al*., 2016), which suggests that although external demands are not the same, they are equally as perceptually demanding for different reasons. Interestingly, however, when pitches were manipulated and the LSG played on a relatively smaller area size it was significantly more perceptually demanding than the SSG (Owen *et al*., 2016). It, therefore, appears that the increased perceptual demands associated with smaller pitches and less players are not a reflection of increased training load associated with traditional velocity based variables but instead are closely related to the volume of change in velocity activities. It is, therefore, important that the physiological demands associated with change of directions are well understood.

2.6 THE DEMANDS OF CHANGE OF DIRECTION

When examining the change of direction literature, it does appear that the increased perceptual demands associated with space restriction in SSG may be the result of increased change of direction demands. Similarly, to the SSG research, internal training load appears to be higher when change of direction demands are amplified in a controlled setting. Heart rate (Dellal *et al*., 2010), RPE (Dellal *et al*., 2010), blood lactate (Buchheit *et al.,* 2010; Dellal *et al*., 2010) and energy cost (Hatamoto *et* al., 2014; Stevens *et al.,* 2015; Zamparo *et al.,* 2015) have all been found to be higher during repeated shuttle running (180^{o} turns) than repeated constant running. These increased demands are likely to be a result of the requirement to apply additional forces to break momentum and decelerate, before a propulsive reacceleration in the new direction when turning. These actions will, therefore, be associated with greater eccentric muscular efforts, which would have required increased anaerobic metabolism and fast twitch muscle fiber contribution. These increased demands appear sufficient to induce fatigue, potentially due to decreased phosphocreatine (PCr) levels that in turn increase the participants' RPE and blood lactate levels.

In the same way as observed in the SSG literature, a comprehensive increase in all associated training load is not witnessed when change of direction demands are amplified in isolated running either. For example, some studies have found similar heart rate responses (Buchheit *et al.,* 2010; Dellal *et al*., 2010) and RPE (Buchheit *et al.,* 2010) between repeated shuttle running and repeated linear running. Some of these discrepancies may be a result of the design variables employed within each of the conditions. For example, the speeds and distances prescribed for both shuttle and linear running will have large implications on the intensity and, therefore, the energetic demands associated with either accelerating and decelerating or running linearly. It must also be expected that the participants' genetic predisposition, previous training history and current training status also has large implications upon the physiological response to each of the conditions. For example, it has been found that football players (irrespective of level) had more favorable repeated sprint ability to repeated change of direction ability ratio than physically active individuals (Wong *et al*., 2012). This suggests that team sport players may be more efficient at change of direction than non-team sport players, therefore, impacting upon the physiological responses to these types of activities.

When reviewing the similarities between the training literature surrounding SSG and change of direction activity it appears that a broader theoretical framework can be applied to the planning of football training. It appears that the greater the restriction of space and, therefore, the greater the change of direction demands, the greater the internal and perceptual cost. It may be presumed that this is due to a greater volume of multidirectional activity made up of accelerations and decelerations. These actions expose players to greater 'biomechanical load' (Vanrenterghem *et al*., 2017) because of the frequent muscular involvement to regularly break momentum and re-propel themselves. When, however, players are exposed to greater relative area, there are less change of direction demands but greater exposure to increased locomotive distances and speeds. These types of activities expose players to greater 'physiological load' (Vanrenterghem *et al*., 2017) because of the kinetic energy requirements to achieve the associated volume of high-speed activity. This is, however, currently a theoretical point of view and to become practically orientated, practitioners and researchers should ensure that the methods of the differing external, internal and perceptual demands are planned as effectively and efficiently as possible. For example, it is not suitable to demonstrate an over reliance on training methods that restrict space. This is demonstrated by the ineffectiveness of SSGs to expose players to max velocity (Djaoui *et al*., 2017) and repeated-sprint bouts (Gabbett & Mulvey, 2008). Also, due to the high perceptual and physiological load attributed to large volumes of change of direction activities, effective monitoring strategies should be incorporated to inform suitable and appropriate prescription of training.

2.7 MONITORING OF THE TRAINING PROCESS IN FOOTBALL

A clear understanding of how the training process and individual responses to the training stimulus impact upon training outcome is imperative in ensuring that suitable and appropriate training is prescribed to players. These individual responses observed in each discrete player are a consequence of their unique characteristics linked to factors such as genetic predisposition and training history. Figure 2 clearly articulates it is these individual differences, which then partially mediate each individual's training outcomes or responses and, therefore, training adaptation for the same external training load. This relevance of a given training load for a specific individual is frequently termed the internal training load (Impellizzeri *et al*., 2005). Two commonly utilised methods to calculate the internal training load are heart rate and subjective indicators such as RPE.

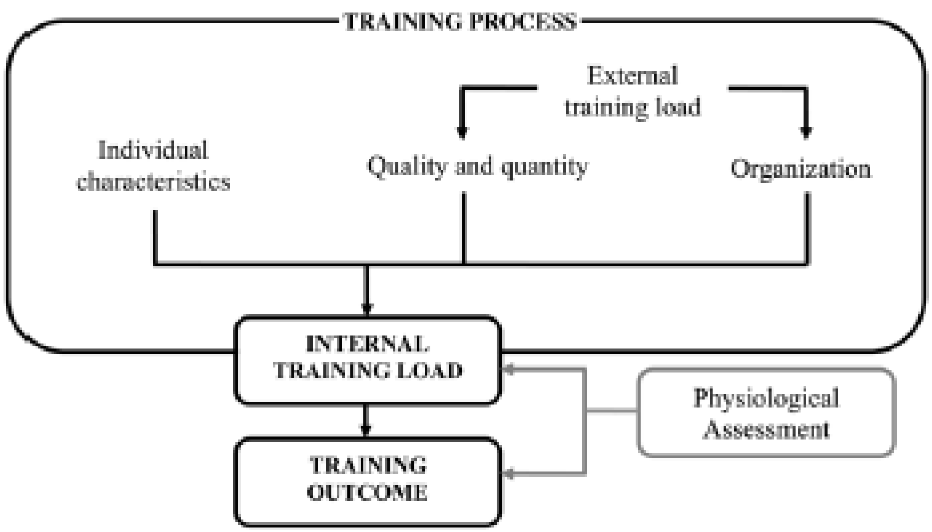


Figure 4. The training process outlining by Impellizzeri *et al*., (2005), which overviews the complex interaction of internal characteristics and external training load factors in determining internal training load and, therefore, training outcome

Several heart rate based internal training load approaches have been proposed and utilised in the literature and practice (Banister, 1991; Edwards, 1993; Lucia *et* al., 2003). Each of these methods attempts to combine heart rate (as a measure of intensity), duration (as a measure of volume) and a weighting factor to calculate the associated internal training load. The differences between the methods are primarily associated with the creation of the heart rate zones that are utilised and the weighting factors attributed to these in any calculations. An attempt to anchor the training load calculations to physiological principles is common (Banister, 1991; Lucia *et* al., 2003) though this approach uses relationships that are established from continuous laboratory exercise tests. As intermittent exercise alters the relationship between heart rate and blood lactate at higher intensities these relationships must be limited in their ability to accurately predict responses related to training and match-play in football. Despite this limitation, the ability of heart rate to be practically applied to give an indication of the internal training load makes heart rate monitoring a useful tool for training load monitoring.

RPE methods gather the perceptual workload of an athlete and, therefore, may be considered a particularly pertinent area of training load monitoring as it may be reflective of both an individual's characteristics and the external training load they are exposed to. Many different approaches have been adopted (Borg 1982; Borg & Kaijser, 2006; Foster, 2001; Foster *et al*., 1995; Weston *et al*., 2005) since it was first introduced (Borg, 1970). The one thing that each variation of approach has in common is that they require an athlete to attribute their own perceptions of internal load to the external load completed with the use of a simple ratio scale. This number, provided as an intensity measure, is then typically multiplied by duration to give a global session-RPE (Foster *et al*., 1995). One benefit is that this approach provides a simple, non-invasive, inexpensive and seemingly valid method for monitoring internal training load (Weston *et al*., 2005). The use of RPE is, however, not without its limitations. It appears that the variability between session-RPE scores is relatively stable even when external training loads vary substantially (Gregson *et al*., 2010). This suggests that the method may not be sensitive enough to significantly differentiate between different training stimuli. It may be up for discussion if this limitation is due to an inability of the athlete to appropriately differentiate between the intensities associated with the scaled ratings or the fact that no exponential weighting factor is attributed to the scale, therefore, possibly underestimating the increasing demands at the higher ranges of the scales.

One method that attempts to add sensitivity to the traditional RPE methods is the use of differential RPE. Differential RPE involves using separate additional scales to quantify breathlessness (RPE-B), leg exertion (RPE-L) and technical demand (RPE-T). This in theory enables the interpretation of different internal training loads from different sensory inputs associated with specific physiological systems (Weston *et al*., 2005). This kind of information may be incredibly useful for practitioners as it may inform the most efficient recovery and preparation interventions by giving specific information for different physiological systems (i.e. the neuromuscular system). The integration of this method alongside GPS and MEMS accelerometers may, therefore, enable the relationships between external training load variables and perceived effort to be more specifically examined in particular reference to different types of workload.

As earlier suggested players' internal training responses are a consequence of their individual characteristics and the external training load they are exposed to. GPS represent one strategy, which is used to establish external training load. The use of GPS has widely been adopted within elite football and are commonly found conveniently harnessed between players scapulae in commercially produced MEMS devises. GPS provide a wide range of variables from a combination of time and distance calculated by positional differentiation (Bourdon *et al*., 2017). It would, therefore, appear intuitive for practitioners to identify which of these variables provide the most relevance to football and which will help inform the training process. Akenhead & Nassis, (2016) monitored current training load practices within elite football identifying the most commonly used GPS derived variables. These included accelerations (across various $m{\cdot}s^{-2}$ thresholds), the total distance and distance covered above 5.5 $m{\cdot}s^{-1}$. Velocity is calculated from the change in distance divided by time or by using the more precise Doppler-shift method (Townshend *et al*., 2008). Acceleration is then subsequently calculated from velocity (Bourdon *et al*., 2017). Velocity and acceleration data may be further processed using smoothing filtering techniques to minimise the inherent 'noise' present (Bourdon *et al*., 2017; Cardinale & Varley, 2017). Although these three variables have been suggested to be the most commonly used variables in football, further analysis is required to establish if they are the most appropriate for the sport.

As previously established football is intermittent and multidirectional. The utility of external training load methods to monitor the change of directions activities, therefore, appears very important. Total distance and distance covered above 5.5 m·s^{-1} are, however, more biased towards locomotion. They would, therefore, be ineffective in appropriately capturing the relevant demands. The other widely employed variable, acceleration, may however, offer some encouragement. It has already been established that the increased demands associated with change of direction is a result of the forces required to decelerate and reaccelerate in these football specific settings. It would, therefore, appear appropriate to directly measure the volume and intensity of these differentiating factors.

Some caution should be taken when using GPS to interpret activities such as acceleration, deceleration, and changes in direction (Bourdon *et al*., 2017). Recent research has attempted to understand the validity and reliability of the devices to measures actions that may have relevance to football. The research suggests that GPS devices are capable of accurately tracking an athlete's distance during team sport activity and possess suitable reliability when the same unit is used (Scott *et al*., 2016). It is also widely accepted that this accuracy increases with a higher sampling rate (Jennings *et al*., 2010; Rampinini *et al.,* 2014; Varley *et al*., 2012). It must, however, be considered that merely accurately describing the total distance a player covers is largely ineffective in capturing the demands of an intermittent sport. Especially one which is characterised by high volumes of changes in speed and direction and performance defined by high speed actions. It is, therefore, particularly pertinent for practitioners to understand that GPS accuracy decreases with increasing speed of movement (Akenhead *et al*., 2014; Jennings *et al*., 2010; Rampinini *et al.,* 2014). The instantaneous nature of some of the change of direction demands associated with football may, therefore, make accurately capturing them via this method limited.

The limitations around the inverse relationship between speed of movement and GPS accuracy is one important consideration that practitioners should be aware of. There are further considerations for practitioners around the processes of collecting, analysing, interpreting and communicating GPS data, which also have huge implications for its accuracy. From a collection and analysis point of view it is important that each player has their own unit assigned to them, thereby, minimising the risk of inter-unit variability in measurement (Jennings *et al.*, 2010). It is also proposed that some form of validation process should occur in conjunction with the use of new hardware/software (Bourdon *et al*., 2017). Important analytical issues such as the dwell time and smoothing filters (associated with acceleration data) should be identified and considered (Malone *et al.*, 2017) during data analysis. This type of information along with a clear understanding of how different activity descriptors are classified may reduce the misinterpretation and communication of data. For example, accelerations are only quantified when time above the given rate of acceleration is achieved. This calculation may not correspond to the subjective interpretation of a player or a coach, therefore, creating a misrepresentation around the expectation of the activities completed in training and games. It is, therefore, imperative that all members of the coaching and high-performance team are educated around how metrics are classified and represent the demands placed on players.

Due to the apparent limitations of GPS devices to accurately and reliably capture the full range of accelerations associated with change of directions demands other measurement solutions should be investigated. In recent years, triaxial accelerometers have been incorporated alongside GPS within MEMS devices. The accelerometers are highly responsive motion sensors that measure the incidence and magnitude of accelerations at the trunk across three dimensions (anterior-posterior, mediolateral and longitudinal) (Boyd *et al*., 2011; Boyd *et al*., 2013). The incorporation of all acceleratory activity within these three planes may offer a potential benefit to more commonly utilised two-dimensional monitoring methods such as video tracking and GPS technologies. This is because of their ability to better recognise the demands associated with changes in velocity. The addition of the third plane (longitudinal) may also enable other important elements of physiological loading, associated with changes in direction and impacts, as well as velocity, to be evaluated (Osnach *et al*., 2010; Varley & Aughley, 2013).

In an attempt to combine the three-dimensional data in evaluations of the total physiological load commercial producers of MEMS devices have devised accelerometer-derived variables. One such variable is PlayerLoad^{TM} (PL), an arbitrary unit that is derived from instantaneous rate of change of acceleration across the three dimensions (Barrett *et al*., 2014). The variable may be attractive to practitioners within elite sport due to it providing (in theory) a snapshot of the multi-planar acceleratory demands via one easily comprehendible value. Each individual commercial MEMS provider utilises different proprietary names for these calculated variables (body load or new body load – GPSports, PL – Catapult Sports, dynamic stress load – Statsports), though in reality they represent very similar outputs. The extent of the information that is available regarding how each of these variables is calculated is also dependent on the commercial company in question, with only the calculation for PL currently made publicly available (Boyd *et al*., 2011). PL is calculated as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (x, y and z axis) divided by 100 (Boyd *et al*., 2011; Montgomery *et al*., 2010). The use of variables such as in both research and practice is partially dependent on its ability to produce consistent results under the same conditions (reliability) as well as measure what it is intending to measure (validity).

From a reliability perspective, it is imperative to establish if PL is reliable within devices, between devices, between participants and within participants. These quality control checks are important to establish if the measurement is consistent and repeatable and within which conditions. Once this is known it may firstly inform the development of robust processes for the collection of information i.e., should each individual wear the same device on each occasion. Secondly, it allows researchers and practitioners to calculate appropriate standard errors of measurements across conditions, ensuring that the interpretation of the data in the applied environment is suitable. The validity of any accelerometer-based variable should also be investigated. It is important to establish ecological validity (the methods, material and setting of the study must approximate the real-world that is being examined (Brewer, 2000)) and criterion-related validity (where a new measurement tool is compared with a previously validated alternative form of measurement tool (George *et al*., 2003)). Once reliability and validity information are gathered, it will provide greater understanding of the accuracy and relevance of the measurement, which in turn will inform how the data should be interpreted and fed back to coaches to inform practice.

The reliability of PL has been investigated under several conditions within the literature over recent years and is displayed in Table 5 (Barreira *et al.*, 2016; Barrett *et al*., 2014; Barrett *et al*., 2015; Boyd *et al*., 2011). The accelerometer-derived variable's reliability has been found to be acceptable both within and between devices under controlled laboratory conditions when using a mechanical shaker as a stimulus (Boyd *et al*., 2011). This type of stimulus is highly controllable. This has the benefit of enabling the reliability of the variable to be assessed precisely as the same stimulus can be applied in each trial. These investigations did, however, use acceleration ranges of less than 3 g. This upper threshold may be appropriate for field sports where very high accelerations above this threshold are not observed but may create problems in the generalisability of the data to other settings where accelerations of more than 3 g may be present. The use of a tightly controlled laboratory setting also leads to some limitations with respect to ecological validity as the activity assessed is not actual human movement. The mixture of random movement patterns associated with human sporting activity may not be the same as systematic mechanical movements therefore impacting the relevance of the data. It is, therefore, imperative that the within and between device reliability is also established within real world sporting environment using appropriate actions.

Studies investigating the reliability of PL within more applied sporting settings have also been carried out (Barreira *et al.*, 2016; Barrett *et al*., 2014; Barrett *et al*., 2015; Boyd *et al*., 2011). The range of applied studies span the spectrum from tightly controlled laboratory based incremental treadmill running protocols (Barrett *et al*., 2014) and controlled football simulation studies (Barreira *et al.*, 2016; Barrett *et al*., 2015) to very uncontrolled, ecologically valid Australian Rules Football matches (Boyd *et al*., 2011). The test-retest of the accelerometer-derived variable was found to be acceptable throughout this range of studies with intra-device reliability ranging from moderate to high (Barreira *et al.*, 2016; Barrett *et al*., 2014; Barrett *et al*., 2015). The between unit reliability and signal: noise ratio was also found to be acceptable when using a competition setting of an Australian Rules Football match (Boyd *et al*., 2011). The findings of these studies would suggest that practitioners could use the accelerometer-derived variable with some confidence. It, therefore, appears that PL is a reliable tool to monitor aspects of external training load during intermittent, multidirectional activity.

Table 5. Summary of PL reliability findings within the reviewed literature

Reference	Participants	Technology	Method	Findings
Barreira *et al.*, 2016	Fifteen male recreational athletes	Viper model (Statsports Technologies, USA) 100 Hz	Modified SAFT[90] completed on three separate occasions (one familiarisation, two experimental). Trunk mounted unit worn each occasion. Jogging, side cut, stride and sprint activities were analysed	PL ICC/ LOA – Jogging = 0.863 / 20.4% Side cut = 0.892 / 19.4% Stride = 0.831 / 37.7% Sprint = 0.949 / 16.8% PL · min−1 ICC/ LOA – Jogging = 0.903 / 17.6% Side cut = 0.921 / 18.5% Stride = 0.806 / 39.7% Sprint = 0.865 / 27.3%

Barrett *et al*., 2014	Forty-four semi-professional and University level soccer players	MinimaxX S4, (Catapult Sports, Melbourne, Australia) 100 Hz	Incremental treadmill test completed on three separate occasions (one familiarisation, two experimental). Two units were worn in each trial – one between scapulae (SCAP), one close to center of mass (COM)	SCAP CV / ICC – PL = 5.9% / 0.93 PLap = 9.1% / 0.92 PLml = 12.0% / 0.80 PLv = 6.3% / 0.93 COM – PL = 5.2% / 0.97 PLap = 7.5% / 0.94 PLml = 11.4% / 0.87 PLv = 7.3% / 0.95
Barrett *et al*., 2015	Twenty semi-professional and University level soccer players	MinimaxX S4, (Catapult Sports, Melbourne, Australia) 100 Hz	$SAFT^{90}$ completed on three separate occasions (one familiarisation, two	SCAP CV / ICC (95% CI) – PL = 3.8% / 0.94 (0.84—0.98)

			experimental). Two units were worn in each trial – one between scapulae (SCAP), one close to center of mass (COM)	PLap = 8.5% / 0.88 (0.70-0.95) PLml = 4.2% / 0.97 (0.93-0.99) PLv = 3.1% / 0.99 (0.96-0.99) COM – PL = 3.6% / 0.95 (0.88-0.98) PLap = 8.7% / 0.90 (0.76-0.96) PLml = 7.7% / 0.90 (0.75—0.96) PLv = 4.9% / 0.94 (0.83-0.97)

Boyd *et al*., 2011	Ten male semi-professional Australian football players currently playing in the Victorian Football League	MinimaxX 2.0 (Catapult Innovations. Scoresby, Victoria) 100 Hz	Static Reliability – Positioned statically for 6x30 sec before 180 min HI team sport activity then 3x30 sec positioned statically. Dynamic Reliability – 8 units attached identically to a hydraulic shaker for 10x10 sec of two protocols. Protocol 1 – 3Hz at 0.5*g*. Protocol 2 – 8Hz at 3.0*g*. Field Assessment – Two aligned units taped	Static Reliability – Within-device CV = 1.0% Between-device CV = 1.0% Dynamic Reliability – 0.5*g* within-device CV = 0.91% 0.5*g* between-device CV = 1.04% 3.0*g* within-device CV = 1.05% 3.0*g* between device CV = 1.02% Field Assessment - Between-device CV = 1.9%

			together were wore for nine AFL matches	Signal (SWD) = 5.88%
Johnston et al. (2012)	Nine well trained male participants	Catapult MinimaxX units (Team Sport 2.5, 5 Hz, Firmware 6.54, Catapult Innovations, Melbourne, Australia)	Each participant completed either 1 or 2 bouts of a Team Sport Simulation Circuit and a maximum of 10x50-m sprints. Two GPS units were worn between the scapulae	Interreliability – PL ICC = 0.87 (very large) PL TEM = 4.9% (good)

Table 6. Summary of the PL validity findings within the reviewed literature

Reference	Participants	Technology	Method	Findings

Barreira *et al.*, 2016	Fifteen male recreational athletes	Viper model (Statsports Technologies, USA) 100 Hz	Modified SAFT[90] completed on three separate occasions (one familiarisation, two experimental). Trunk mounted unit worn each occasion. Jogging, side cut, stride and sprint activities were analysed. Convergent validity was evaluated through within-participant variation in PL and PL · min^{-1} using coefficient of	PL (CV) – Jogging = 14.5% Side cut = 15.2% Stride = 24.5% Sprint = 23.4% P = 0.00 PL.min^{-1} (CV) – Jogging = 18.2% Side cut = 17.8% Stride = 21.2% Sprint = 22.1% P = 0.00

			variation (CV).	
Barrett *et al*., 2014	Forty-four semi-professional and University level soccer players	MinimaxX S4, (Catapult Sports, Melbourne, Australia) 100 Hz	Incremental treadmill test completed on three separate occasions (one familiarisation, two experimental). Two units were worn in each trial – one between scapulae (SCAP), one close to center of mass (COM). PL and HR and VO_2 were compared.	SCAP between-subjects' correlations (HRav) – PL = -0.32 / -0.20 PLap = -0.22 / -0.43 PLml = 0.16 / 0.03 PLv = -0.38 / -0.17 (VO_2) – PL = 0.12 / 0.31 PLap = 0.14 / 0.33 PLml = 0.29 / 0.29 PLv = -0.02 / 0.24 SCAP within-subjects'

				correlations (HRav) – PL = 0.98 / 0.98 PLap = 0.94 / 0.94 PLml = 0.93 / 0.93 PLv = 0.93 / 0.93 (VO_2) – PL = 0.96 / 0.96 PLap = 0.93 / 0.93 PLml = 0.93 / 0.93 PLv = 0.92 / 0.92 COM between-subjects' correlations (HRav) – PL = -0.20 / 0.09 PLap = -0.28 / -0.20 PLml = -0.22 / 0.05

				PLv = -0.11 / 0.16 (VO_2) – PL = -0.03 / 0.09 PLap = 0.19 / -0.02 PLml = -0.02 / 0.13 PLv = 0.02 / 0.00 COM within-subjects' correlations (HRav) – PL = 0.98 / 0.98 PLap = 0.97 / 0.97 PLml = 0.94 / 0.94 PLv = 0.93 / 0.93 (VO_2) – PL = 0.96 / 0.96 PLap = 0.97 / 0.97

				PLml = 0.95 / 0.95 PLv = 0.94 / 0.94
Barrett *et al*., 2016	Sixty-four professional soccer players from three Premier League U21 teams	MinimaxX S4 (Catapult Sports, Melbourne, Australia) 100 Hz	Data was collected from 574 match observations across 86 games. The match recordings were dissected into 15 min periods to assess the within-match patterns of PL, PLap, PLml and PLv and TD. PL was made relative to TD as a measure of players'	0–15 min = sig. greater for PL (0.36–0.43), PLap (0.25–0.38), PLml (0.22–0.38) and PLv (0.29–0.42) in comparison to all other time periods 2nd half = All PL variables progressively decreased in successive 15 min match periods ($p \le 0.01$)

			locomotor efficiency (PL:TD).	No within-match changes in the relative PL% contributions were present. Significant increases were observed for PL:TD towards the end of each half (0.11–0.29). CV (95% CI)- PL = 6.6 ± 2.4 (6.0-7.2) PLap = 8.8 ± 4.0 (7.4-10.4) PLml = 9.0 ± 4.1 (6.9-11.0) PLv = 7.3 ± 2.5 (5.7-8.9)

				TD = 6.6 ± 2.8 (3.5-9.5) PL:TD = 6.4 ± 2.9 (2.0-10.8)
Boyd *et al*., 2013	Forty Australian Football League (AFL) players	MinimaxX 2.0 (Catapult Innovations, Scoresby, Victoria, Australia) 100 Hz	Data was collected from 24 matches and 32 training sessions. Analysis between elite and sub elite players for corresponding positions were conducted. Training analysis was compared between drills.	Elite v sub elite matches PL · min−1 ES (± 90% CI) – Midfielders = 0.59 ± 0.29 small Nomadics = 0.89 ± 0.25 mod Deeps = 0.20 ± 0.43 unclear Ruckman = 0.67 ± 0.59 mod

				PL_{slow} · m−1 ES (± 90% CI) – Midfielders = 0.52 ± 0.30 small Nomadics = 0.68 ± 0.25 mod Deeps = 0.00 ± 0.44 unclear Ruckman = 0.84 ± 0.61 mod Between drills PL · min−1 %diff / ES ± 90% CI – SSG v match practice 14.6% /

				0.37 ± 0.16 SSG v tactical 87.7% / 1.36 ± 0.15 SSG v open 48.8% / 1.04 ± 0.18 SSG v closed 43.1% / 1.05 ±0.15 Match practice v closed 24.9% / 0.72 ± 0.14 Match practice v open 29.9% / 0.73 ± 0.18 Match practice v tactical 63.9% / 1.12 ± 0.15 Tactical v closed 23.8%

				/ 0.65 ± 0.14 Tactical v open 20.7% / 0.51 ± 0.16 Closed v open 0% PL_{slow} · m−1 %diff / ES ± 90% CI – SSG v match practice 84.7% / 1.49 ± 0.16 SSG v tactical 67.7% / 1.16 ± 0.15 SSG v open 103.3% / 1.77 ± 0.17 SSG v closed 81.3% / 1.38 ± 0.14 Match practice v open

				10.1% / 0.31 ± 0.17 Match practice v tactical 9.2% / 0.26 ± 0.15 Tactical drills v closed 8.1 % / 0.20 ± 0.13 Tactical v open 21.2% / 0.55 ± 0.16 Closed v open 10.8% / 0.34 ± 0.15
Casamichana *et al*., 2013	28 semi-professional soccer players of a Spanish Third Division team	MinimaxX, v.4.0 (Catapult Innovations) 100 Hz	In this study, players' training activities were monitored using GPS technology,	Pearson correlation coefficient - PL – TD = 0.70 (large) PL – Edwards TRIMP =

			and the resulting activity categories were assumed as constructs representing individual external load. Convergent construct validity of sRPE and Edwards TRIMP methods were assessed examining their association with objective measures of training activities.	0.72 (very large) PL – sRPE = 0.76 (very large)

Gabbett, 2015	One hundred and eighty-two elite male rugby league players from 11 teams competing in the Queensland Cup rugby league competition	MinimaxX Team S4 (Catapult Innovations, Melbourne, Australia) 100 Hz	PL, 2DPL, and PL_{slow} data was collected from 26 matches (totalling 386 appearances). The data was compared among positional groups. Pearson product-moment correlation coefficients were used to determine the relationships between PL, 2DPL, and PL_{slow} and total collisions and RHIE	Pearson product-moment correlation coefficients - Forwards – PL – 2DPL = 0.97 PL - PL_{slow} = 0.78 PL – TD = 0.83 PL – LSA = 0.83 PL – HSR = 0.72 PL – Collisions = 0.69 PL – RHIE = 0.61 2DPL - PL_{slow} = 0.78 2DPL – TD = 0.79 2DPL – LSA = 0.78 2DPL – HSR = 0.68

			activity for (a) all positions and (b) forwards, hookers, adjustables, and outside backs.	2DPL – Collisions = 0.62 2DPL – RHIE = 0.60 PL_{slow} – TD = 0.64 PL_{slow} – LSA = 0.64 PL_{slow} – HSR = 0.42 PL_{slow} – Collisions = 0.61 PL_{slow} – RHIE = 0.52 Hookers – PL – 2DPL = 0.90 PL - PL_{slow} = 0.91 PL – TD = 0.95 PL – LSA = 0.95 PL – HSR = 0.50

				PL – Collisions = 0.65 PL – RHIE = 0.56 2DPL - PL_{slow} = 0.99 2DPL – TD = 0.85 2DPL – LSA = 0.85 2DPL – HSR = 0.41 2DPL – Collisions = 0.50 2DPL – RHIE = 0.32 PL_{slow} – TD = 0.87 PL_{slow} – LSA = 0.87 PL_{slow} – HSR = 0.41 PL_{slow} – Collisions = 0.52 PL_{slow} – RHIE = 0.35

				Adjustables – PL – 2DPL = 0.94 PL - PL_{slow} = 0.57 PL – TD = 0.57 PL – LSA = 0.57 PL – HSR = 0.14 PL – Collisions = 0.28 PL – RHIE = 0.30 2DPL - PL_{slow} = 0.56 2DPL – TD = 0.55 2DPL – LSA = 0,55 2DPL – HSR = 0.19 2DPL – Collisions = 0.35 2DPL – RHIE = 0.34

				PL_{slow} – TD = 0.33 PL_{slow} – LSA = 0.33 PL_{slow} – HSR = -0.28 PL_{slow} – Collisions = 0.20 PL_{slow} – RHIE = 0.37 Outside backs – PL – 2DPL = 0.95 PL - PL_{slow} = 0.59 PL – TD = 0.50 PL – LSA = 0.50 PL – HSR = 0.26 PL – Collisions = 0.19 PL – RHIE = 0.13 2DPL - PL_{slow} = 0.55

				2DPL – TD = 0.48 2DPL – LSA = 0.48 2DPL – HSR = 0.28 2DPL – Collisions = 0.30 2DPL – RHIE = 0.21 PL_{slow} – TD = 0.37 PL_{slow} – LSA = 0.37 PL_{slow} – HSR = -0.19 PL_{slow} – Collisions = 0.23 PL_{slow} – RHIE = 0.24
Polglaze *et al.*, 2015	Elite male players from the Australian National	Minimax S4 (Catapult Innovations, South	Data from 581 competition	Pearson product-moment correlation

	Hockey Squad	Melbourne, Victoria, Australia) 100 Hz	observations within 105 matches and 647 training observations within 137 sessions was collected and analysed. Competition data was represented by positional groups (STR, AMF, DMF, DEF). Data from different formats of SSGs was analysed from training.	coefficients – Match Absolute TD – PL - STR = 0.694 AMF = 0.863 DMF = 0.808 DEF = 0.863 All = 0.868 Match Relative TD – PL - STR = 0.132 AMF = 0.441 DMF = 0.627 DEF = 0.581 All = 0.486

				Absolute Training TD – PL – All = 0.742 Relative Training TD – PL – All = 0.633
Scott *et al.,* 2013	Fifteen male soccer players from a professional Australian A-League team	MinimaxX 2.0 (Catapult Innovations, Scoresby, Australia)	Data was collected from 29 training sessions. HR, RPE, GPS and accelerometer data was collected for each player. Relationships between the various	Pearson product-moment correlations (95% CI) – PL – sRPE = 0.84 (0.77-0.89) PL – Banister's TRIMP = 0.73 (0.62-0.81) PL - Edwards' TRIMP =

			measures of internal TL and external TL were analysed using Pearson product-moment correlations	0.80 (0.71-0.86)
Sparks *et al.,* 2016	Thirteen male University standard soccer players	MinimaxX V4.0 (Catapult Innovations, Victoria, Australia)	HR, GPS and PL data was collected during 5 soccer matches. A correlation coefficient and confidence interval was calculated to determine the relationship between	Velocity v PL – Correlation (90% CI) – Low (time) = 0.92 (0.90 to 0.94) Low (%) = 0.84 (0.78 to 0.88) Moderate (time) = 0.90 (0.86 to 0.92)

			each variable	Moderate (%) = 0.83 (0.78 to 0.87) High (time) = 0.81 (0.74 to 0.85) High (%) = 0.64 (0.54 to 0.72) HR v PL - Correlation (90% CI) – Low (time) = 0.54 (0.41 to 0.65) Low (%) = 0.24 (0.09 to 0.39) Moderate (time) = 0.61 (0.49 to 0.70) Moderate (%) = 0.37

				(0.23 to 0.50) High (time) = 0.10 (-0.06 to 0.26) High (%) = 0.02 (-0.13 to 0.18)
Wundersitz *et al*., 2015[1]	Twenty-five male athletes competing in the Victorian Rugby Union Premier Division	MinimaxX S4, (Catapult Innovations, Australia) 100 Hz	Peak-impact acceleration data collected from an accelerometer compared to a motion analysis system during physical-collision tasks (10xbump-pad and	Frequency *P* / bias / Cohen *d* - Raw = $P < 0.006$ / 0.60g / 0.28 30 Hz = $P < 0.006$ / 0.34g / 0.16 25 Hz = $P = 0.041$ / 0.21g / 0.10 20 Hz = $P = 1.00$ / 0.01g

			tackle-bag and 5xtackle-drill). Raw accelerometer data and data filtered at several cut off frequencies were compared.	/ 0.01 15 Hz = *P* = 0.06 / -0.31g / -0.15 10 Hz = *P* < 0.006/ -0.92g / -0.47 8 Hz = *P* < 0.006/ -1.33g / -0.69 6 Hz = *P* < 0.006/ -1.87g / -1.03 Band bias / Cohen *d*- <3.0g = 0.08g / -0.20 3.0 – 3.99g = -0.04g / -0.04 4.0 – 4.99g = 0.20g / 0.20

				5 – 5.99g = 0.08g / 0.08 6 – 6.99g = 0.09g / 0.09 7 – 7.99g = 0.04g / 0.04 8 – 8.99g = -0.21g / -0.21 9 - 9.99g = -0.47g / -0.47 >10g = -0.17g / -0.17 Task bias / Cohen *d* – Tackle bag = -0.28g / -0.16 Bump pad = 0.20g / 0.13 Tackle drill = 0.21g / 0.10

Wundersitz *et al*., 2015[2]	76 recreationally active, healthy, male participants competing in one or more amateur team sport competitions per week	Minimax S4 (Catapult Innovations, Australia) 100 Hz	Participants completed a team sport circuit. Accelerations were collected concurrently at 100 Hz using an accelerometer and a 36-camera motion analysis system. The largest peak accelerations per movement were compared in 2 ways: i) pooled together and filtered at 13 different cut-off frequencies	Raw, 25, 20, 19, 18, and 17Hz = 0.22–0.56 (Cohen's *d*); $P < 0.007$ 6 Hz = -0.51 (Cohen's *d*); $P < 0.007$ 16–10 Hz = -0.14 to 0.18 (Cohen's *d*); P = 0.29–1.00 Raw = 1.13 ± 0.83*g* (mean bias); 0.56 (Cohen's *d*); -0.51 to 2.76*g* (95 % LoA); 1.40*g* (RMSEP); 23.4% (CV) 12 Hz = -0.01 ± 0.27 *g* (mean bias); -0.01

			(range 6–25 Hz) to identify the optimal filtering frequency, and ii) the optimal cut-off frequency split into the 7 movements performed	(Cohen’s *d*); −0.55 to 0.53*g* (95 % LoA); 0.27*g* (RMSEP); 5.5 % (CV) Mean Bias ± SD; Cohen’s *d*; 95% LoA; RMSEP; CV – DL Jump = -0.18 ± 0.14*g*; -0.20; -0.45-0.10*g*; 0.23*g*; 4.6% Jog = 0.03 ± 0.13*g*; -0.05; -0.22-0.28*g*; 0.13*g*; 3.7% COD = 0.11 ± 0.20*g*; 0.18; -0.27-0.50*g*; 0.23*g*; 6.2%

				SL Jump = -0.06 ± 0.31*g*; -0.06; -0.66-0.55*g*; 0.31*g*; 5.3% Sprint = 0.14 ± 0.28*g*; 0.20; -0.40-0.69*g*; 0.31*g*; 6.9% Walk = 0.03 ± 0.04*g*; 0.24; -0.04-0.11*g*; 0.05*g*; 6.3% Tackle = -0.18 ± 0.43*g*; -0.14; -1.02-0.67*g*; 1.95*g*;

				4.8% All = -0.01 ± 0.27*g*; -0.01; -0.55-0.53*g*; 0.28*g*; 5.6%

PL has been proposed as a reliable variable for evaluations both within participants and between devices. It has not yet, however, been established as producing reliable data between different participants for a similar task. Variability between participants in accelerometer-derived data is frequently observed (Barrett *et al*., 2014; Barreira *et al.*, 2016). It has been suggested that this variability between individuals is likely to be a result of different locomotive strategies rather than any intrinsic anthropometric differences between individuals (Barreira *et al.*, 2016). This information would indicate that PL values might be limited to the assessment of different training load patterns for an individual over time rather to compare and infer training load differences between individuals. This would suggest that caution should, therefore, be used when comparing PL values between players. Such insights are, as they will have implications for the interpretation of the training load information collected.

It is important for researchers to establish the validity of any measurement tool in addition to the reliability of a measurement tool. Table 6 overviews the PL validity studies within the scientific literature. It is apparent that PL demonstrates sensitivity in identifying between differences within and between match and training scenarios throughout a range of sports. This, therefore, suggests that the measure demonstrates good ecological validity in the sporting environment when applied to relevant movements and activities. Research has investigated PL use during match scenarios where it was found to differentiate between playing position (Boyd *et al*., 2013; Dalen *et al*., 2016; Gabbett, 2015; Polglaze *et al*., 2015), standard of play (Boyd *et al*., 2013) and stage of game (Barrett *et al*., 2016). It has also been found to differentiate between types of training activities (Barreira *et al.*, 2016; Boyd *et al*., 2013; Wundersitz *et al.,* 2015) and between competitive matches and training (Boyd *et al*., 2013; Montgomery *et al*., 2010; Polglaze *et al*., 2015). The sensitivity demonstrated in the available research, suggests that PL may be a valid measure for differentiating between the training loads associated with different training scenarios. Further investigation is, however, needed to establish if this sensitivity is a result of different training volumes, intensities or the specific change of direction demands.

Criterion-related validity may help establish what aspect of training load PL may be closely associated to. Validity of this nature has been investigated by comparing with three-dimensional (3D) motion analysis (Wundersitz *et al*., 2015[1], Wundersitz *et al*., 2015[2]) and training load markers such as distance covered, RPE and heart rate (Barrett *et* al., 2014; Casamichana *et al*., 2013; Gabbett, 2015; Polglaze *et al*., 2015; Sparks *et* al., 2017; Scott *et al.,* 2013). When compared to 3D motion analysis the raw accelerometer data calculated, via Catapult S4 devices, was found to overestimate compared to the concurrent 3D motion analysis acceleration data (Wundersitz *et al*., 2015[2]). When the data was, however, filtered at 20 Hz, the validity of PL during treadmill walking, jogging and running (Wundersitz *et al*., 2015[1]) and rugby specific tackle activities (Wundersitz *et al*., 2015[2]) improved. These findings suggest that acceleratory load, associated with Catapult S4 devices, can differentiate between different locomotive intensities and movements (e.g. tackles). Similar criterion-related validity has been established with both external training load markers such as distance covered (Gabbett, 2015; Polglaze *et al*., 2015; Scott *et al.,* 2013), low speed distance (Gabbett, 2015; Sparks *et* al., 2017) and internal training load markers such RPE (Scott *et al.,* 2013) and heart rate (Barrett *et* al., 2014; Casamichana *et al*., 2013; Scott *et al.,* 2013; Sparks *et* al., 2017). These studies may initially support the notion that PL is a valid marker of training load as it has been suggested that a close relationship exists between PL and distance covered. It should be considered, however, that the variables may simply represent a different approach to representing the same training load data. The close association between total distance and PL has been suggested to be highly dependent upon accelerations measured in the vertical plane (z-axis), which in part represents ground contact while running (Scott *et al*., 2013). This may, therefore, lead to an assumption that there is a direct relationship between PL and the distance covered because of the volume of foot contacts an athlete makes. This should, however, not necessarily be the case, as the triaxial nature of the technology detects movements other than those associated with locomotive biased demands of training. Even so, it appears that some scientists perceive this to be a real problem with attempts made to reduce the large locomotive bias presented.

Three different derivatives of PL have been proposed within the literature that allow accelerometer data to be expressed via a slightly different calculation. One such measure is two dimensional PL (2DPL), which is established from only the accelerations in the medio-lateral and anteroposterior planes (as the vertical vector of the PL equation is removed) (Gabbett, 2015). The second, PL_{slow}, removes any activity above 2 $m \cdot s^{-1}$ (Boyd *et al*., 2013; Gabbett, 2015), which may be useful as this would appear to remove any locomotive based activity and particular capture the multidirectional actions that may typically happen at low locomotive speeds. Although the two variables are derived differently, their purpose appears to be the same for a theoretical perspective i.e. to minimise the impact of linear locomotive demands upon the PL variable. Mathematically these variables allow this modification to be achieved, though this appears to be at the expense of a variable that summarises the total load associated with multidirectional training demands. For example, it does not seem appropriate to assume that change of direction movements do not involve accelerations in the vertical plane. The removal of these accelerations, therefore, would discount some valuable multidirectional derived training load as opposed to providing a better description of the total demands. Similarly, PL_{slow}, which has recently been found to be successful in differentiating the volume and type of physical contact in sports such as Australian rules football and rugby league (Boyd *et al*., 2013; Gabbett, 2015), may miss some key multidirectional training loads associated with greater speeds ($>2 m \cdot s^{-1}$) within football. It, therefore, appears that these two accelerometer based variables may lack sufficient utility for football.

A third accelerometer PL derivative is $PL \cdot m^{-1}$, which is calculated from the ratio of PL: Total Distance (Barrett *et al*., 2016), which displays PL to a relative distance, therefore, possibly offering insight around how the distance was covered. The variable does not appear to discount important external training load information, while attempting to reduce the locomotive bias. As a result, $PL \cdot m^{-1}$, theoretically, appears to be the most valid variable of the PL derivatives proposed for describing the multidirectional demands associated with activity. As the variable is expressed relative to distance, it appears to offer the practitioner a density marker of but not an accumulated volume of the multidirectional demands. It should, therefore, be considered that the variable will offer little insight when viewed in isolation. Instead, it may be most effective when considered in combination with a training load marker, which appropriately captures the volume of training that PL per meter ($PL.m^{-1}$) appears to miss.

The reliability and validity of accelerometers under certain conditions, along with their increased accessibility has resulted in their increased use across sports. The technology is widely adopted as a training load quantification tool in football (Barrett *et al*., 2015; Barrett *et al*., 2016; Barreira *et al.*, 2016; Dalen *et al*., 2016; Scott *et al.,* 2013), Australian rules football (Boyd *et al*., 2011; Boyd *et al*., 2013; Cormack *et al*., 2013), rugby union (Wundersitz *et al.,* 2015), rugby league (Gabbett, 2015), basketball (Montgomery *et al*., 2010) and hockey (Polglaze *et al*., 2015). While the available literature provides some confidence with respect to key measurement issues it must still be firmly established if the information that the technology provides can add insight to the data that is already collected to support the description and evaluation of the training process. The current literature, however, does not appear to have attempted to establish if this acknowledged sensitivity is merely a consequence of the differing locomotive load between scenarios. It, therefore, appears that the literature is inconclusive in identifying PL as a suitable training load variable for summarising the multidirectional loads associated with training. In fact, attempts have been made to use derivatives of the variable to more efficiently establish these multidirectional training loads, however, limitations to these methods have also been proposed. It, therefore, appears that further research is needed to establish if PL or one of its derivatives are in fact appropriate to evaluate the multidirectional training loads, which are so difficult to quantify in field based team sports.

2.8 SUMMARY

In summary, the literature suggests that the multidirectional and intermittent requirements of football appear extremely important for match performance. It is, therefore, imperative that coaches suitably prepare players for these demands within training. There does not, however, appear to be much practically orientated research that has been conducted in an elite football environment to demonstrate that this may be the case. In fact, very little training load information from Premier League clubs has been made publicly available within the literature. It, therefore, appears pertinent to further explore what typical training load patterns in preparation for match play look like in an elite Premier League population. Due to the limited research in the area it is also unknown if training patterns are consistent between different coaching groups or if similarities are present. This will, therefore, be investigated also.

One area that there does appear to be some consensus within the literature is that a restriction in space, either within football related activities or isolated running based activities, appears to be related to greater change of direction demands. Due to the earlier referenced importance of multidirectional activity for football performance, this appears to be an important training design consideration. The effective and convenient monitoring of these manipulated demands does, however, appear to be a challenge that is faced within research and practice. The commonly utilised and reported monitoring approach of using distances in specific speed thresholds does not adequately capture these changes in movement requirements and, therefore, does not appropriately evaluate the complete physical requirements of football. The ability to effectively and conveniently monitor the movement requirements associated with these changes in training session design does, therefore, appear to represent a gap within practice and research. It is, therefore important that the current research explores an effective method of monitoring football demands.

The research literature associated with monitoring methods such as GPS, MEMS accelerometer, internal and perceptual measures of load have all been presented herewith and their utility and limitations discussed. Due to the apparent mixed research observations and practical applications of these methods, further investigation with reference to their relevance to the specific movement requirements of elite football training methods and activities is required. The research around MEMS accelerometer variables appears to offer the most potential due to its relevance to movement rather than locomotion and the associated reliability, validity and accessibility reported within the current literature. It is, therefore, imperative that this technology in particular is appropriately investigated in relation to its utility to effectively capture the movement requirements in football training. This will be explored in ecological valid, uncontrolled elite football training and within a semi-controlled manipulation of football training.

CHAPTER 3

TRAINING LOAD PATTERNS WITHIN PREMIER LEAGUE FOOTBALL – DIFFERENTIATED BY VOLUME NOT DENSITY

3. TRAINING LOAD PATTERNS WITHIN PREMIER LEAGUE FOOTBALL – DIFFERENTIATED BY VOLUME NOT DENSITY

3.1 RESEARCH ORIENTATION

One of the key unwritten responsibilities of any football fitness coach/ sport scientist is to act as the conduit between departments (science, medicine, players and coaching), consistently communicating messages between the disciplines and relevant members of staff. The revered role of presenting the post-training training load report to the head coach is one of these very tasks. This daily routine is a very important event in the role of an applied sport science as it is the big opportunity to have a private audience with the gatekeeper to the most important processes that occur within a Premier League training ground. I often use the occasion to discuss observations and interpretations around training and attempt to inform training design for the next day's session. The format and structure of these encounters is extremely dependent upon the head coach in post. The personality, mood and current work load of the individual must be taken into account when framing these conversations. It has been my experience that every head coach has their own individual preference of how they would like to receive this information, however, this was not always clearly articulated and more often than not I would have to use my intuition to decipher how best to deliver the information. For some head coach's this would be very formally in a meeting scenario, while for other head coaches this would be a huge professional taboo. Instead I would have to think laterally about how best to deliver the messages around training; maybe in the canteen, the gym, the dressing room or on the training pitch. One thing that has been very apparent to me in recent times is that when fulfilling this role, the variables that I have been recording and feeding back to coaches, medics and players via daily training reports and conversations do not appear effective at capturing the differences between coaching methods and different types of training.

This observation is one of the large motivating factors for formulating the current research problem and the rationale for the aim of the thesis in question. I spend every training session on the grass supporting the delivery of the training process. Due to this role I have a clear understanding of the coaches training philosophies and the principles of play, which inform these. I also get a real 'feel' for the associated demands players are exposed to. It is these observations, combined with my responsibilities of capturing these demands via GPS, MEMS accelerometery and heart rate, which have led me to realise that the current methods and measures I am using do not seem to be appropriate at capturing the full picture of the training load that players are exposed to in reference to change of direction demands. If this is a true limitation, then it may be having huge implications on the effectiveness of the information I am delivering to coaches and how I am informing practice.

This trail of thought has led me to think that I should see if the variables I have been collecting, interpreting and feeding back over recent seasons demonstrate differences between the coaching groups I have worked with. Due to my fortunate (or unfortunate) experience of working as part of the same sport science department under the leadership of five different head coaches I have access to a longitudinal data set, which lends itself to suitable comparisons. Each of these head coaches have demonstrated very different training and coaching methods. One may be perceived to have included large volumes of position specific patterns of play, another has included lots of conditioned small sided games and possessions, another lots of tactical based team shape work, while another was more likely to prescribe greater volumes of realistic 11v11 based matches on a full pitch. One thing is for sure they have all demonstrated clear differences in training methods and, therefore, the associated change of direction demands. Subjectively, I have definitely observed differences in the associated movement requirements. We have not, however, been capturing this type of demand very effectively. I, therefore, want to formally interrogate the evidence more forensically to explore if my assumptions are correct. A comparison between the training loads associated with each of the head coaches, therefore, appears like an appropriate place to start to answer the research question.

Each section of the current study is split into two sections; Part A – The Research and Part B – The Dissemination. Part A is structured as a traditional scientific study, overviewing the investigation that took place to answer the research question and scientific aim. Part B overviews the Introduction, Methods, Results and Discussion relating to the video animation dissemination strategy that was conducted.

3.2 INTRODUCTION

3.2.1 Part A – The Research

The modern Premier League football player has seen the physical demands increase in recent years (Barnes *et al*., 2014). This, coupled with the global attention and financial importance of match outcomes requires teams to attempt to optimise their training processes in preparation for competition. While the general approach to football training is relatively well researched within the scientific literature (Bangsbo, 2006; Hill-Haas *et al.,* 2011; Reilly, 2005) and is frequently described at a practical level, the amount of research which specifically investigates the loading patterns of this training (periodisation) is relatively scarce. Investigations of this nature would be particularly valuable as it may help inform training practice, directing coaches towards effective loading patterns for performance and/ or development.

The limited amount of research on the perioidisation of training within elite football appears to suggest that little variation is present between mesocycles and between microcycles (Malone *et al*., 2015). This may suggest that periodisation in its traditional sense does not dominate the strategies used by coaches to prepare players. On smaller time scales of planner, such as a microcycle (i.e. 7 days of training) periodisation strategies do, however, become visible (Malone *et al*., 2015, Anderson *et al*., 2016). Such principles are represented by the numerous studies that have reported a taper of training load in preparation for a fixture (Akenhead *et al*., 2015; Anderson *et al*., 2016; Malone *et* al., 2015; Thorpe *et al.,* 2015). One-day (Malone *et* al., 2015; Thorpe *et al.,* 2015), two-day (Anderson *et al*., 2016) and four-day tapers (Akenhead *et al*., 2015) have all been observed. This taper in training volume is not echoed in training intensity, which has been found to be maintained throughout the training week as no statistical differences in density ($m.min^{-1}$) have been observed between days (Akenhead *et al*., 2015). The differences in approaches observed suggests that there may be considerable inter-individual approaches in the planning and implementation of the micro-cycles used within the sport. It has been suggested that the length of taper within Premier League football is reliant upon the subjective philosophy of specific key decision makers such as managers and coaches.

The research related to training load in elite football has yet to investigate if different coaching groups working within the Premier League employ different in-season training load patterns in preparation for matches as studies have largely been restricted to investigations that relate to a single team and a single coach. Previous research has also been limited by the training load variables that have been used when investigating the training load patterns employed. This minimalist approach may mean that some insight around the training load patterns utilised in the Premier League may have been overlooked. For example, the locomotive demands (total distance covered and meters per minute) investigated may describe the volume and density of training approaches, however, they fail to capture details around the different types of training methods utilised. The current study will, therefore, investigate if different Premier League coaching groups employ different training load patterns within a week in preparation for a match. The patterns used by four different coaching groups employed at a Premier League club will be described. Furthermore, a range of training load variables will be examined to investigate if different variables in this type of analysis may help differentiate between the coaching groups training methods and hence better describe training patterns.

3.2.2 Part B – The Dissemination

Certainly, one of the greatest challenges to researchers, be they applied practitioner-researchers or academics, is to disseminate the research accessibly to the target audience where it is hoped to have an impact. Impact is defined by the Research

Councils UK (2018) as ‘the demonstrable contribution that excellent research makes to society and the economy.’ It has recently been highlighted within the sport science literature that traditional academic publication may demonstrate limitations in regard to effectiveness of dissemination and impact (Barton, 2017; Buchheit, 2017; Reade & Hall 2008). It has been suggested that the constraints are that it takes years to reach publication due to its paper format (Reade & Hall 2008) and remains inaccessible to most coaches, athletes and practitioners due to the cost of journal subscription (Reade & Hall 2008). To have a demonstrable contribution, research must reach its desired population efficiently and effectively. It is, therefore, imperative that the sport science community think innovatively to maximimse research translation.

One approach to research dissemination that has proved very popular over recent years is infographics. An infographic is the graphic visual representation of information (Anon, 2018). The French researcher, Yann Le Meur, has pioneered this method within the sport science field, frequently representing academic research in this format, sharing it online (Le Meur, 2018) and via social media through a twitter account (@YLMSportScience) that reaches 71.3k followers. The strength of this approach to dissemination is the attractive and easily digestible way that information can be presented, via the use of graphs, diagrams and figures. The information can also be rapidly disseminated to the intended audience using vehicles such as social media. This results in the content being widely available to the industry.

The current research will, therefore, aim to utilise contemporary visualisation techniques via software packages such as PowerBi (data visualisation) and GoAnimate (video animation) to innovatively display the findings of the study. The creative visualisations will allow the key findings to be shared in the future with the applied football science community via social media. This process will provide an opportunity to develop and evaluate new dissemination skills which may be of benefit professionally in the future.

3.3 METHODS

3.3.1 Part A – The Research

3.3.1.1 Participants

99 elite outfield football players from a Premier League team (mean ± SD: age 28 ± 5 years; height 1.52 ± 0.07 cm; body mass 83.2 ± 7.4 kg) participated in the study. All senior professional outfield players training with the club's First Team were included in the study. No goalkeepers were included. All players provided written consent for their training data to be used for the purposes of the study. The study was conducted according to the requirements of the Declaration of Helsinki and was approved by the University Ethics Committee of Liverpool John Moores University.

3.3.1.2 Experimental Design

To investigate if any differences existed between the training load patterns employed by four different Premier League coaches employed at the same Premier League Football Club a large data set from several successive seasons was analysed. A retrospective approach was, therefore, chosen for the study. This approach was possible as a consequence of the continuity of scientific support staff and data collection processes across a number of seasons in the club in question. All first-team training data that had previously been collected and analysed for a period of four seasons (560 training day observations) was included and further analysed. This data had previously been collected, analysed and stored within standardised excel (Microsoft, Redmond, USA) spreadsheets. These multiple excel spreadsheets were, therefore, firstly collated into one large dataset for further analysis for the research study. All field based training, both group and individual, was included. All gym based training was excluded as it was not directed by the coach and not reflective of their field based training methods. No data from competitive Premier League or cup matches was included in the study as a result of the de-limitation to examine training activities in isolation. As the study was retrospective in nature, the design or implementation of training sessions was not influenced in any way by the investigation. Training was either completed at the football club's outdoor training pitches or at a relevant training venue during a team training camp.

3.3.1.3 Data Collection

At the time of initial data collection, each player's physical activity during each training session was monitored using MEMS tracking devices (S4 & S5, Catapult Sports, Melbourne, Australia). A recognised limitation of the study is that different MEMS units were used during the duration of the study, this is discussed further in the discussion. The MEMS units included a GPS chip, accelerometer, gyroscope and magnetometer technology and heart rate monitors (Polar T31, Helsinki, Finland). The MEMS device used in this investigation sampled GPS at 10 Hz to record time motion analysis data. For data to be included the number of satellites exceeded 6 and have a horizontal dilution of precision (HDOP) that was less than 1.5. The tri-axial piezoelectric linear accelerometer (Kionix: KXP94) contained within the MEMS tracking device sampled at a frequency of 100 Hz (Barrett *et al*., 2016). The output of the MEMS accelerometer measuring ± 13 g (Barrett *et al*., 2016). The device contained a microprocessor with 1GB flash memory and a USB interface to store and download data (Barrett *et al*., 2016). The device was powered by an internal lithium ion battery with 5 h of life weighing 67 g and is 88 × 50 × 19 mm in dimension (Barrett *et al*., 2016). The firmware was continually updated in line with the manufacturers recommendations and the most up to date version was always installed at the time of data collection. Prior to the start of each season units were calibrated in line with the manufacturers guidelines.

The MEMS devices were activated for 30-mins under open sky before data collection to allow acquisition of satellite signals as per manufacturer's instructions. The MEMS device was then fitted in a small neoprene pouch within an undergarment with the unit located posteriorly between the scapulae. Heart rate monitors were worn around the torso, level with the xiphoid process. To minimise inter-unit variability, players were assigned their own MEMS device and heart rate monitor, which was worn by the individual during each training exposure. All players were well familiarised with training in the MEMS tracking device and heart rate monitor. During the original data collection, the time for the start and end of each separate discrete training activity and the head coach responsible for training was noted by the lead researcher.

3.3.1.4 Data Analysis

Following each training session, data recorded on the MEMS device was downloaded on the relevant commercially available software package (Sprint & Openfield, Catapult Sports, Melbourne, Australia). A recognised limitation of the study is that different software was used during the duration of the study, this is discussed further in the discussion. As the study was designed to examine the utility of a range of training load variables, total distance (TD; m), meters per minute ($m.min^{-1}$; m), PL^{TM} (PL; au) and training impulse (TRIMP; au) were selected for analysis. TD and $m.min^{-1}$ were calculated from GPS. The GPS variables were chosen to offer an insight into the locomotive volume and density, respectively. PL was calculated from accelerometry data and was determined from the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (x, y and z) and divided by 100 (Boyd *et al.,* 2011). Heart rate was recorded every 5-sec during training. The relevant TRIMP was calculated for each training activity via the relevant commercially available software package. TRIMP was calculated from assigning an intensity of 1, 1.2, 1.5, 2.2, 4.5 and 9 to the time spent in the respective heart rate zones, 0-50%, 50-65%, 65-75%, 75-85%, 85-92%, 92-100% heart rate maximum.

All training session data was split into the separate discrete activities within each training sessions. The start and end times noted during the session were verified by the velocity curves displayed within the software upon download, which allowed players' movements to be identified. This enabled the relevant period of activity associated with the training to be selected and total session duration to be recorded. The data was then downloaded from the software into excel via comma-separated value (CSV) reports. Each training day was categorised for two key factors; the head coach responsible for the training design and delivery, and the training day's relative position (in days) from a match day (MD+1, MD+2, MD-4, MD-3, MD-2 and MD-1). Both details were recorded within the excel spreadsheet. At the stage of data analysis, the seasonal excel spreadsheets from each of the four seasons was amalgamated for further analysis. Only data collected from training days that occurred within a typical weekly training schedule were included in the amalgamated data set. All other training data (i.e. international breaks) was excluded from the data set.

3.3.1.5 Statistical Analysis

The mean and standard deviation (mean ± SD) were calculated for all variables across all coaches and for relative training days in the micro-cycle. All differences are presented as means with 95% confidence limits (mean ± 95% CL). Cohen's d effect sizes were calculated from the ratio of the mean difference to the pooled standard deviation to establish standardised differences. Effect sizes of <0.20 represented trivial, 0.21-0.50 small, 0.51-0.80 moderate, >0.81 large differences. A magnitude-based inference approach was used to interpret practical significance between group differences. The threshold for change considered to be practically important (the smallest worthwhile change (SWC)) was 0.2 multiplied by the between subject standard deviation, based on Cohen's d effect size principle. The probability that the magnitude of change was greater than the SWC was rated as <0.5% most unlikely, 0.5-5% very unlikely, 5-25% unlikely, 25-75% possibly, 75-95% likely, 95-99.5% very likely and 99.5-100% most likely. The probability was rated as unclear if the chance of a substantially positive and negative effect were >5%.

3.3.2 Part B – The Dissemination

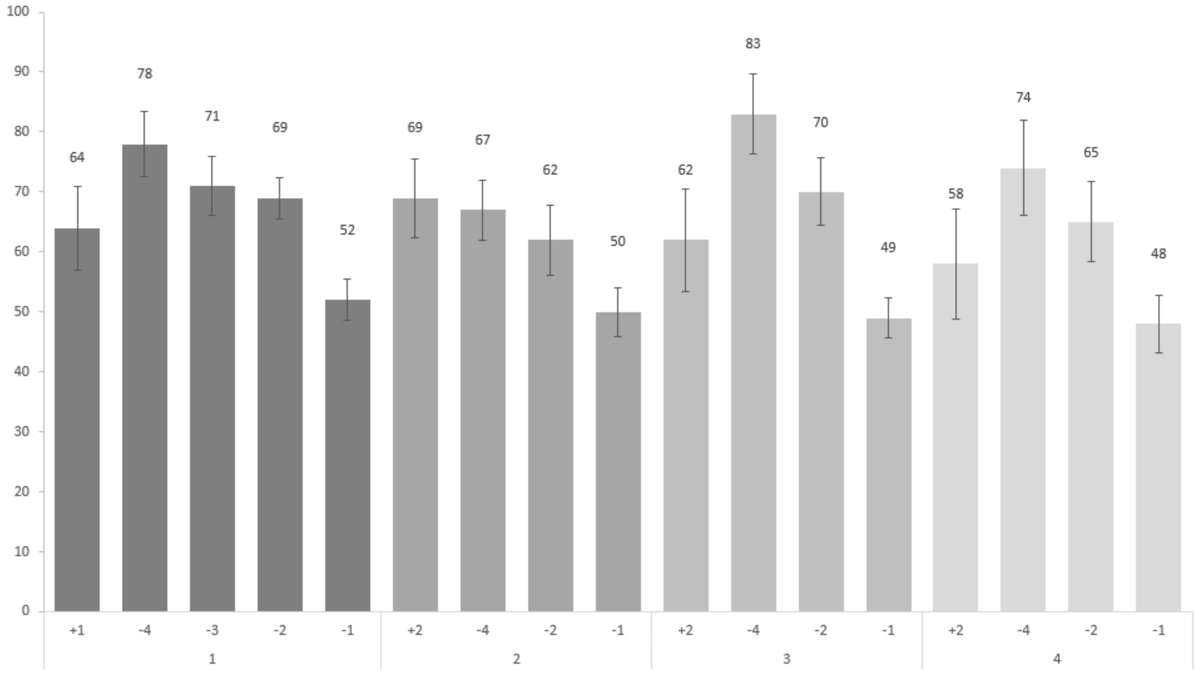
Following organisation of the data, the multiple season excel based data set was uploaded into the data visualisation software package, PowerBi (Microsoft, Redmond, USA). The software was then utilised to visualise the independent and dependent variables in multiple scatter plots, bar charts and histograms. Once the data was appropriately visualised, the video animation package, GoAnimate (San Mateo, USA), was used to create two short films overviewing the key findings of the research.

3.4 RESULTS

3.4.1 Part A – The Research

The figures below overview some of the visualisation and analytical comparisons of the data. Figures 1-5 display some of the within microcycle training load pattern visualisations. Figures 6-11 display the analytical comparisons that were made between coaches. Figures 12-15 display the analytical comparisons that were made between typical training days. This wide data interrogation and analysis occurred ahead of the key findings being described in the video animation. No written commentary supports the figures, as the video animation is the chosen method of disseminating the associated explanations.

TD (m)

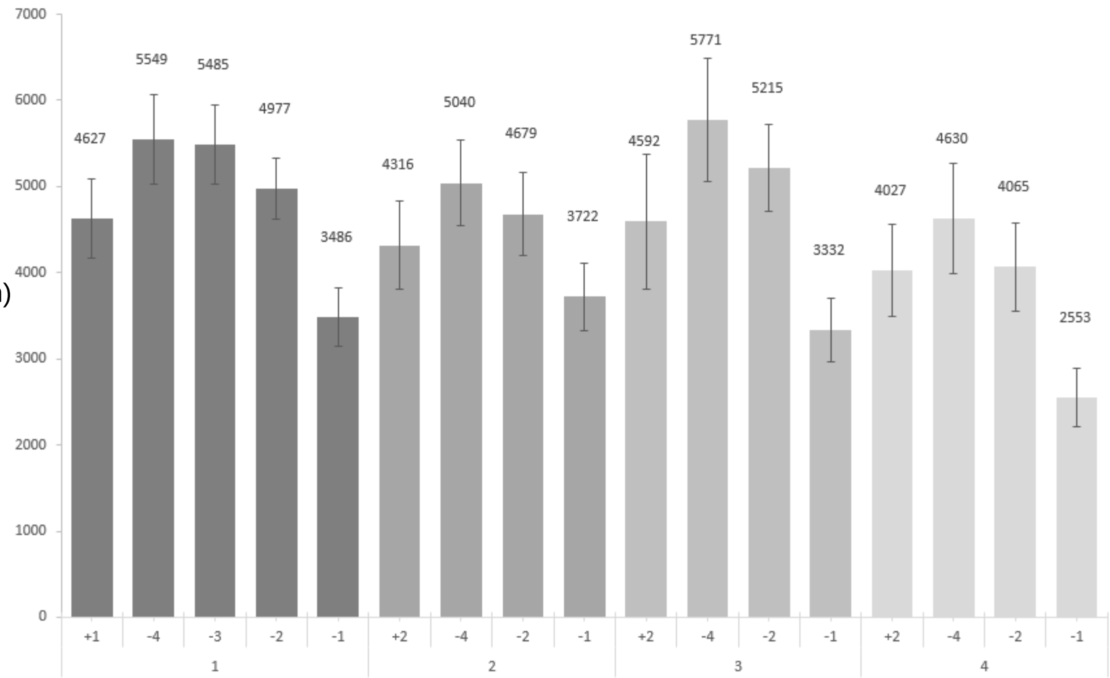


Typical training day (days relative to match day)

Coach

Figure 5. Duration (mean ± SD) for each typical training day employed by a Premier League football team across four different coaching groups

Duration (min)



Typical training day (days relative to match day)

Coach

Figure 6. TD (mean ± SD) for each typical training day employed by a Premier League football team across four different coaching groups

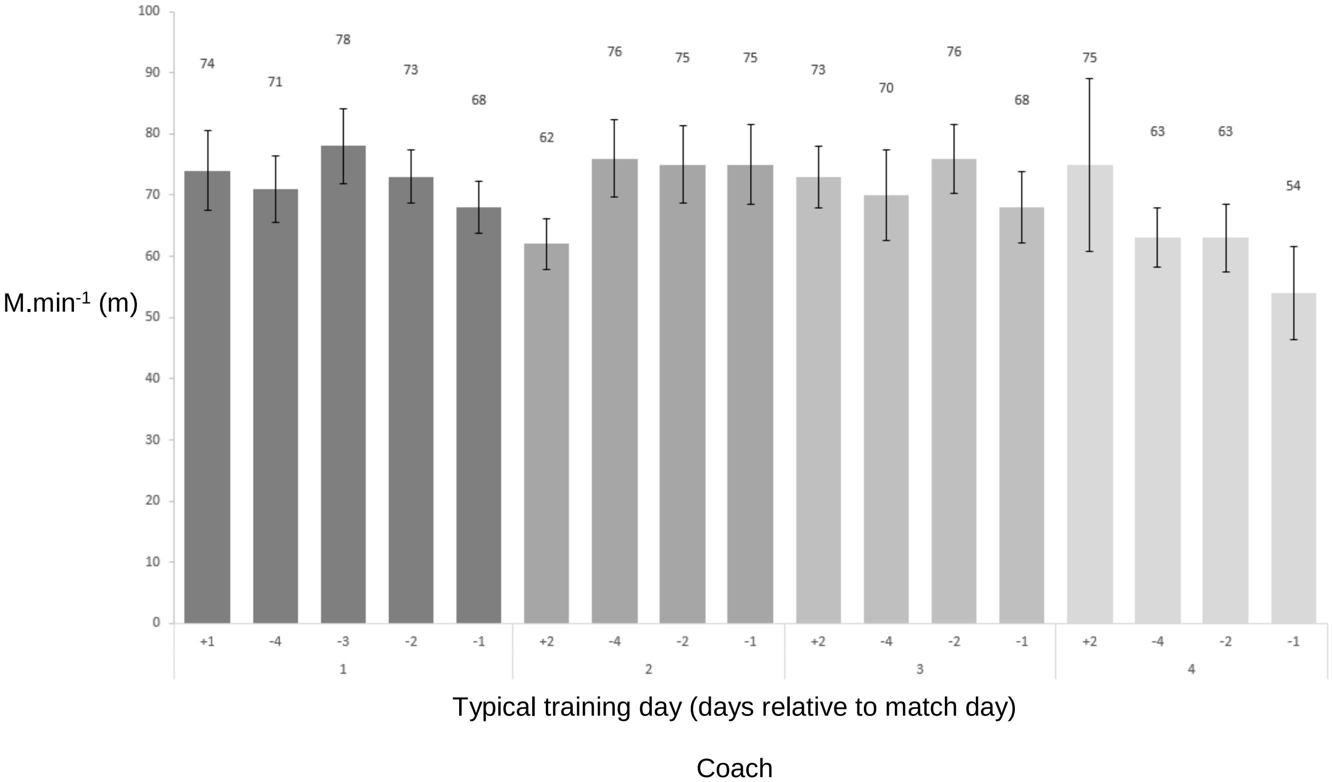


Figure 7. M.min^{-1} (mean ± SD) for each typical training day employed by a Premier League football team across four different coaching groups

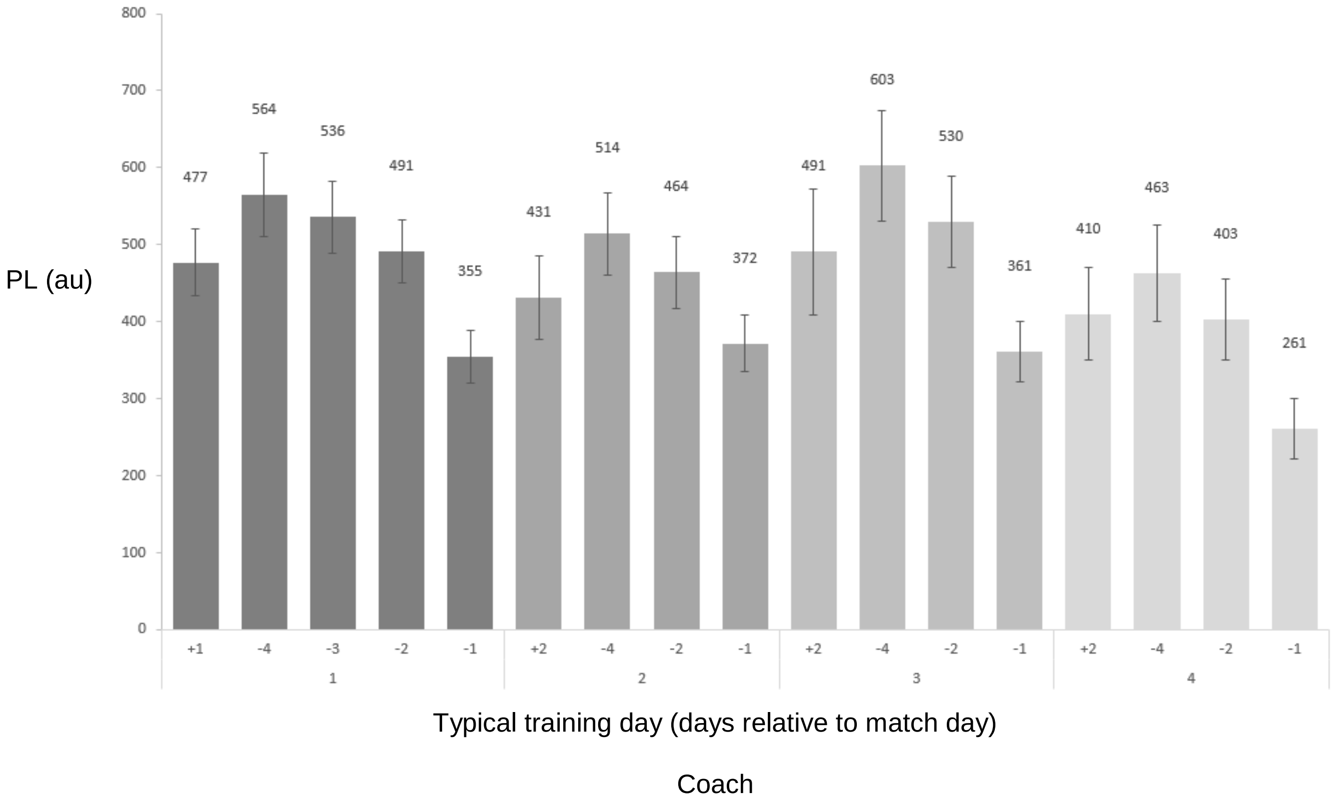


Figure 8. PL (mean ± SD) for each typical training day employed by a Premier League football team across four different coaching groups

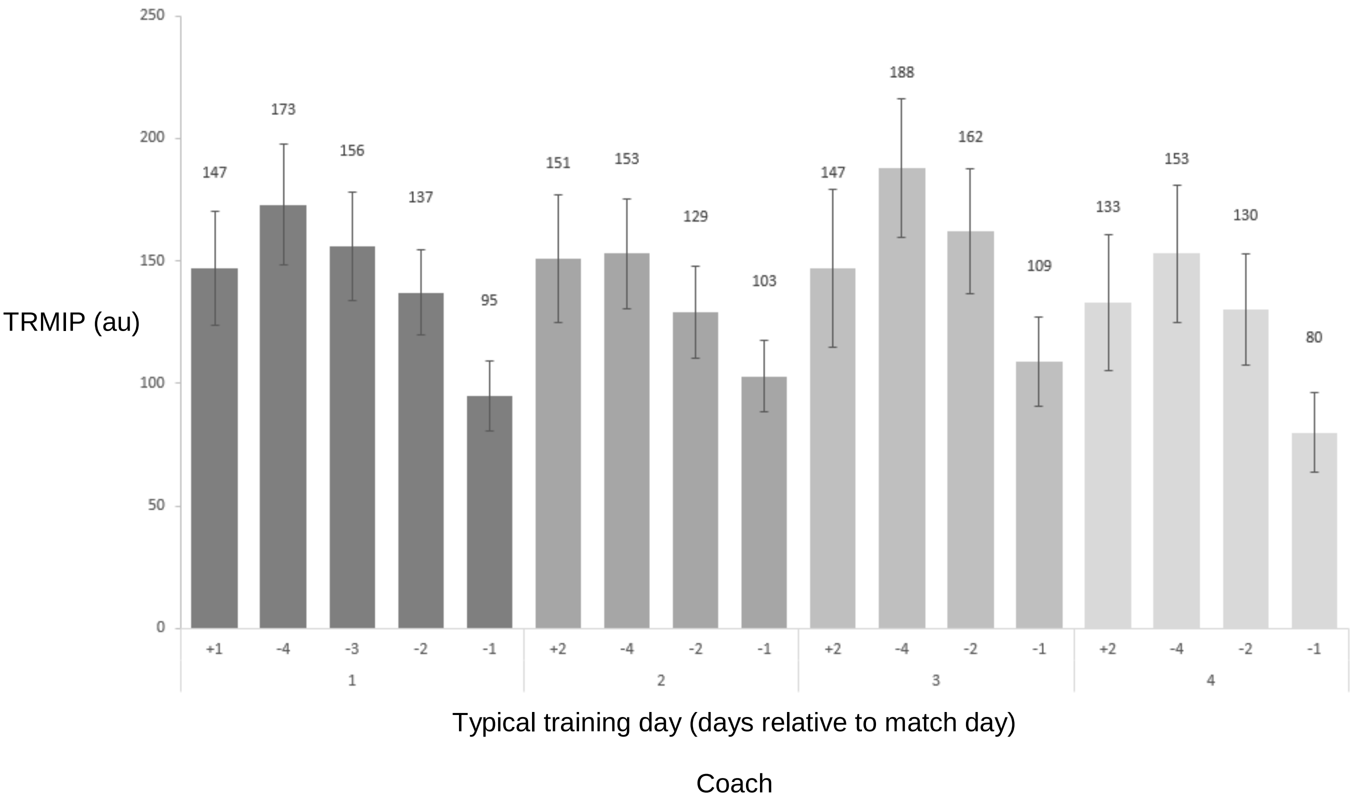


Figure 9. TRIMP (mean ± SD) for each typical training day employed by a Premier League football team across four different coaching groups

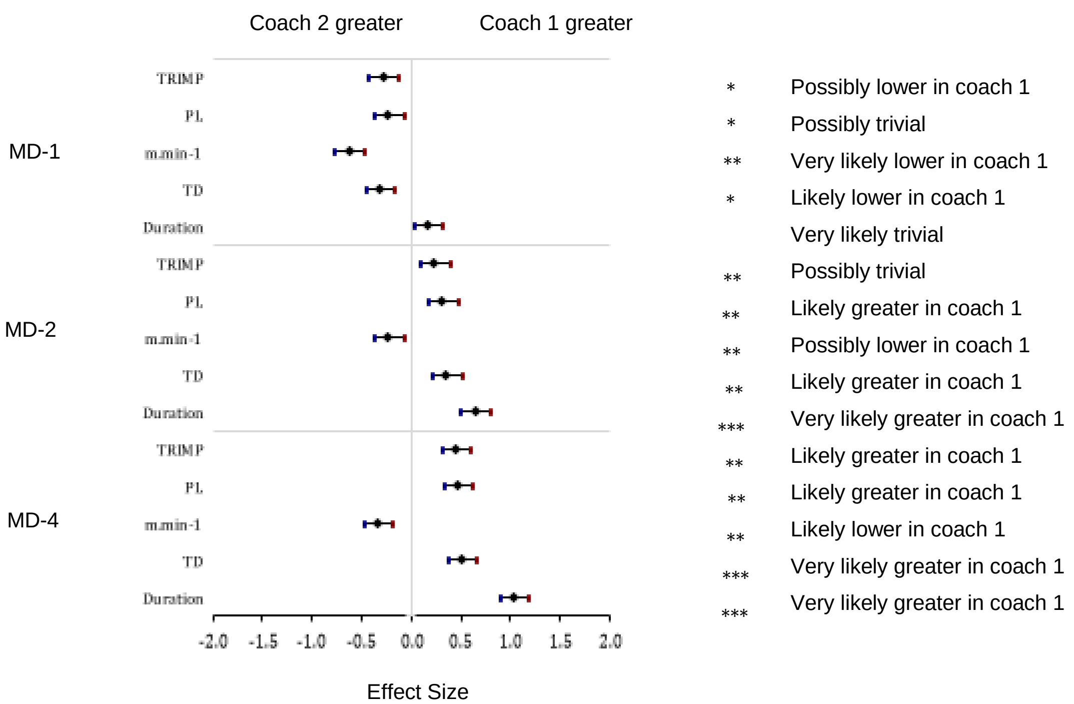


Figure 10. Cohen's D effect size ± 95% CL differences for training load variables between coach 1 v coach 2 across three typical training days (∗ = 0.21-0.50, small;

∗∗ = 0.51-0.80, moderate; ∗∗∗ = >0.81 large differences) (magnitude-based inference)

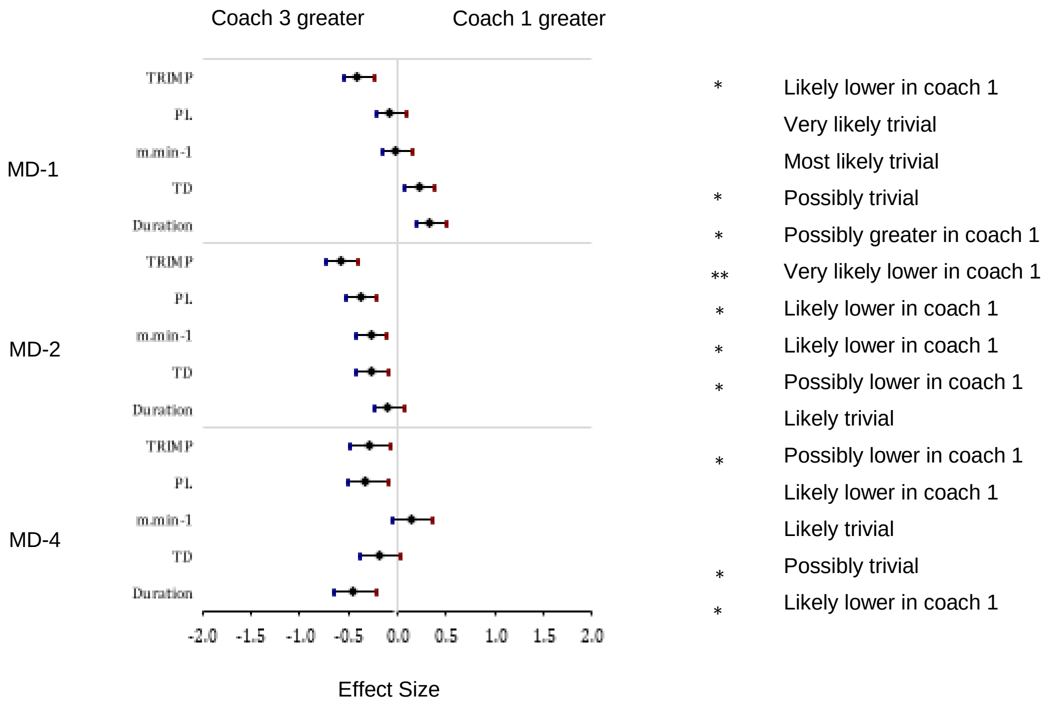


Figure 11. Cohen’s D effect size ± 95% CL differences for training load variables between coach 1 v coach 3 across three typical training days (∗ = 0.21-0.50, small; ∗∗ = 0.51-0.80, moderate; ∗∗∗ = >0.81 large differences) (magnitude-based inference)

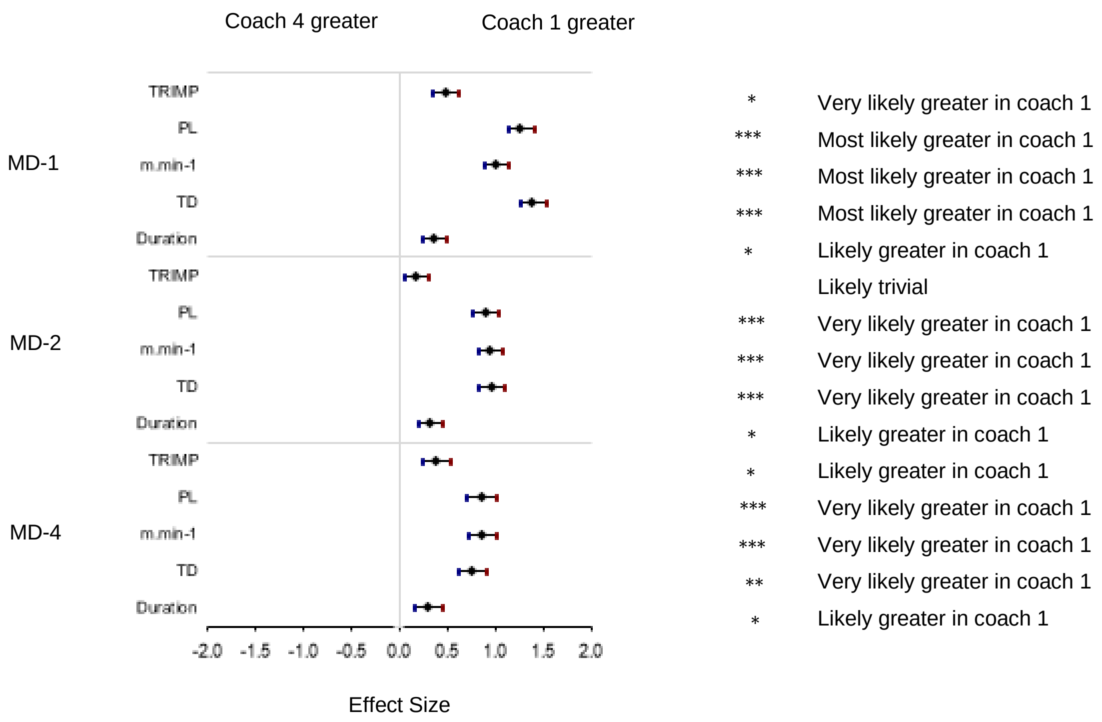


Figure 12. Cohen's D effect size ± 95% CL differences for training load variables between coach 1 v coach 4 across three typical training days (* = 0.21-0.50, small; ** = 0.51-0.80, moderate; *** = >0.81 large differences) (magnitude-based inference)

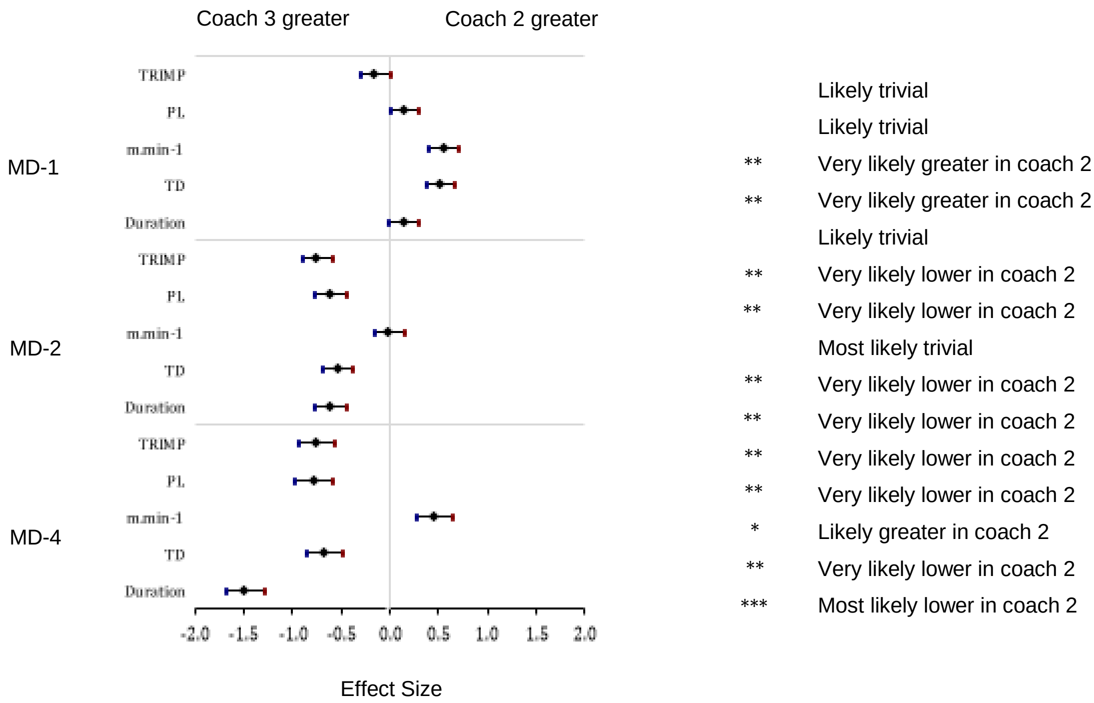


Figure 13. Cohen's D effect size ± 95% CL differences for training load variables between coach 2 v coach 3 across three typical training days (∗ = 0.21-0.50, small; ∗∗ = 0.51-0.80, moderate; ∗∗∗ = >0.81 large differences) (magnitude-based inference

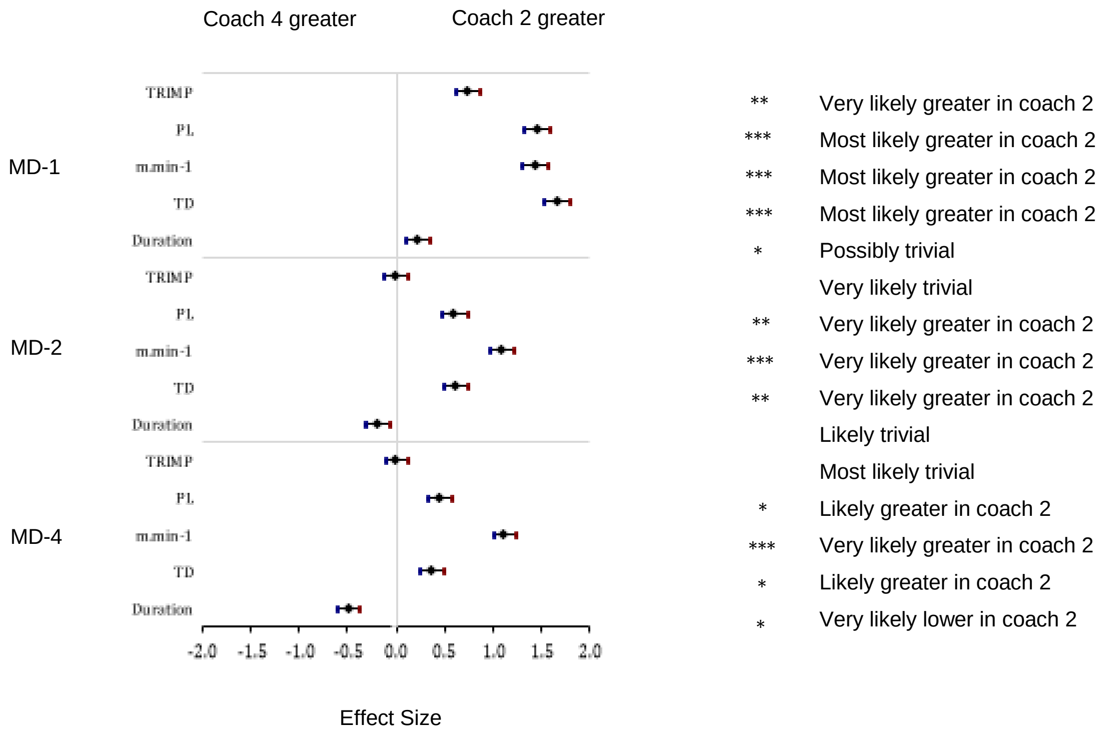


Figure 14. Cohen's D effect size ± 95% CL differences for training load variables between coach 2 v coach 4 across three typical training days (∗ = 0.21-0.50, small; ∗∗ = 0.51-0.80, moderate; ∗∗∗ = >0.81 large differences) (magnitude-based inference)

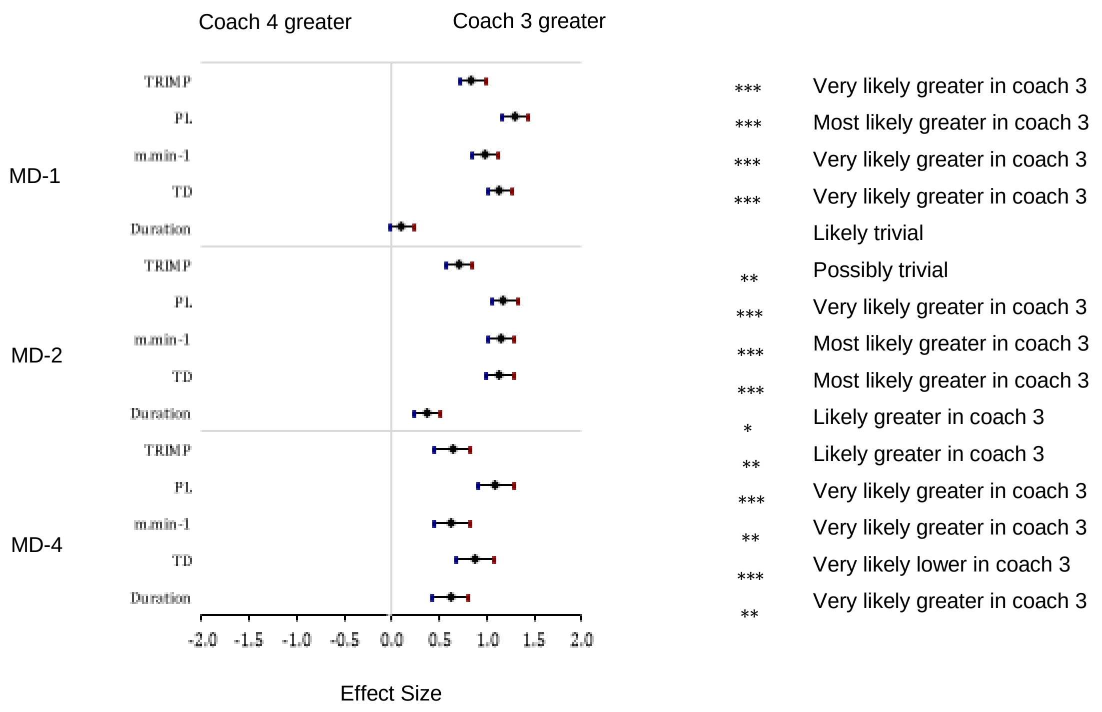


Figure 15. Cohen's D effect size ± 95% CL differences for training load variables between coach 3 v coach 4 across three typical training days (∗ = 0.21-0.50, small; ∗∗ = 0.51-0.80, moderate; ∗∗∗ = >0.81 large differences) (magnitude-based inference)

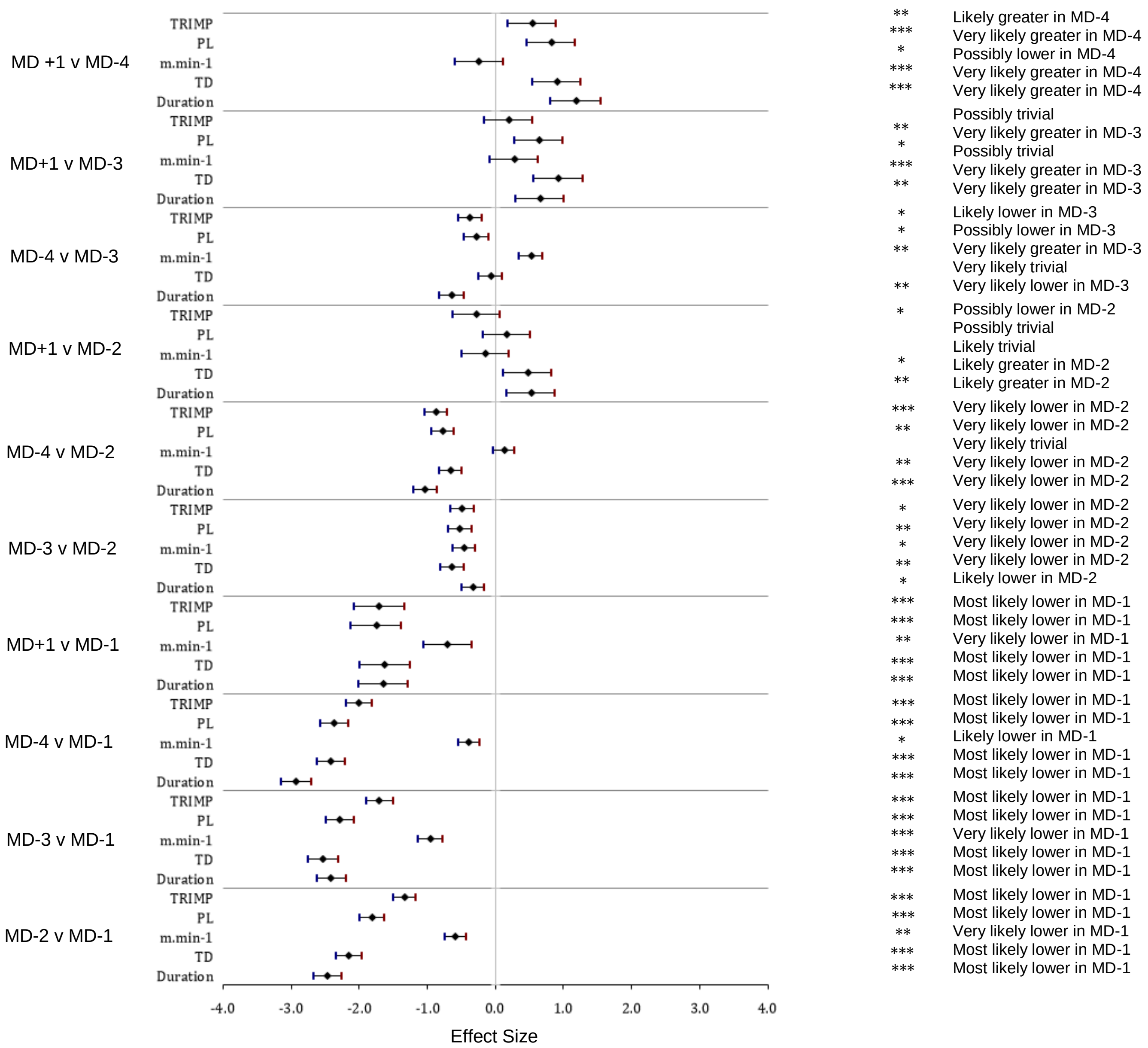


Figure 16. Cohen's D effect size ± 95% CL differences for training load variables between typical training days for coach 1 (* = 0.21-0.50, small; ** = 0.51-0.80, moderate; *** = >0.81 large differences) (magnitude-based inference)

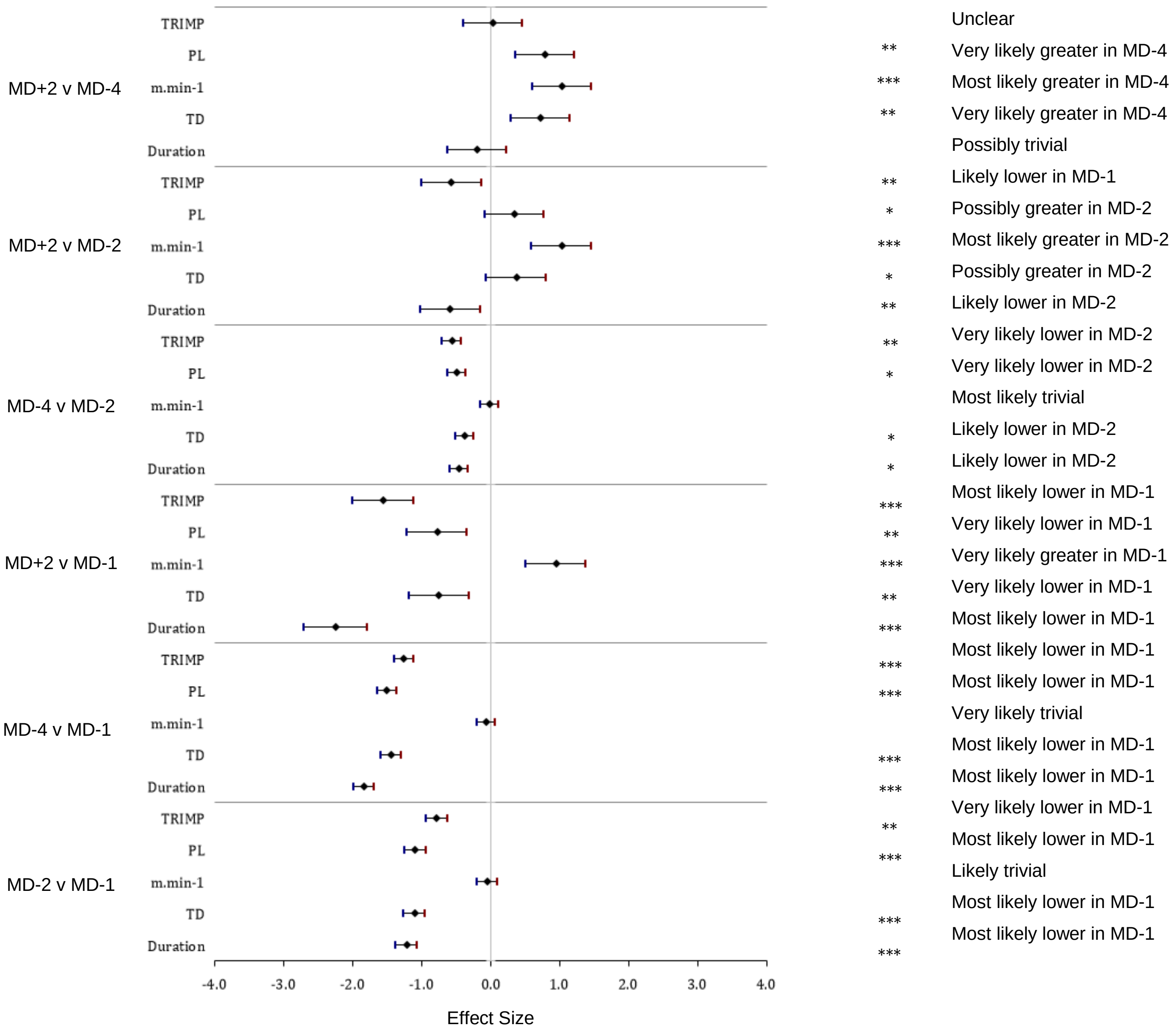


Figure 17. Cohen's D effect size ± 95% CL differences for training load variables between typical training days for coach 2 (∗ = 0.21-0.50, small; ∗∗ = 0.51-0.80, moderate; ∗∗∗ = >0.81 large differences) (magnitude-based inference)

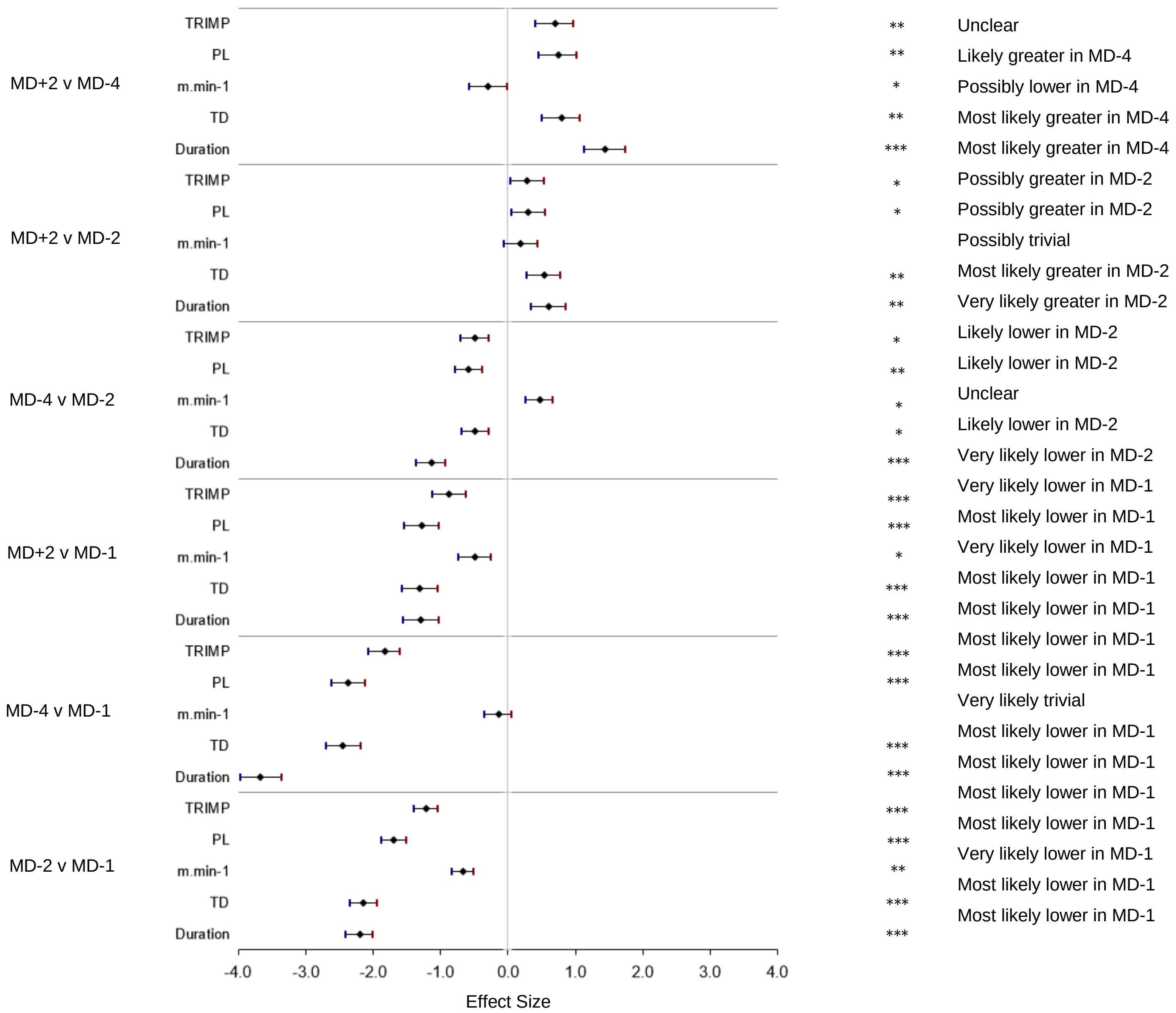


Figure 18. Cohen's D effect size ± 95% CL differences for training load variables between typical training days for coach 3 (∗ = 0.21-0.50, small; ∗∗ = 0.51-0.80, moderate; ∗∗∗ = >0.81 large differences) (magnitude-based inference)

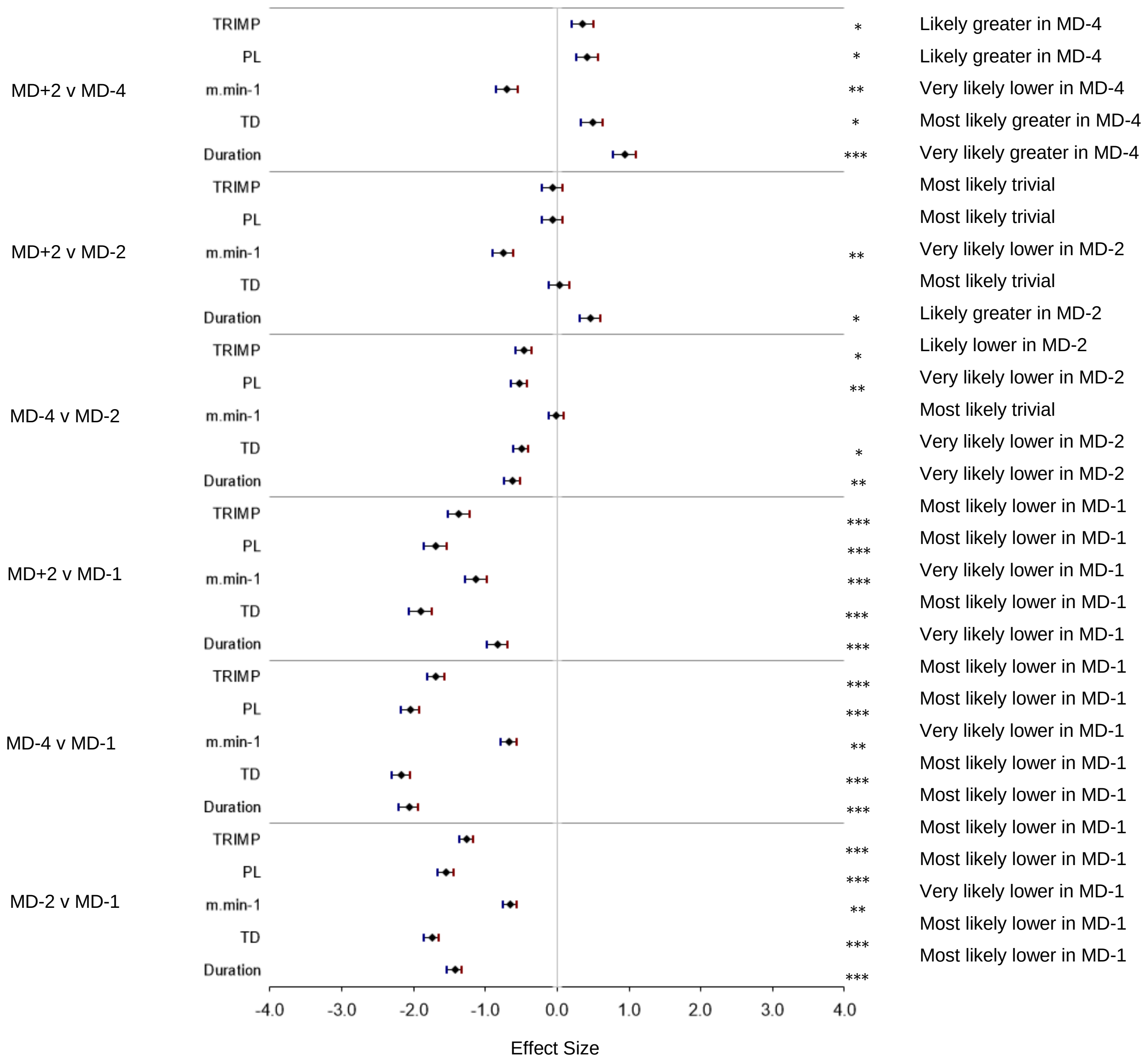


Figure 19. Cohen's D effect size ± 95% CL differences for training load variables between typical training days for coach 4 (* = 0.21-0.50, small; ** = 0.51-0.80, moderate; *** = >0.81 large differences) (magnitude-based inference)

3.4.2 Part B – The Dissemination

Part 1 -

https://goanimate.com/videos/0xzyiTlYVHAc?utm_source=linkshare&utm_medium=linkshare&utm_campaign=usercontent

Part 2 –

https://goanimate.com/videos/0Tin67cTG-q8?utm_source=linkshare&utm_medium=linkshare&utm_campaign=usercontent

3.5 DISCUSSION

3.5.1 Part A – The Research

The aim of the study was to investigate if different Premier League coaching groups demonstrate different training load patterns within an in-season weekly micro-cycle in preparation for a match. To enable the research question to be answered a large dataset across multiple seasons from an elite Premier League football team was required. This approach was possible as the same science staff and scientific processes had been in place at the club, which was investigated. The retrospective nature of the study did, however, also provide limitations. As highlighted within the method section, the hardware, software and firmware utilised throughout the period had changed in line with commercial developments. Due to this limitation, it was decided that only variables that were minimally influenced by these developments would be used. TD, PL, TRIMP and $m.min^{-1}$ were, therefore, investigated.

The results suggest that there are more similarities than differences between the training load patterns observed between coaching groups. The volume related variables (duration, TD, PL and TRIMP) were found to peak on MD-4 within all coaching groups (with exception of duration for coach two). Further, irrespective of the coaching group a taper in all of the volume related variables was observed from the peak until match day. One final shared observation between the coaching groups was that the $m.min^{-1}$ demonstrated similarities. As $m.min^{-1}$ was similar between coaching groups but total distance clearly different, it may be assumed that a key finding from the study is that duration appears to modulate the training load differences observed.

The findings, therefore, suggest that the training load variables investigated (with exception of $m.min^{-1}$) are merely controlled via the time spent training. This proposal is supported by the fact that when the microcycle bar charts (figure 1-5) and effect size figures (figure 6-15) are inspected; duration, TD, PL and TRIMP all appear reflective of one another. Each variable, therefore, may simply represent a different way to present training volume. This theory is supported elsewhere within the literature where PL has been found to demonstrate similarities with other volume related training load variables; distance covered, session-RPE and heart rate (Barrett *et* al., 2014; Casamichana *et al*., 2013; Gabbett, 2015; Polglaze *et al*., 2015; Scott *et al.,* 2013). It, therefore, appears that although PL is accelerometer derived and multiplanar in nature, due to the accumulative nature of the measure, any sensitivity around its utility to capture movement may be drowned out by the impact of duration. These observations support the rationale that deeper consideration around monitoring methods is required. Simply examining a broader range of different training load variables does not necessarily appear to add further insight to monitoring the training process in football. Instead a deeper consideration around what should be monitored appears important.

The observation that there were limited differences between the training load variables examined appears to meet the second aim of the study. The aim stated that a range of training load variables will be examined to investigate if different variables in this type of analysis may help differentiate between the coaching groups' training methods. Hence, better describe training patterns. It appears that the wider range of training load metrics analysed, do not help better describe training patterns between coaching groups. This, therefore, suggests that the related training load measures collected and analysed lack sensitivity to effectively capture the true demands of training.

The measurement issues highlighted may explain why there were fewer differences between the training patterns employed by the different coaching groups than anticipated. In fact, there was only two key differences between the coaching groups and both were independent of training methods employed. Firstly, the scheduling of the day(s) off within the weekly microcycle. Three coaches (two, three and four) all allocated two days off per microcycle (on MD+1 and MD+3). This was not observed for coach one who typically allocated only one day off on MD+2. Secondly, the volume of training load delivered on each training day. For example, the average total distance observed on the peak MD-4 varied between 5549 ± 1029 m, 5040 ± 990 m, 5771 ± 1427 m and 4630 ± 1281 m for coach one to four, respectively. These microcycle design decisions appear to be dependent on the views of the key decision makers in the coaching process and may be largely influenced by contextual factors such as the players' age (training, chronological and biological) and the requirements of the group (tactical, technical, physical, cognitive and social). For example, one head coach may want to do a lot of tactical work due to the team conceding a lot of goals recently and, therefore, increase their coaching time with the players to develop the teams' defensive organisation. Another head coach may believe that maintaining physical freshness in his older players is key to maximising performance and, therefore, keep training duration short, programming an extra day off in preparation for a match day. Due to the complex multifactorial nature of training design, there is little literature available, which would help direct coaches to appropriate structure and volume of training in preparation for competitive match play in the unpredictable applied football environment. It, therefore, appears that many of these programming decisions are made from tacit applied experience rather than a relevant scientific literature base.

It would be assumed that the same influencing factors that prompted differences in the training structure and volume may have influenced different training load patterns to be delivered within an in-season microcycle by each coaching group. This was, however, not the case with the same training load pattern observed between coaching groups. All four coaching groups appeared to adhere to similar training load programming principles where a period of low training load was prescribed post-match, peak training load delivered mid-week and then reduced training load prescribed pre-game. This model of microcycle design is supported within the tactical periodisation literature, which promotes a period of recovery, loading and taper (Oliveira, 2007).

The fact that all four coaching groups prescribed their highest volume training session on MD-4 and then tapered until match day appears practical. It could be perceived that MD-4 was the most suitable training day to deliver the greatest volume of work due to its position within the week, furthest from the previous and next competitive fixture. In three of the coaching groups it also preceded a day off for players. The taper observed between groups would then allow residual fatigue after this session to be minimised, maximising preparedness on a match day. The observation of a taper reflects previous research, which has reported a taper in training load in preparation for competitive matches (Akenhead *et al*., 2015; Anderson *et al*., 2016; Malone *et* al., 2015; Thorpe *et al.,* 2015). No consistent pattern of taper was observed within the previous studies between the different coaching groups, with one-day (Malone *et* al., 2015; Thorpe *et al.,* 2015), two-day (Anderson *et al*., 2016) and four-day tapers (Akenhead *et al*., 2015) all identified. The observation that all four coaching groups within the current study seemed to have operated a taper from MD-4 may, therefore, have been unexpected. Due to the large bias that duration has on the measures of TD, PL and TRIMP, all that these findings really demonstrate is the programming of training time.

Unlike these variables, $m.min^{-1}$ does not associate with duration as it captures the distance covered relative to time. It may, therefore, be considered that this measure offers some insight into the different training methods delivered, which the other variables cannot. The density of training, as described by $m.min^{-1}$, however, also demonstrated similarities between coaching groups. All four coaching groups appeared to limit the variation of training density throughout the week. For example, only trivial differences were observed between MD-2 and MD-4 within all coaching groups. The magnitude of $m.min^{-1}$ was also similar between coaching groups. For example, when comparing the MD-2 and MD-4 between coaches one, two and three, the differences in $m.min^{-1}$ was trivial to likely. These similarities across coaching groups appear to suggest that $m.min^{-1}$, similarly to the previous investigated measures may lack sensitivity in differentiating between different training methods.

It may be a little simplistic to assume that $m.min^{-1}$, similar to the other measures, may be inappropriate to capture training demands. Firstly, the method of largely limiting the variation in training density in preparation for competitive match performance is a strategy that is also present within the previous literature. Similar variables have been found to be maintained throughout the training week (Akenhead *et al*., 2015; Malone *et al*., 2015). These observations fit with the seminal tapering literature, which suggests that intense exercise is often a performance determining factor during match play in team sports and should, therefore, be maintained in preparation for competition (Mujika, 2010). The limited variation observed may, therefore, be a strategy rather than a measurement limitation. Secondly, although it appears that training density is similar between Premier League coaching groups in the current study, the values observed do not concur with previous research conducted within a Premier League club. The values observed within the previous research, ranged from between 79 ± 7 to 85 ± 6 $m.min^{-1}$ (Malone *et al.* 2015). The highest daily value observed in the current study was 78 ± 12 $m.min^{-1}$. These differences between studies do, therefore, appear to suggest that $m.min^{-1}$ may be a measure independent of duration that could be sensitive to identify differences in the training methods administered.

The variable m.min^{-1} can only be expected to illustrate the differences of the component of load it measures, locomotive density. This may explain why such similarities were observed between the variable when training methods may have been perceived to be different. For example, if the differences in training methods were focused around the multidirectional demands of training then m.min^{-1} cannot be expected to capture this type of information. Further research is, therefore, required around other measures that may offer utility into capturing training load information irrespective of duration. It is hoped that a measure, which can suitably detect the specific movement requirements of different football training methods may be identified. Due to the multiplanar nature of accelerometers, this may be an appropriate next step in the research process. One way to investigate this area further would be to study if the technology is sensitive enough to distinguish between the movement demands associated with football drills of different activity types and pitch dimensions.

In conclusion, the elite football training load pattern observed between four different coaching groups was very similar in relation to the volume related training load measures investigated. The pattern in density of training as displayed via m.min^{-1}, also demonstrated some similarities between coaching groups and within a weekly microcycle. The observed training load patterns of TD, PL, TRIMP and m.min^{-1} observed appear to suggest that elite football training loads were largely modulated via duration. These findings suggest that the volume related training load monitoring methods investigated appear to be ineffective in differentiating between the training methods utilised between coaching groups. $M.min^{-1}$ may, however, offer some utility as a marker of locomotive density due to its independence of duration. The measure does not, however, offer any information around the multidirectional requirements of the training methods. Further research is, therefore, required in an attempt to identify effective methods of capturing the movement requirements of football training.

3.5.2 Part B – The Dissemination

The aim of the dissemination was firstly to utilise contemporary visualisation techniques via software packages such as PowerBi (data visualisation) and GoAnimate (video animation) to innovatively display the findings of the study. Secondly, this was hoped to allow the development and evaluation of new dissemination skills which may be of professional benefit in the future. It appears that these two aims are closely related as to reach the outcome of effective visualisation of the findings via contemporary techniques, the process of developing the skills to achieve it must be accomplished. These integrated aims were achieved as two concise and eye catching, social media friendly videos have been created to disseminate the key findings of the study. To achieve this, relevant skills around the contemporary methods of creatively visualising the findings were developed.

The outcome of the dissemination piece is displayed in the results section. Two short videos, which are designed to be disseminated via social media have been created. The key findings are clearly articulated in an attractive and modern format. The innovative representation of the research is planned to be shared with the football science community via Twitter. The utilisation of software packages such as PowerBi and GoAnimate have ensured that the end result has enabled the research to be packaged in a really accessible and digestible way. Until the videos have been shared it is difficult to completely appraise the success of the outcome. It appears, however, that the animations will certainly allow the key research findings to be disseminated to a much wider and different audience than would have been possible if only traditional scientific dissemination techniques were utilised. For the findings to be visualised so creatively some new skills had to be developed.

Data interrogation and visualisation skills were established using PowerBi in two ways. Firstly, formal attendance at a two-day Microsoft workshop, where the time was spent with a data scientist and a data engineer who assisted in the development of the key skills required to use the software and maximise productivity. The second way that this upskilling was achieved was via the frequent informal utilisation of the software with the research data set, interrogating and manipulating the information in a variety of forms, becoming truly familiar with the information. This was also supported by web based support such as blogs and tutorial videos of how to use specific widgets and data visualisation tools within the software.

The software had many benefits. It was visually very striking and brought the data to life. It was also extremely user friendly and after a short familiarisation period was very easy to use. The data could be visualised in multiple forms and formats at the click of a button, which allowed the researchers to deeply understand the data, enabling effective observations to be drawn. There was, however, also some limitations to the programme. Firstly, all of the extremely large data set had to be in exactly the same format, with consistent labelling of all columns and rows within the excel data import sheet. Due to the multiple season approach to the research, this took a huge investment of time and resource. The second limitation observed is that although very flexible, there was some variations of the data visualisations that were a little fixed and were not able to be manipulated in the way that was hoped during the process. Overall, however, the software and the skills developed allowed the data to be suitably interrogated and visualised as hoped, allowing the further dissemination method to be considered.

The dissemination method chosen was via video animation via GoAnimate. The skills were developed by the informal utilisation of the program. The skills required to effectively use the program were relatively easy to self-teach. If any challenges were faced when developing the video animation, useful video tutorials were available to quickly assist. This ease of use and the surprisingly time efficient nature of the cloud based software was its major strength. It was also very effective in achieving the goal of innovatively packaging the research as it allowed the messages to be displayed attractively in a novel and eye catching format. The one limitation of the software was its limited data visualisation options, however, this is countered by the fact that graphs and figures can easily be imported from elsewhere as demonstrated in the animation produced. The software and skills developed, therefore, appear to offer an exciting dissemination opportunity for the current research.

The development of the practical skills required to creatively visualise and disseminate research is a valuable addition to the researcher’s skill set. It is hoped that the researcher will continue to hone these skills and, therefore, maximise the impact of their future projects. It is important to acknowledge, however, that this newly acquired expertise is only a complimentary addition to the traditional research skill set and should not be perceived as a substitution. The value of the scientific rigor involved in peer review scientific publication should still be acknowledged and respected with the more innovative style either practically orientating the findings of the traditional scientific investigations to encourage translation into the applied setting or as a method of sharing more effectiveness style research conducted within the applied environments of elite sport, however, still abiding by the robust principles of scientific enquiry.

3.6 PROFESSIONAL SKILLS DEVELOPMENT REFLECTION

Research Skills

When it comes to the specifics of training load monitoring I am very firmly of the opinion that you are only as good as the information that you share and practice that you inform. Spreadsheets with fancy excel macros may do lots for a scientist's ego, however, very few league matches have been won with data saved on a hard drive. One of the skills that I am currently really enjoying developing is that associated with the use of the bespoke visualisation software, Microsoft PowerBi. It is something that is a real key developmental benefit from my current engagement with the research. The programme allows me to display training load information quickly and attractively, bringing data to life. It has allowed me to really get to know the data, cutting it up in multiple formats at the click of a button. I am still to use it to communicate relevant information to coaches, however, I have demonstrated its utility to other scientists and physiotherapists who have also instantly been captured by the potential it could have in the applied football environment. Going forward, I can see so many benefits in utilising it within my professional environment to visualise key data more attractively in a format that is appropriate for whoever the target audience may be.

If the skills I am currently developing around the data visualisation software may help me disseminate information internally within the club, then certainly the skills I am developing from using the GoAnimate video animation software will allow me to more effectively share research externally to the wider football or science community. As proposed by an IJSPP editorial (Buchheit, 2017), the dissemination vehicle for applied research (like that in question) is an important consideration to maximise impact. I, therefore, see the ability to use software like the video animation programme to be an imperative skill set for any scientist hoping to share their research to a wider audience. The results appear really digestible and could be simply accessed via social media, which makes it an attractive dissemination method in the modern climate. I have picked the skill up a lot quicker than I anticipated and once again it represents something that will now stay with me as a direct result of my professional doctorate, which I can use in future research or practice.

Dissemination and Networking Skills

At this early stage of the project I feel that I am also working towards developing the main networking and dissemination objectives that I set myself - regular exposure to public speaking and presenting to a variety of different audiences. A reflective extract below demonstrates some of the lessons that I have recently learnt in this area at the early stages of my professional doctorate journey:

I have spent the last couple of days in Lisbon delivering two conference presentations to European science and fitness practitioners at the Catapult Sothern European Conference. This opportunity has been the first exposure I have had of public speaking and presenting since my professional doctorate self-audit where I set engagement into this type of experience as a clear objective. One session was around the use of data for injury prevention and the other was the use of match data. There was a Q&A after each section of presentations. I enjoyed the event and I am beginning to really enjoy presenting. I was pleased and proud to be invited and it was great to experience delivering in a different culture and country with a different language. I felt that my injury prevention presentation went very well and I was really clear. I feel I, however, lacked this clarity in the match data presentation. I find the Q&As more difficult as cannot prepare and feel that you need to get a balance between scientific rationale and real life informal experiences. It was also a great networking event, meeting lots of the staff from abroad and the Catapult organisation. I think I particularly enjoyed the event as it felt more educational due to the limited experience of the delegates. I think that this reinforces the fact that I really enjoy the development side of the profession. I believe that my presentation design skills are much improved, however, the big improvements I can make are my ability to present and sell the story. I think that the professional doctorate lecture we received in module one on the topic of presentation design and delivery by James Morton and the fact that I have based a lot of my methods around the book presentation-zen has given me lots of tips around effective slide design. I think precision/ clarity of thought and delivery is key to this. I *think if I am being really picky, I could have prepared slightly better. I did, however, only have a week to put the presentations together and largely redrafted them from the feedback of colleagues. The key thing learnt is to go very simple with just 3 headlines and then sell the story. I think I could prepare for the Q&A aspect too, as there are only so many themes the questioning could go. Overall, I think that this experience has been really developmental. I should continue to expose myself to these experiences as it may be a key skill for me as my career develops, especially with reference to disseminating my research and good practice.*

CHAPTER 4

DO EXTERNAL TRAINING LOAD VARIABLES EFFECTIVELY DESCRIBE THE DEMANDS OF ELITE FOOTBALL TRAINING?

<u>4. Do External Training Load Variables Effectively Describe the Demands of Elite Football Training?</u>

4.1 RESEARCH ORIENTATION

The results of the previous study appear to support a lot of the concerns that drove my original rationale for formulating the research question. The training load measures utilised and, therefore, examined do not appear effective at differentiating between the different coaching methods that I have observed. Any sensitivity the measures may capture are clearly drowned out by the associated duration of training. I am certainly of the opinion that this inappropriateness is due to measurement issues associated with capturing change of direction and movement requirements as opposed to evidence of there being limited differences between the head coaches training loads. The results challenge a lot of the concepts and methods around traditional training load monitoring in football. What are we really trying to do? Why are we investing so much time and finance into a methodology that appears relatively ineffective at illustrating the intermittent, multidirectional demands of football training. It appears that we are currently adopting a training load methodology, which has been borrowed from continuous sports such as endurance running before appropriately considering what is important to measure and what information we need to inform relevant training processes? I have strong feelings that a lot of the current processes around training load monitoring are currently framed around describing training rather than informing it. The current research should, therefore, hopefully help coaches and practitioners be steered more towards the later as opposed to simply adding a data commentary to training. In a recent conversation with Barry he captured a lot of these feelings into one great caption; ‘Are we monitoring what we can or what we should?’

If my observations are correct that the drills that the different coaches have utilised is where the differences in training load may be evident then this would be a logical next step in the research journey. Do different drills (that clearly have different associated movement requirements) demonstrate differences in training load variables? If not, then I would have real concerns in the validity of the measures I (and large portions of the sport science community) have been using over recent years. Further, from recent reading and practical experience it appears apparent that MEMS accelerometers may demonstrate utility specifically in describing the movement requirements of an activity. This should again be an area that I look to investigate further as the thesis progresses.

Within my role as the First Team Fitness Coach at WBA FC, I spend every training session on the grass with the coaching groups, delivering, supporting and observing training. Ahead of this I am involved in the planning and preparation stages for the same training process. The extent of my involvement in the planning stages has always been dependent upon the beliefs of the head coach in charge. Sometimes I have been an integral part of the coaching team who were responsible for designing training to the smallest degree, ‘what pitch size should we use there, Matt?’. While during the reign of other head coaches I have had a less prominent role at the embryonic stage of the training process. Instead I may have only informed the process on much more global levels such as ‘we will need to pull the reigns a little today, Gaffer.’ Whatever my role in the training process may be, I have always believed that it is extremely important that I should possess an appropriate knowledge of football coaching practice; the technical and tactical principles, the relevant training activities and how these training sessions may influence the physical outputs.

Most of this knowledge and understanding has been developed by a mixture of experiential evidence and research within the literature. When it comes to classifying training activities in reference to movement demands, however, a large emphasis is placed upon practical assumptions rather than being truly underpinned from research. The practical requirements of my current role along with the further research questions posed following the competition of study one have led me to ask the current research questions expressed in the current study. For example, if differences in training loads are no apparent between head coaches, are the training activities selected associated with different demands or, similarly, is there limited sensitivity in differentiating between the movement requirements? What types of drills should I be suggesting are included in training on days when we want low movement requirements and what training activities may be prescribed on high movement loading days?

4.2 INTRODUCTION

Monitoring of training load within elite football is widely utilised. The process of monitoring is important as they allow coaches and support staff to gather data, which may inform practices around optimising training for development, performance or to reduce the risk of injury. The challenge that practitioners face in the field is ensuring that the monitoring methods available are used appropriately to effectively capture training demands to help inform these processes. It appears that MEMS technology is one methodology that is currently widely used. In a study that investigated the use of monitoring methods across high level football, from the forty-two clubs questioned, all forty-two were using the technology (Akenhead & Nassis, 2016). The same study found that GPS derived variables are the most commonly utilised training load variables; with acceleration (various thresholds), total distance and distance covered above 5.5 $m.s^{-1}$ the top three (Akenhead & Nassis, 2016).

The fact that training load monitoring in elite football places such an emphasis on GPS based variables does not appear entirely logical. Due to footballs' intermittent and multidirectional nature it appears counterintuitive for such an emphasis to be placed on the locomotive distances gathered from GPS, as the associated physiological demands of these activities will be underestimated. Due to the apparent limitations of GPS devices to accurately and reliability capture the full range of change of directions demands associated with football, other technological solutions have been investigated.

Triaxial MEMS accelerometers, which have been incorporated alongside GPS within MEMS devices are one such technology. The MEMS accelerometers are highly responsive motion sensors that measure the incidence and magnitude of accelerations at the trunk across three dimensions (anterior-posterior, mediolateral and longitudinal) (Boyd *et al*., 2011; Boyd *et al*., 2013). In an attempt to combine the three-dimensional data to evaluate the total physiological load, commercial producers of MEMS devices have devised accelerometer-derived variables. One such variable is PL, an arbitrary unit that is derived from instantaneous rate of change of acceleration across the three dimensions (Barrett *et al*., 2014). PL has previously demonstrated sensitivity in differentiating between the training loads associated with different training scenarios (Barreira *et al*., 2016; Boyd *et al*., 2013; Wundersitz *et al.,* 2015). No research, however, was conducted with elite footballers in real-world effectiveness studies.

Due to the absence of research utilising MEMS accelerometers in real world elite football training scenarios, their utility is unknown. It may, however, be hypothesised that the technology may be appropriate to differentiate between different training activities due to increased sensitivity to movement, which is absent from GPS measures. The current study, therefore, aims to identify if MEMS accelerometer variables are effective at describing differences in movement in Premier League football training. This will be achieved by investigating the differences associated with different types of training activity, which will influence the associated movement.

4.3 METHODS

4.3.1 Participants

99 elite outfield football players from a Premier League team (mean ± SD: age 28 ± 5 years; height 1.52 ± 0.07 m; body mass 83.2 ± 7.4 kg) participated in the study. Players were assigned to the playing position they were considered for at the time of the associated training session and may, therefore, have been assigned to two different positions during two different seasons e.g. one season one player may have been considered a central defender and the following season a wide defender. This

was only the case in seven players throughout the period. The positional breakdown was 17 central defenders (CD), 23 wide defenders (WD), 22 central midfielders (CM), 20 wide midfielders (WM) and 24 center forwards (CF). No goalkeepers were included in the study. All players provided written consent for their training data to be used for the purposes of the study. The study was conducted according to the requirements of the Declaration of Helsinki and was approved by the University Ethics Committee of Liverpool John Moores University.

4.3.2 Experimental Design

To investigate if external training load variables effectively describe the demands associated with different types of football training activities and pitch dimensions a large data set was required for analysis. A retrospective approach was, therefore, chosen for the study. This approach was possible as the same science staff and scientific processes had been in place at the club, which was investigated. All first-team training data that had previously been collected and analysed for a period of four years and four months between 27th October 2012 and 24th February 2017 (23759 observations) was included and further analysed. This data had previously been collected, analysed and stored within standardised excel (Microsoft, Redmond, USA) spreadsheets. These multiple excel spreadsheets were, therefore, firstly collated into one large dataset for further analysis for the research study. All field based training, both group and individual, was included. All gym based training was excluded as it was not directed by the coach and not reflective of their field based training methods. No competitive Premier League or cup match data was included as the study was solely concerned with examining training activities. As the study was retrospective in nature, the design or implementation of training sessions was not influenced in any way by the investigation. Training was either completed at the football club's outdoor training pitches or at a relevant training venue during a team training camp.

4.3.3 Data Collection

At the time of initial data collection, each player's physical activity during each training session was monitored using MEMS tracking devices (S4 & S5, Catapult Sports, Melbourne, Australia). A recognised limitation of the study is that different MEMS units were used during the duration of the study, this is discussed further in the discussion. The MEMS units included a GPS, accelerometer, gyroscope and magnetometer technology and heart rate monitors (Polar T31, Helsinki, Finland). The 10 Hz GPS recorded time motion analysis data. For data to be included the number of satellites must have exceeded 6 and a HDOP was less than 1.5. As previously outlined elsewhere in the literature the tri-axial piezoelectric linear accelerometer (Kionix: KXP94) contained within the MEMS tracking device sampled at a frequency of 100 Hz (Barrett *et al*., 2016). The output of the MEMS accelerometer measures ± 13 g (Barrett *et al*., 2016). The device contains a microprocessor with 1GB flash memory and a USB interface to store and download data (Barrett *et al*., 2016). The device is powered by an internal lithium ion battery with 5 h of life weighing 67 g and is 88 × 50 × 19 mm in dimension (Barrett *et al*., 2016). The firmware was continually updated in line with the manufacturer's recommendations and the most up to date version was always installed at the time of data collection. Prior to the start of each season units were calibrated in line with the manufacturer's guidelines.

The MEMS devices were activated for 30-mins under open sky before data collection, to allow acquisition of satellite signals as per manufacturer's instructions. The MEMS device was fitted in a small neoprene pouch within an undergarment located posteriorly between the scapulae. The heart rate monitors were worn around the torso, level with the xiphoid process. To minimise inter-unit variability, players were assigned their own MEMS device and heart rate monitor, which was worn by the individual during each training exposure. All players were well familiarised with training in the MEMS tracking device and heart rate monitor.

At the original data collection stage, the time associated with the start and end of each separate discrete training activity was noted. The pitch dimensions (length and width) of each activity (yards) was measured. The dimensions were calculated via a combination of using the pitch markings available and/or measured via strides around the activity area. The number of outfield players involved in each activity was also noted.

4.3.4 Data Analysis

Following each training session, data recorded on the MEMS device was downloaded on the relevant commercially available software package (Sprint & Openfield, Catapult Sports, Melbourne, Australia). A recognised limitation of the study is that different software was used during the duration of the study, this is discussed further in the discussion. As the study was designed to examine the utility of MEMS accelerometer variables to effectively describe the demands associated football training, PL (au) and PL.m^{-1} (au) were selected for analysis. PL was calculated from accelerometry data and is determined from the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (x, y and z) and divided by 100 (Boyd *et al.,* 2011). PL.m^{-1} was calculated from accelerometry and GPS data and is determined from PL divided by the total distance covered. It has previously been proposed that PL.m^{-1} presents a measure of a player's locomotive efficiency (Barrett *et al*., 2016).

All training session data was split into the separate discrete activities (23759 observations). The start and end times noted during the session were verified by the velocity curves displayed within the software upon download, which allowed players' movements to be identified. This enabled the relevant period of activity associated with the training to be selected and the associated duration to be recorded. The data was then downloaded from the software into excel via CSV reports. The pitch dimensions, number of players and activity type were all recorded within the excel spreadsheet. The spreadsheet was formulated to calculate area per player ($yards^2$ / number of outfield players) for each activity. To allow for this calculation, if an activity was linear in nature (e.g. pass and follow a to b), the width was recorded as 1 yard. The activity type for each activity within the session was classified following a discussion between the lead researcher and a coach responsible for training following its completion. Following the amalgamation of each of these seasonal excel sheets into the full research data set, a master list of all the training activities completed throughout the examined period was collated. In consultation with a selection of the coaches who had been responsible for delivering different training activities throughout the investigated period, a hieratical categorisation of activity type descriptions were established and discussed. Table 1 overviews the classification system and definitions of each activity type that was formed. At the time of amalgamation, if any of the required information, activity type, dimensions or number of players were missing, the specific activity's data was omitted from analysis.

Table 6. A hieratical categorisation of activity types and associated descriptions of the training activities observed

Activity Type	Description
Game Activities	
Game	A training game delivered with typical match design e.g. full pitch, 11v11, no constraints
Possession	An activity delivered that has either a tactical or technical focus where two teams must keep possession of the ball from each other. It may be directional or non-directional. There may be conditions or constraints included, however, full size goals and goalkeepers are not involved
Small Sided Game	A competitive activity delivered in a directional game format, which has a technical, tactical, physical or cognitive focus. Player numbers, pitch size and conditions may be manipulated for overload
Physical Focused Activities	
Aerobic	An activity delivered that has a physical focus predominantly to improve the aerobic capabilities of the players. Principally not football specific and typically involves bouts of running for 60 sec or longer
Speed	An activity delivered that has a physical focus predominantly to improve the speed capabilities of the players. The activity may be either linear or multidirectional and associated with an intensity at or

	near maximal.
Speed Endurance	An activity delivered that has a physical focus predominantly to either improve the ability to sustain speed for prolonged periods of time or be able to recover more effectively between speed exposures
Tactical Focused Activities	
Attacking	An activity delivered with a tactical focus predominantly to improve the awareness of individual responsibilities and team effectiveness in offensive situations
Defending	An activity delivered with a tactical focus predominantly to improve the awareness of individual responsibilities and team effectiveness in defensive situations
Set Pieces	An activity delivered with a tactical focus predominantly to improve the awareness of individual responsibilities and team effectiveness in set piece situations. Either defending or attacking set pieces
Team Shape	An activity delivered with a tactical focus predominantly to improve the team organisation in match specific situations. Typically, full pitch, 11 v 11 and coached throughout
Technical Focused Activities	
Crossing & Finishing	An activity delivered with a technical focus predominantly to improve the crossing and finishing execution of players. Typically occurs in the final third of the pitch
Finishing	An activity delivered with a technical focus predominantly to improve the finishing execution of players. Typically occurs in and around the 18-yard box
Passing	An activity delivered with a technical focus predominantly to improve

	the passing and receiving execution of players. May be in opposed or unopposed situations
Skills Game	An activity delivered with a technical focus predominantly to improve the specific individual skills of players. Typically delivered in a fun and/ or competitive format

4.3.5 Statistical Analysis

The study design represents multi-season training data of five different coaches for the same Premier League football club. Thus, this data consisted of repeated measures of training for players along with unbalanced data sets (e.g., some players performed different numbers of sessions and different coaches conducted different numbers of sessions). In order to handle this type of data structure a mixed model approach was taken (Cnaan *et al*., 1997). Separate mixed models were constructed for the two dependent training load variables (PL and PL.m^{-1}). Fixed effects consisted of training duration, area per player, training activity, and positional group. Random effects consisted of individual players nested within the specific coach in order to represent the repeated measures of training recorded on players for specific coaches. In order to satisfy the assumption of homogeneity of variance, a constant variance function was specified within the model to allow for different variances across training activities. Models were fit iteratively starting with an intercept only model and variables added based on domain expertise. Candidate models were compared using Bayesian Information Criterion (BIC) Model comparisons with the model consisting of the lowest BIC being retained for presentation within this manuscript (Kwok *et al*., 2007). Data is represented as mean ± SD for training load variables, pooled over the entire data set. Model coefficients are presented along with their corresponding 95% confidence limit (± 95% CL). All statistics were conducted using the nlme package. A magnitude-based inference approach was used to interpret practical significance between each dependent variable and the intercept. The threshold for change considered to be practically important (the SWC) was 0.2 multiplied by the between subject standard deviation, based on Cohen's d effect size principle. The probability that the magnitude of change was greater than the SWC was rated as <0.5% most unlikely, 0.5-5% very unlikely, 5-25% unlikely, 25-75% possibly, 75-95% likely, 95-99.5% very likely and 99.5-100% most likely. The probability was rated as unclear if the chance of a substantially positive and negative effect were >5%.

4.4 RESULTS

The activity types associated with the highest duration and PL were games, SSG and team shape, which are displayed in Table 2. This may, therefore, suggest that these two variables and/ or three training activities share a relationship. Speed and passing were both associated with the lowest duration and PL. This once again demonstrates that the two variables appear to be related to one another. The fact that PL is an accumulative measure and may be interpreted to quantify volume explains this. It, therefore, appears that PL does not effectively describe the differences in movements in football training due to the influence of activity duration.

PL.m^{-1} did, however, associate with different activities than the other variables. Defending, possession and skills games demonstrated the highest PL.m^{-1}. Interestingly, it could be suggested that these three activity types may be more closely associated with change of direction movements patterns than linear locomotive actions. The lowest PL.m^{-1} was associated with tactical focused activities, team shape, attacking and crossing and finishing. Conversely to the earlier activity types, it may be suggested that these activities are more associated with greater locomotive movements than change of direction patterns.

Table 7. Mean ± SD for each dependent training load variable associated with each activity type

	Duration	PL	PL.m^{-1}
Game Activities			
Game	22 ± 11	190 ± 120	0.09 ± 0.01
Possession	9 ± 4	60 ± 32	0.12 ± 0.03
SSG	15 ± 7	118 ± 60	0.10 ± 0.02
Physical Focused Activities			
Aerobic	12 ± 6	98.18 ± 77	0.10 ± 0.01
Speed	3 ± 3	20.28 ± 15	0.11 ± 0.02
Speed Endurance	8 ± 5	76.57 ± 51	0.10 ± 0.02
Tactical Focused Activities			
Attacking	13 ± 5	71 ± 29	0.09 ± 0.01
Defending	14 ± 8	88 ± 59	0.12 ± 0.03
Set Pieces	13 ± 5	34 ± 21	0.10 ± 0.02
Team Shape	21 ± 10	118 ± 63	0.09 ± 0.01
Technical Focused Activities			
Crossing & Finishing	9 ± 4	50 ± 24	0.09 ± 0.01

Finishing	10 ± 8	59 ± 53	0.10 ± 0.02
Passing	7 ± 4	46 ± 27	0.11 ± 0.02
Skills Game	7 ± 6	50 ± 29	0.12 ± 0.02

Figure 1 and 2 overview the mean PL and PL.m^{-1} ± 95% CL differences for each activity. The magnitude-based inference associated with each activity type compared to the intercept is also displayed. The intercept was composed of CB positional group and the aerobic activity type. Training duration, area per player, training activity and positional group are all fixed effects and are, therefore, controlled for bias. As different coaches were responsible for training during the examined period, random effects consisted of individual players nested within the specific coach.

In figure 1, seven of the thirteen activities show trivial differences, which suggests that PL does not appear to differentiate between the range of training activities even when duration is controlled for. In figure 1, games were the only activity that were found to be likely greater than the intercept (30 ± 7) in respect to PL. Set pieces were found to be very likely lower than the intercept (-62 ± 3). Attacking and team shape were two other activity types that were associated with lower values than the intercept, qualitatively described as likely lower (-30 ± 5; -30 ± 3). It, therefore, appears that only tactically focused activities were likely or very likely lower than the intercept with three of the four classified tactical activities likely to very likely lower than the intercept in relation to PL. Crossing & finishing and speed activities were found to be possibly lower than the intercept (-28 ± 3; -24 ± 3). All other activities' PL differences with the intercept were found to be trivial.

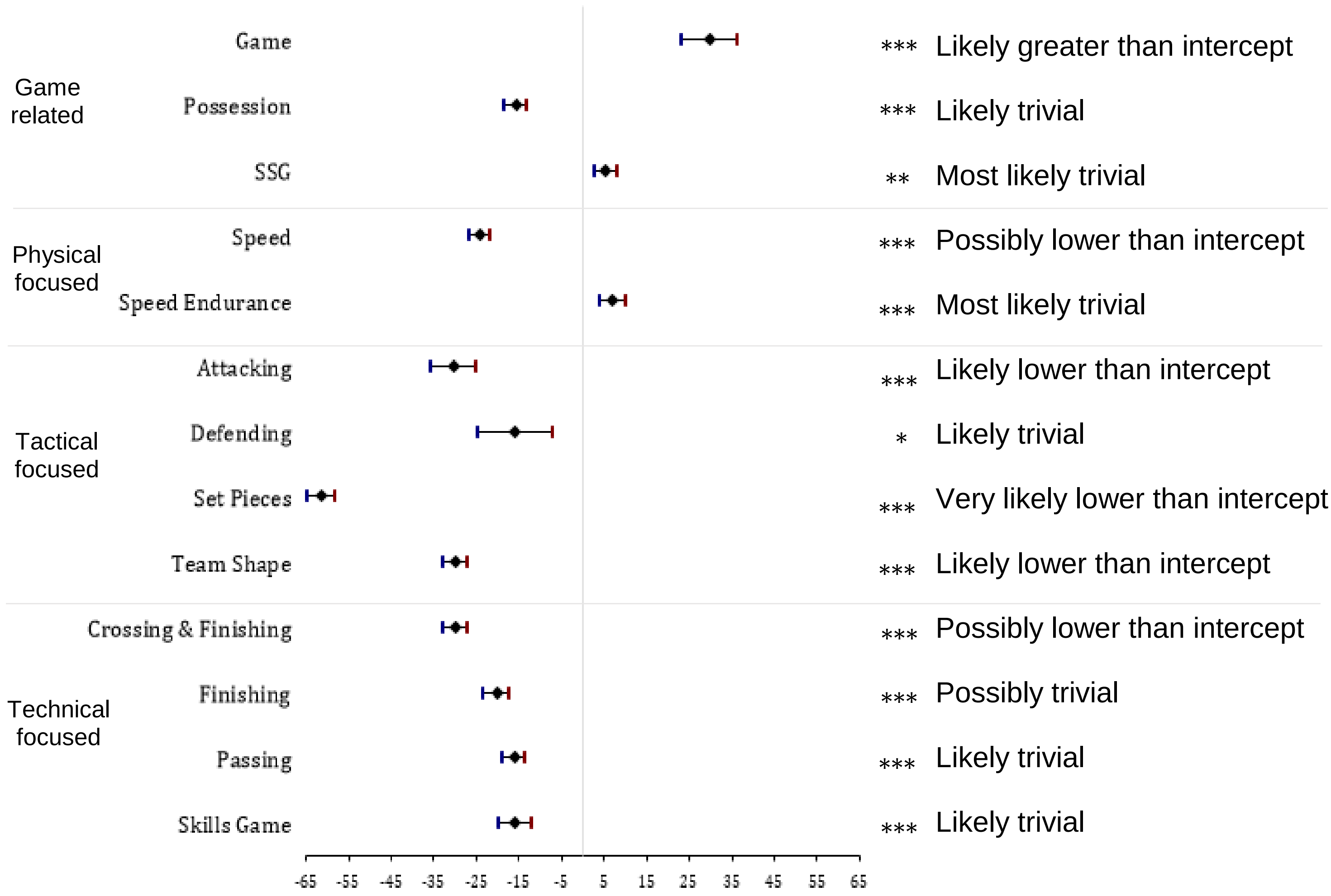


Figure 20. PL coefficient ± 95% CL differences between activity type (* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$) (magnitude-based inference)

In figure 2, PL.m^{-1}, unlike PL, does appear to be sensitive to differentiate between activity types. Only three of thirteen activity types were associated with trivial differences to the intercept with one further activity demonstrating unclear differences. Figure 2 displays that the PL.m^{-1} associated with possession, defending and skills games were most likely greater than the intercept (0.03 ± 0.00; 0.02 ± 0.01; 0.02 ± 0.00) and suggests for every increase in 20 m possession, defending and skills games were found to increase PL.m^{-1} by 0.51, 0.49 and 0.47, respectively in CB's when compared to aerobic activities. These results are particularly of interest as it suggests that the outcome focus (game related, tactical, technical or physical) may not have a bearing on the $PL.m^{-1}$ as one game related, one tactical and one technical focused activity are associated with a most likely greater difference than the intercept. Passing was very likely greater than the intercept (0.01 ± 0.00) and speed and SSG likely greater (0.01 ± 0.00; 0.01 ± 0.00), suggesting that for every increase in 20 m, passing, speed and SSG were found to increase $PL.m^{-1}$ by 0.26, 0.15 and 0.12, respectively in CB's when compared to aerobic activities. Team shape was very likely lower than the intercept (-0.01 ± 0.00) and attacking and game likely lower (-0.01 ± 0.00; -0.01 ± 0.00) and suggests for every increase in 20 m, team shape, attacking and game were found to decrease $PL.m^{-1}$ by 0.17, 0.15 and 0.12, respectively in CB's when compared to aerobic activities. Although two of these activities are tactical and one game related, they do possess similarities. All three are typically completed under match realistic conditions (player numbers and pitch sizes), which suggests that $PL.m^{-1}$ may be sensitive to the activity type and associated demands. All other activity type $PL.m^{-1}$ differences with the intercept were found to be trivial.

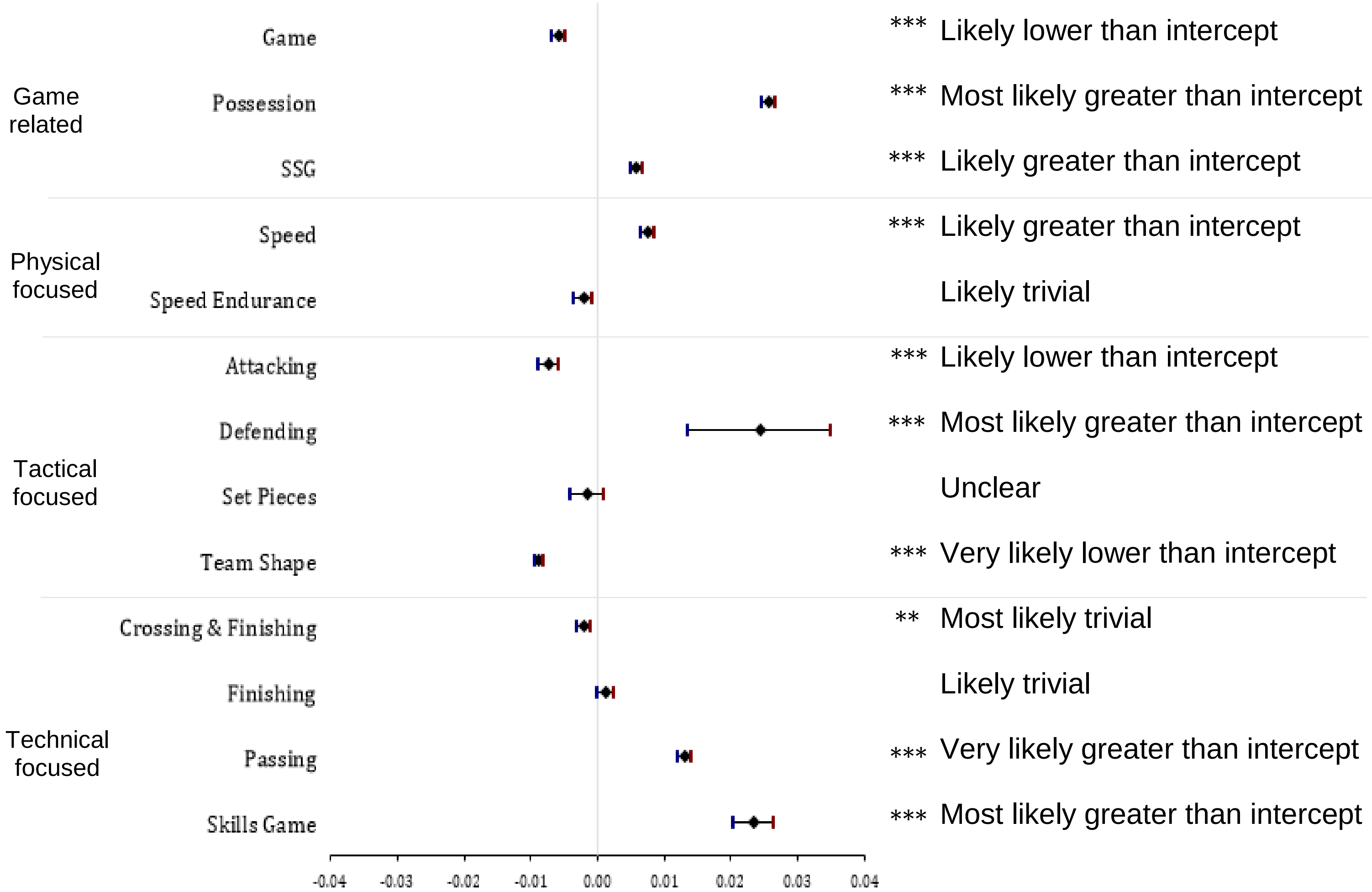


Figure 21. $PL.m^{-1}$ coefficient ± 95% CL differences between activity type (∗ $p \leq 0.05$; ∗∗ $p \leq 0.01$; ∗∗∗ $p \leq 0.001$) (magnitude-based inference)

When duration was not controlled for PL demonstrated an extremely large effect size when compared to duration (0.99) and no effect with area per player (0.08). These results appear to suggest that PL is extremely influenced by duration but not at all by the area size the activity is completed within. Unlike PL, $PL.m^{-1}$ demonstrated a small effect size when compared to duration (0.10). The area per player did, however, possess an effect size, although only small (0.20). This may, however, be influenced by the very small numbers that are associated with $PL.m^{-1}$.

Games were associated with the greatest variation in PL (variation function = 3.40) and speed the lowest variation in PL (variation function = 0.44), which may be because of the different positional roles completed within games unlike the standardised requirements between positions in speed activities. Possession was associated with the greatest variation for $PL.m^{-1}$ (variation function = 1.00) and games the lowest variation (variation function = 0.33). These variations may unlike the between player differences within activities be associated with between activity differences as possession activities may be associated with many different conditions between occasions, whereas games have very little variation between occasions as they were always associated with the same pitch size, player number and rules.

4.5 DISCUSSION

The aim of the study was to establish if MEMS accelerometers were effective in describing differences in Premier League football training. This was investigated by examining the differences in the measures associated with different types of football training activities, which, therefore, may influence movement requirements. It was theorised that the technology would offer utility in the area due to increased sensitivity to movement, which is absent from GPS measures. The results appear to support the hypothesis; however, it appears that it is $PL.m^{-1}$ rather than the more widely utilised PL, which may be more effective in capturing movement requirements. This conclusion was drawn from the fact that $PL.m^{-1}$ appeared to differentiate between training, with only three activity types from the thirteen investigated demonstrating trivial differences with the intercept. PL on the other hand was observed to demonstrate trivial differences with the intercept in seven of the thirteen activity types. It, therefore, appears more complex than broadly accepting that MEMS accelerometers may or may not offer utility in monitoring movement requirements in elite football. Instead, the specific details around the measurements and derivatives utilised is imperative.

From the retrospective analysis of the large dataset of elite Premier League football training activities, $PL.m^{-1}$ appeared to be the most effective training load variable in differentiating between different activities. Possession, defending and skills games were the three activities that were most likely greater than the intercept. Perceptually, these three activity types may be expected to include high volumes of multidirectional activities. On the other hand, the activities that may be perceived to be associated with lower multidirectional movements and more locomotive in nature, such as team shape, game and attacking were very likely to likely lower than the intercept. It, therefore, appears that the differences in $PL.m^{-1}$ may reflect the movement requirements associated with the different training activities.

Further to activity type, $PL.m^{-1}$ was also found to have an effect with area per player. If $PL.m^{-1}$ could be expected to be sensitive to different movement requirements this is an observation that would be anticipated as relative pitch size have been found to influence change of velocity demands (Gaudino *et al*., 2014). The only surprise, therefore, was that only a small effect was observed. One rationale for an underreported effect between area per player and $PL.m^{-1}$ may be the result of the challenge faced when trying to quantify a value for the area per player during linear based running. The decision to record the width as 1 yard may have underestimated the equivalent relevant area.

The observed sensitivity of PL.m^{-1} does fit with previous research in the area. Although conducted in very uncontrolled circumstances, a change in the variable was observed towards the end of the first and second half of elite competitive football matches (Barrett *et al*., 2016). The researchers associated the difference with an increased fatigue and greater risk of injury (Barrett *et al*., 2016). The researchers' assumption that a change in the MEMS accelerometer variable may be associated with an increased injury risk does appear to be an over generalisation from the research. It may, however, be proposed that the variable was sensitive to a change in movement patterns. Due to the findings of the current study, the suggestion that PL.m^{-1} may represent movement requirements appears more appropriate than the 'locomotive efficiency', which was proposed in the previous study. When the findings of the current and previous study are considered collaboratively, it does appear that PL.m^{-1} may be sensitive to differences in movement as a result of fatigue, activity type or pitch dimensions. No further research, however, has investigated PL.m^{-1} in controlled conditions in the applied environment, therefore, conclusions around the variable's utility may still be limited.

In regard to PL, it was previously established in study one, that the measurement is largely influenced by duration. Duration was, therefore, controlled for within the mixed model for each dependent variable. The results, however, appear to suggest that PL still offered little sensitivity in describing differences between the activity types or area per player examined. This proposal is made upon the evidence that for the thirteen activity types, seven are grouped with similar PL values. There does also appear to be a large range of movements contained across these closely grouped activity types. For example, it may be assumed that the highly multidirectional SSG and the largely linear aerobic running would require different movement requirements, however, their PL differences are most likely trivial.

The observations that PL may not be effective in distinguishing between different activity types appears to conflict with some of the research in the area. The previous research, which has investigated PL use during match scenarios would suggest it was found to differentiate between playing position (Boyd *et al*., 2013; Dalen *et al*., 2016; Gabbett, 2015; Polglaze *et al*., 2015), standard of play (Boyd *et al*., 2013) and stage of game (Barrett *et al*., 2016). It has also been found to differentiate between types of training activities (Barreira *et al*., 2016; Boyd *et al*., 2013; Wundersitz *et al.,* 2015[1], Wundersitz *et al.,* 2015[2]) and between competitive matches and training (Boyd *et al*., 2013; Montgomery *et al*., 2010; Polglaze *et al*., 2015). It may be suggested, however, that many of these differences may be accounted for by the close relationship, which has previously been established between PL and external training load markers such as distance covered (Gabbett, 2015; Polglaze *et al*., 2015; Scott *et al.,* 2013) and low speed distance (Gabbett, 2015). It may, therefore, be argued that PL may be suitable to differentiate between conditions where the locomotive demands are very different, however, may underestimate the differences between activities where the differences are associated with movement demands. The close relationship between PL and distance covered may, therefore, simply represent a different approach to representing training load data that is already quantified via a different external load volume related variable.

The close association between total distance and PL has been suggested to be highly dependent upon accelerations measured in the vertical plane (z-axis), which in part represents ground contact while running (Scott *et al*., 2013). This may, therefore, provide a rationale for why there is a direct relationship between PL and the distance covered because of the volume of foot contacts a player makes. It, therefore, appears intuitive to expect that the further distance ran, the more foot contacts and, therefore a greater associated PL. The rationale, therefore, for the present study's proposal that PL.m^{-1} may offer encouragement in distinguishing between different movement requirements, may be a direct result of the reduction of the locomotive bias associated with PL via making the MEMS accelerometer variable relative to distance covered. As MEMS accelerometers are multiplanar it may be perceived that PL.m^{-1} offers a method of identifying the mean multiplanar accelerometer demands associated with every meter covered.

Further evidence that PL.m^{-1} may be effective at differentiating between different movement requirements is observed within the between activity type variation data. The same information supports the limitation of PL for the same purposes. For PL.m^{-1} the greatest variation was present between possession activity types and the lowest was present between games. This was very different to PL, where the largest variation was associated with games and the lowest with speed. These findings may support some of the earlier observations, as PL variation may be the result of the inter-positional differences associated with the different locomotive distance requirements. Due to the generic nature of speed drills every player is exposed to the same volume of activity, which may, therefore, explain why the smallest variation exists within this activity type for PL. On the other hand, the smallest variation between PL.m^{-1} was observed in games. This may be because the conditions (pitch size, number of players, no coach interaction etc.) associated with games were the same throughout each occasion, which may lead to very similar movement requirements on each occasion the activity was completed. Possession, however, has huge variations in the conditions applied between each occasion with pitch dimension, player number, directional v non-directional, restrictions on number of passes all possible examples amongst others. It is, therefore, likely that this large variety of drill design factors that may be manipulated, may influence the movement requirements between activities without largely influencing the locomotive demands. This would, therefore, influence the PL.m^{-1} observed.

The fact that such a large dataset containing so many varieties and volumes of training activities across multiple seasons from an elite Premier League football team was a real strength to the study. This approach was possible as the same science staff and scientific processes had been in place at the club, which was investigated. The retrospective nature of the study did, however, also provide limitations. Firstly, the hardware, software and firmware utilised throughout the period had changed in line with commercial developments. It was, however, perceived that the two MEMS accelerometer derived variables that were chosen to be investigated were minimally influenced by these developments. The uncontrolled retrospective nature of the study does, however, still lead to some limitations. It is, therefore, proposed that future research should be conducted in a more tightly controlled prospective investigation. This area of research would then allow deeper interrogation into the components of training activities that may influence the associated demands, particularly in regard to movement requirements. Finally, to add real insight into elite football training design, more work needs to be completed that looks to identify how the external demands of drills relate to the internal demands and, therefore, physiological adaptation. This would, therefore, enable the planning and delivery of training to take a truly informed approach.

In conclusion, it appears that $PL.m^{-1}$ may be an effective external training load variable for describing the movement requirements of training activities. The measure appeared sensitive to both different types of football training activities and pitch dimensions. Although, PL is well supported as a training load variable elsewhere within the literature, it appears that it does not clearly distinguish between the movement requirements of training activities or the relative area per player. PL instead appears to be closely related to training volume. The application of $PL.m^{-1}$ appears to fill a gap in practice and research as no external training load variable has previously been well utilised or supported to capture differing movement requirements. Further research is, however, required to test the proposal in a more controlled applied football environment.

4.6 PROFFESIONAL SKILLS DEVELOPMENT REFLECTION

Research Skills

The one key research skill that have been really keen to develop from the outset of the professional doctorate is my data analysis and interpretation skills. Historically this has been a skill set that I have tended to pick up and drop as required when engaging in academic research. I am, however, really keen to develop this as a skill set and ensure that I do not only use it within my academic and research realms but I would love to integrate it effectively into my professional role. I have had a fascinating development in this area over the course of the layered statistical analysis approach in study two. Firstly, I have engaged with Patrick Ward (a PhD student of Barry's from Seattle). He has an incredible knowledge around the analysis of large data sets and practically analysing them to inform applied scientific decisions. Patrick has been fantastic and took me on a journey of development through the analysis of the data set. A lot of our initial discussions have been around 'getting to know' the data via me exploring scatter plots of data to develop my understanding of possible relationships and then utilising PowerBi to visualise the data to enable me to make early interpretations. We have since had several conversations around what we wanted the analysis to look like to enable the research question to be effectively answered. Patrick has then completed the sophisticated mixed linear model around the large data set and provided me with the results relative to an intercept. Although I didn't personally complete this stage of the analysis due to my limited expertise and the time constraints I am currently under, I feel I have certainly developed a much better understanding of the rationale and methods for this type of analysis. The area that I am, however, currently developing is the analysis associated with the final stage of the current study, the practical interpretation of the results via MBI.

MBI is an area of analysis that I have used previously for applied case studies and during my BASES Supervised Experience. I have not, however, continued to use it within my daily professional practice. I guess I have always been aware of its utility and knew that it would be really beneficial to use not only in research but in practice. For a reason unbeknown (other than limited expertise) I have not explored its integration into my current practical data monitoring, interpretation and feedback strategy. In fact, following my refamiliarisation of the methods, I am a little bemused into why I have not been using the relatively simple yet practically relevant methods before now. I am, therefore, really keen to develop a further understanding of the methods and would love to get to the level where I could utilise it across the wide data sets that I collected within my role. The benefits and rationale for its utilisation in practice are well overviewed in the commentary by Martin Buchheit in IJSPP (Buchheit, 2016). Following my current engagement in this method of analysis, I am definitely comfortable that I could use the Hopkins' spreadsheets (www.sportsci.org) to make practical interpretations around group or individual changes. It is, therefore, certainly something I will be integrating into my practice.

Management and Leadership Skills

At this stage of the project I feel that I am continuing to work towards developing the skills related to management and leadership, which I set my self at the self-assessment stage of the professional doctorate. A reflective extract below demonstrates some of the lessons that I have recently learnt in this area as I pass the midway point of my professional doctorate journey:

> *Now I sit here just over halfway through my professional doctorate journey I feel the time is right to reflect upon one of the key professional skills that I wanted to develop over this time; management and leadership. I feel that at this stage of my pathway I have made some important steps in theoretically improving this and conceptually have developed some strong beliefs and ideas in the area. I have done this by a lot of wider management and*

leadership related reading. I am, however, having limited exposure to a wide variety of these kinds of activities within my professional life and, therefore, have limited exposure to practically apply some of the principles that I think are important. Yes, I do have managerial responsibility for some staff, however, this would largely be for only a couple of direct reports. I would, however, unofficially manage/ mentor a much wider team of further support staff; nutrition, S&C, academy staff etc. I do, however, feel the fact that I do not officially line manage this wider department make it difficult for me to completely engage in the processes that I perceive is required. I plan to raise this at the end of the season as I feel that this would improve the effectiveness of the science team and add clarity around roles and responsibilities, aligning our mission and strategy. The area that I do have a real passion for and one that I am currently engaging in and starting to see some beneficial results in is the development of the other staff. I have taken on the responsibility for organising the internal and external CPD requirements of the staff and have lots of supervisory/ mentorship responsibility. I feel that these two areas are both roles that I really enjoy and certainly take great personal reward from engaging in. I do, however, feel that I am currently learning as I go along in both areas and would hope to complete some formal supervisory/ mentorship training in the near future. I, therefore, intend to explore what are the best professional development pathways in this area once I complete my professional doctorate.

CHAPTER 5

THE SENSITIVITY OF EXTERNAL TRAINING LOAD TO DESCRIBE DIFFERENCES IN FOOTBALL SPECIFIC MOVEMENT

5. THE SENSITIVITY OF EXTERNAL TRAINING LOAD TO DESCRIBE DIFFERENCES IN FOOTBALL SPECIFIC MOVEMENT

5.1 RESEARCH ORIENTATION

The results of the previous study appear to suggest that MEMS accelerometer may offer a suitable measurement method in differentiating between the movement requirements of different training activities. I am, however, a little surprised that it was not PL (when normalised for duration) that was found to demonstrate effectiveness in capturing these differences. Historically, I would always particularly examine this variable and associate it with high multidirectional demands. On reflection, however, I think that this has largely been due to the theoretical sense that it has made rather than the practical observations that I have made. This is an example of why any practitioner should look to make their own practical interpretations of technology rather than being commercially led or purely trusting their theoretical compass. The other investigated variable $PL.m^{-1}$ did, however, appear to offer some insight between training activities. I have previously used the measure occasionally within practice. I have typically examined it as part of a 6-weekly submaximal yo-yo assessment that all players have completed. I have always been of the opinion that the variable appeared sensitive to change within this assessment. I have, however, always been very reluctant to make any grand assumptions about what these differences may represent. Was it a change in gait? A change in surface? Could it capture fatigue? Could it capture stiffness? Is it influenced by a change in footwear? There have been, therefore, more questions than answers that have arisen when I have practically investigated the measure. The current study does, however, appear to support what I have seen in practice that the variable does appear to be sensitive to change; between activities in this instance.

The variable described has, however, only been found to differentiate between activity. The reasons for this differentiate are still to be established. When I have looked at the training activity types that are associated with greater and smaller differences when compared to the intercept there does, however, appear to be a theme…in theory. The activities that are recognised to be greater than the intercept appear to be the more change of direction, movement orientated activities, while the activities at the other end of the continuum, which are similar or lower than the intercept appear to be more locomotive and linear in nature. This, therefore, appears to suggest that the variable may potentially be a viable option for capturing the movement requirements, as desired. This hypothesis does, however, need further investigation and will need to be tested in the following study. One way of testing this is by a more controlled efficacy-based assessment, which attempts to manipulate the dependent variable of movement.

When it comes to training design there are many factors that must be considered; activity type, area size, number of players, conditioning, duration, rest periods, number of reps and sets etc. One area of high importance for my practice as an applied sport scientist within elite football is that I must have a really good grasp on how subtle variations in these factors may impact upon the physical demands of a drill. As I am fortunate enough to be involved in the training planning process, an in-depth knowledge of this area allows me to offer great insight into the coaching or interdisciplinary training planning meeting, therefore, informing the training process. I am, however, of the opinion that frequently a lot of these training design discussions may be steered without a true understanding of how some of the subtle manipulations in these design factors may have huge implications for the physical components of the drill, not just the technical and/or tactical components, which frequently dictate the training design variables selected. One of the physical components of drills, which I think is grossly misunderstood is the specific movement requirements. I think this is largely since there is no consensus or wide recognition what the most effective measure for monitoring these requirements is. Typically, these demands are captured using a combination of measures that could be perceived to be some of the most inaccurate available from MEMS units (GPS derived accelerations/ decelerations), which surely just dilutes their validity and application even further.

Study two attempted to identify the appropriateness of MEMS accelerometers to differentiate between training activities. The exact factors relating to the drill, which were captured are still, however, to be established. The questions, therefore, that are still to be posed are relating to the sensitivity of these measures (or other GPS, heart rate or perceptual measures) to capture the specific movement requirements associated with training activities. The systematic manipulation of these movement requirements will, therefore, been examined in the current study by changing the relative pitch dimensions. This study will further test the hypothesis that had been proposed following study two, where $PL.m^{-1}$ was suggested to be sensitive to different training activities (possibly due to differing movement requirements).

5.2 INTRODUCTION

Theoretically, it may be perceived that MEMS accelerometers offer potential in capturing the multidirectional activity demands, which GPS methods underestimate. In fact, the technology has been found to be sensitive to treadmill walking, jogging and running (Wundersitz *et al*., 2015[1]), within match patterns in competitive football (Barrett *et al*., 2016), movement activities (Barreira *et al.*, 2016) and rugby specific tackle activities (Wundersitz*et al*., 2015[2]). From these results it may, therefore, be hypothesised that MEMS accelerometers may also be useful in capturing and differentiating between the training loads associated with different movement demands in football. Previously, however, the research that is available in the area of monitoring football with MEMS accelerometers has tended to be either uncontrolled competitive matches or training scenarios (Barrett *et al*., 2016; Dalen *et al*., 2016; Scott *et al.,* 2013) or tightly controlled laboratory experiments (Barrett *et al*., 2015; Barreira *et al.*, 2016). It is, therefore, important to establish if the technology offers utility in differentiating between the controlled systematic manipulation of movement requirements within the real-world effectiveness training environment.

Movement requirements within football specific activities may be systematically manipulated by altering relative pitch size. Theoretically, the less relative area a player is exposed to the greater the change of direction load as opposed to opportunities to run in long linear patterns. This theoretical proposal is supported within the literature where an increased volume of accelerations, decelerations and total number of changes in velocity was observed in pitches sizes that had a relatively smaller area per player (Gaudino *et al*., 2014). When reviewing the similarities between the training literature surrounding SSG and change of direction activity it appears that a broader theoretical framework can be applied throughout training methods. Heart rate (Dellal *et al*., 2010), RPE (Dellal *et al*., 2010), blood lactate (Buchheit *et al.,* 2010; Dellal *et al*., 2010) and energy cost (Hatamoto *et* al., 2014; Stevens *et al.,* 2015; Zamparo *et al.,* 2015) have all been found to be higher during the movement requirements of repeated shuttle running (180^{o} turns) than repeated constant running. The movement requirements when players are exposed to greater relative area are very different with less change of direction demands but greater exposure to increased locomotive distances and speeds. This theoretical point of view must, however, become more practically orientated. This may be achieved by researchers and practitioners ensuring that the most effective external training load monitoring methods to differentiate between these movement requirements of different training scenarios are investigated and applied.

There appears to be limited research that has looked to identify the most appropriate external training load method to identify between different football training scenarios. There appears to be a complete absence of effectiveness research in this area of monitoring the changes in movement patterns associated with different training methods. The current study, therefore, aims to firstly, examine the sensitivity of MEMS accelerometer, GPS, heart rate and perceptually derived variables to changes in movement requirements. Secondly, it hopes to identify the most effective training load variable to describe differences in movement requirements in football specific activities. To meet these aims the independent variable (movement) will be systematically manipulated via a change in pitch dimensions (large and small) across structured (running), semi-structured (dribbling) and unstructured (possession) training activities.

5.3 METHODS

5.3.1 Participants

26 elite outfield football players from a Premier League U18 and U23 squad (mean ± SD: age 18 ± 1 years; height 1.82 ± 0.06 m; body mass 74.9 ± 5.7 kg) participated in the study. Players consisted of 5 central defenders (CD), 3 wide defenders (WD), 7 central midfielders (CM), 5 wide midfielders (WM) and 6 center forwards (CF). No goalkeepers were included in the study. All players were made aware of the purpose of the study and provided written consent. The study was conducted according to the requirements of the Declaration of Helsinki and was approved by the University Ethics Committee of Liverpool John Moores University.

5.3.2 Experimental Design

The study was designed to investigate if training load variables can effectively differentiate between the movement requirements of systematically manipulated training activities. Three controlled experimental testing sessions were organised. One experimental training session required participants to complete running based activities, one possession based activities and the other dribbling based activities. The three experimental training sessions replaced scheduled training sessions during three consecutive weeks within the competitive season. Two different formats of the activity were completed by the participants. One activity was with relatively large pitch dimensions and one with relatively small pitch dimensions. The running and dribbling training sessions were completed in a crossover design. Table 8 outlines the format and order of each group of participants completed the experimental training sessions. Participants were randomly assigned to the groups. A standardised 15-min warm up proceeded each experimental training session. All experimental training sessions took place at the club's official training facilities on a grass pitch. All dimensions were measured used a measuring wheel (Hilka, Chessington, UK).

Table 8. Crossover format and order of each experimental training session

Experimental Session 1		Experimental Session 2		Experimental Session 3	
Running		Possession		Dribbling	
Long (LRun)	Short (SRun)	Large (LPoss)	Small (SPoss)	Long (LDrib)	Short (SDrib)
Group 1 (n = 10)	Group 2 (n = 10)	All (n = 20)		Group 1 (n = 10)	Group 2 (n = 10)
Group 2 (n = 10)	Group 1 (n = 10)		All (n = 20)	Group 2 (n = 10)	Group 1 (n = 10)
Group 1 (n = 10)	Group 2 (n = 10)	All (n = 20)		Group 1 (n = 10)	Group 2 (n = 10)
Group 2 (n = 10)	Group 1 (n = 10)		All (n = 20)	Group 2 (n = 10)	Group 1 (n = 10)

5.3.3 Experimental Training Sessions

The running experimental training sessions required players to complete four 4-min bouts of interval running. The change of direction demands were systematically manipulated between two different training activities. Activity one was a long course with players required to turn 180º every 106 m (LRun) and activity two a short course with players required to turn 180º every 26.5 m (SRun) (Figure 1). Each activity was completed twice. Three minutes passive recovery occurred between bouts. Players were instructed to run at a high-intensity pace that they could sustain for four minutes. The activities were completed in a crossover design, which is outlined in Table 1. The start and end time of each bout was noted.

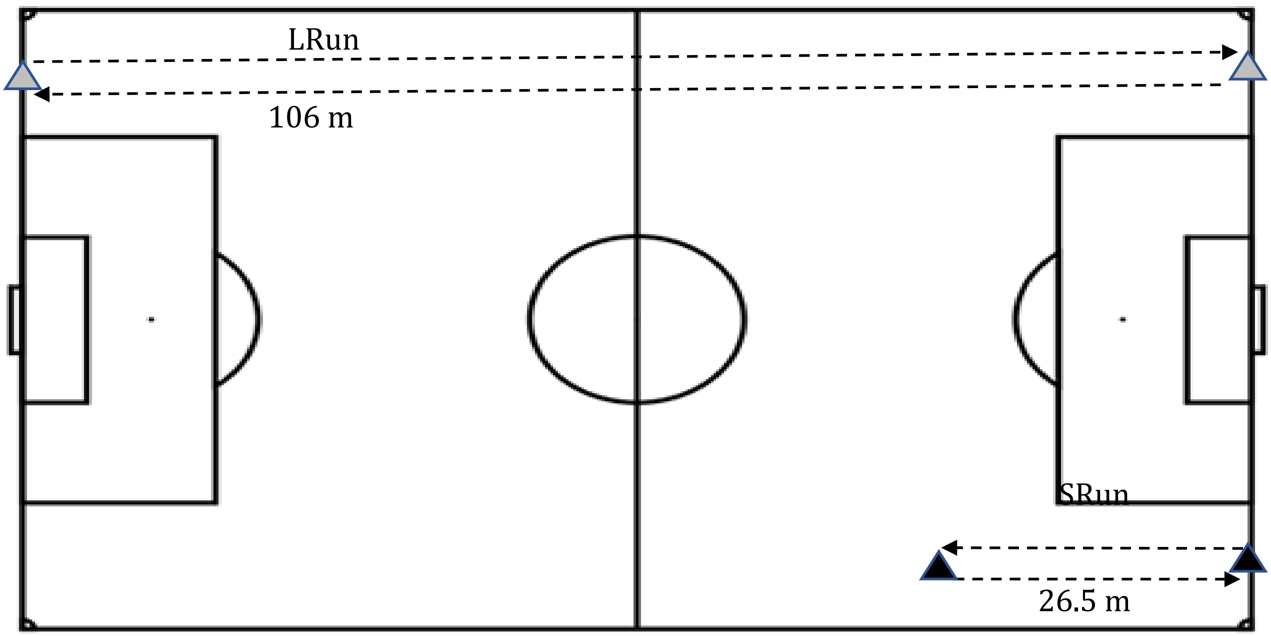


Figure 22. Field based set up for experimental training session 1 (SRun and LRun)

The possession based experimental training session required players to complete four 4-min bouts of possession activities. The activity dimensions and, therefore, respective area per player were systematically manipulated between two different training activities. Activity one was a 10 v 10 on a relatively large pitch (53 x 56 m; 148 m^2 per player) (LPoss) and activity two a 10 v 10 on a relatively small pitch (37 x 40 m; 74 m^2 per player) (SPoss) (Figure 2). Players were instructed that there was no restriction on the number of touches and each team was instructed to attempt to make as many consecutive passes as possible, which were counted by a coach. Each activity was completed twice as outlined in Table 1. Three minutes passive recovery occurred between bouts. The start and end time of each bout was noted,

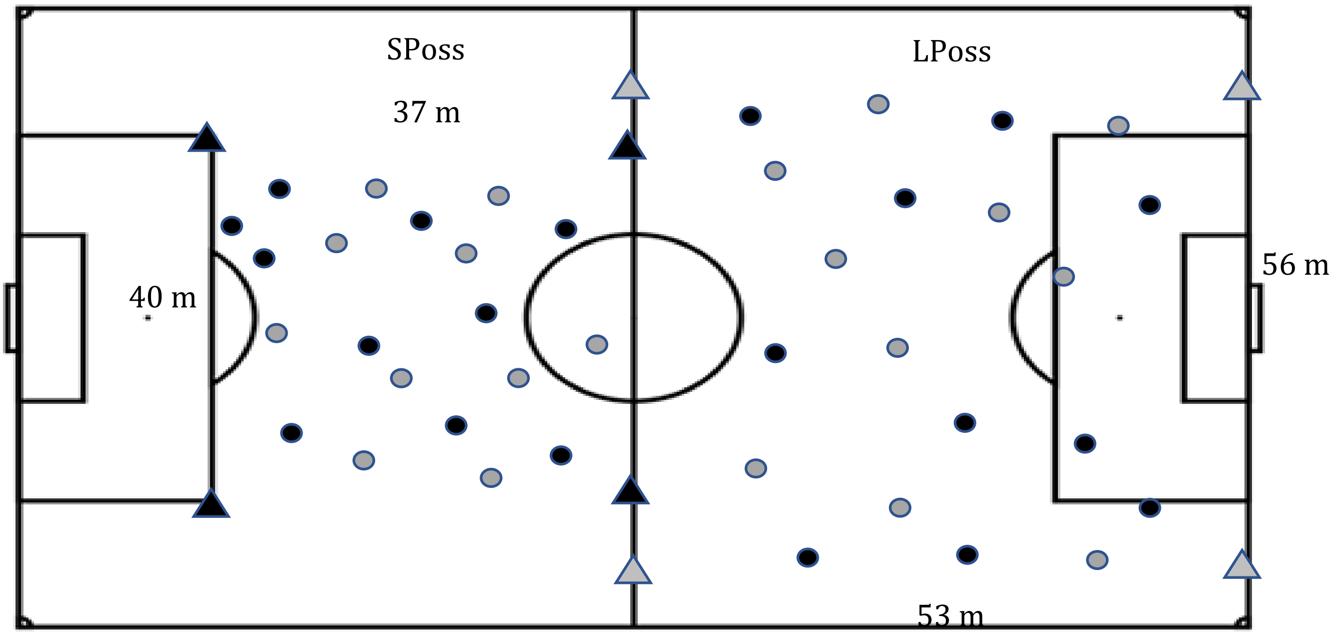


Figure 23. Field based set up for experimental training session 2 (SPoss and LPoss)

The dribbling experimental training session required players to complete four 4-min bouts of dribbling around a designated course. The change of direction demands were systematically manipulated between two different training activities. Activity one was a long course with players required to complete a lower volume of turns (LDrib) (Figure 3) and activity two a short course with players required to turn more frequently (SDrib) (Figure 4). Each activity was completed twice. Three minutes passive recovery occurred between bouts. Players were instructed to dribble at a high-intensity pace that they could sustain for four minutes. The activities were completed in a cross over design, which is outlined in Table 1. The start and end time of each bout was noted,

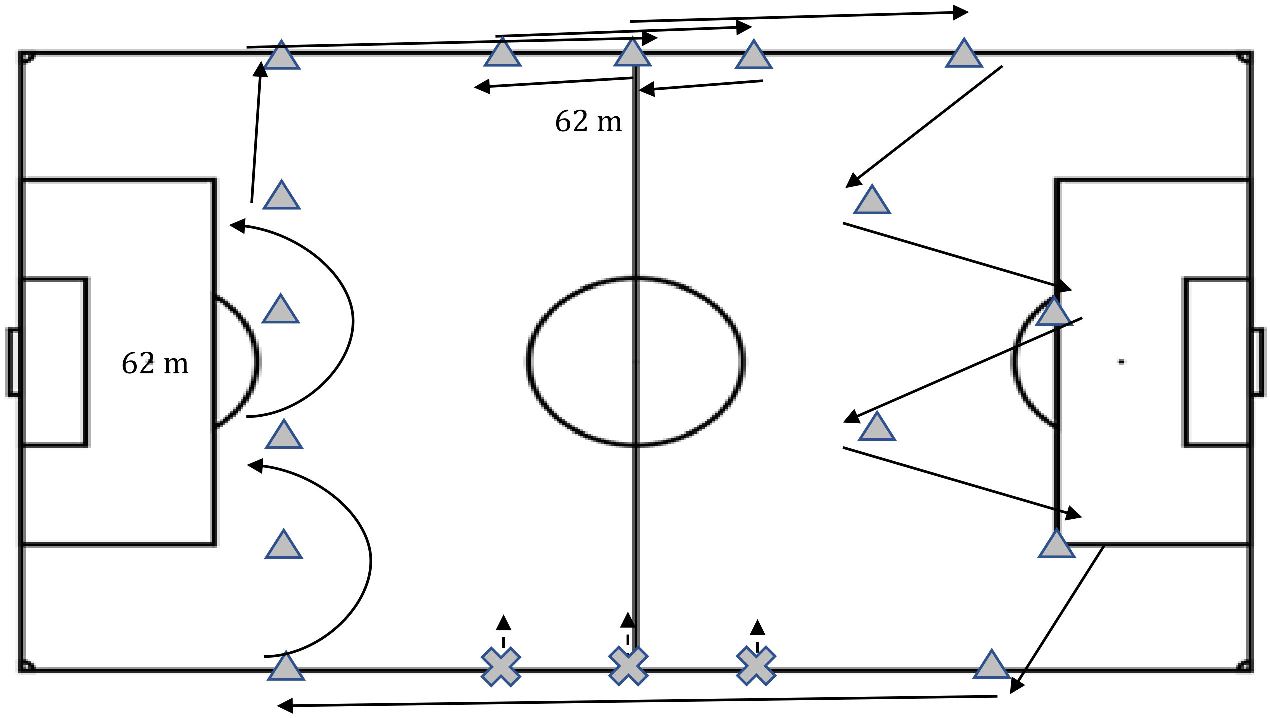


Figure 24. Field based set up for experimental training session 3 (LDrib)

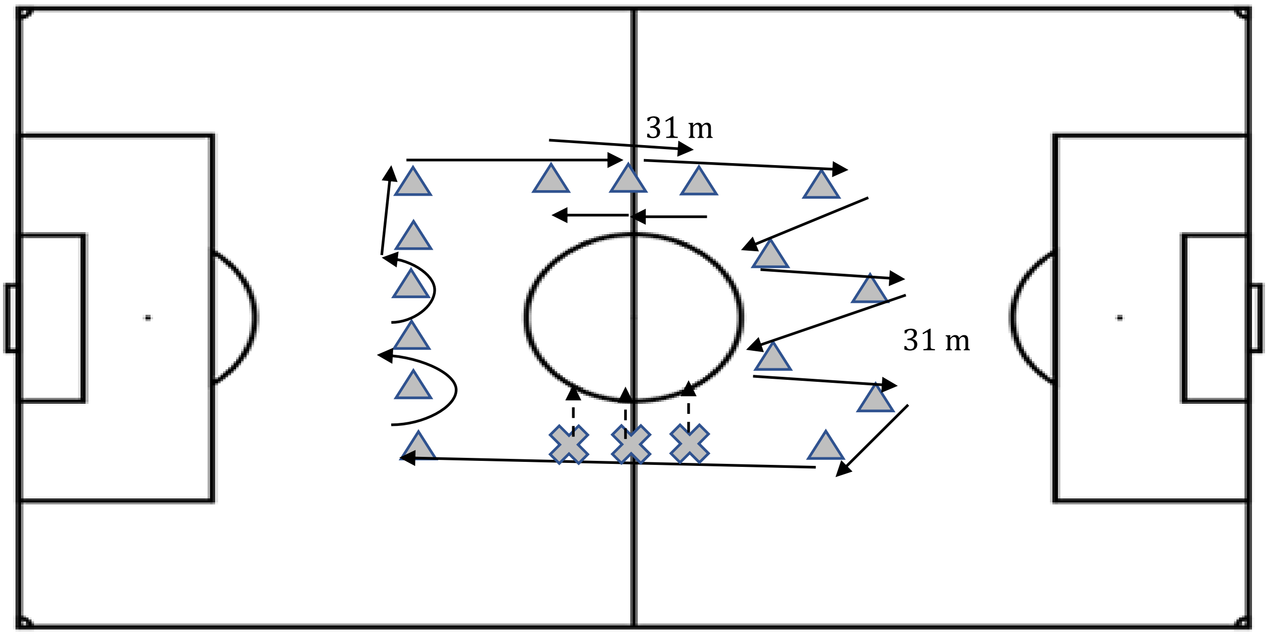


Figure 25. Field based set up for experimental training session 3 (SDrib)

5.2.4 Data Collection

Each player's physical activity during each experimental training session was monitored using microelectromechanical systems (MEMS) tracking devices (S5, Catapult Sports, Melbourne, Australia), which include a GPS chip, MEMS accelerometer, gyroscope and magnetometer technology and heart rate monitors (Polar T31, Helsinki, Finland). The 10 Hz GPS recorded time motion analysis data. For data to be included the number of satellites must have exceeded 6 and a HDOP was less than 1.5. As previously outlined elsewhere in the literature the tri-axial piezoelectric linear accelerometer (Kionix: KXP94) contained within the MEMS tracking device sampled at a frequency of 100 Hz (Barrett *et al*., 2016). The output of the MEMS accelerometer measures ± 13 g (Barrett *et al*., 2016). The device contains a microprocessor with 1GB flash memory and a USB interface to store and download data (Barrett *et al*., 2016). The device is powered by an internal lithium ion battery with 5 h of life weighing 67 g and is 88 × 50 × 19 mm in dimension (Barrett *et al*., 2016). The firmware was updated in line with the manufacturer's recommendations and the most up to date version (7.25) was installed at the time of data collection. The units were calibrated in line with the manufacturer's guidelines. The MEMS devices were activated for 30-mins under open sky before data collection, to allow acquisition of satellite signals as per manufacturer's instructions. The MEMS device was fitted in a small neoprene pouch within an undergarment located posteriorly between the scapulae. Heart rate monitors were worn around the torso, level with the xiphoid process. To minimise inter-unit variability, players were assigned their own MEMS device and heart rate monitor, which was worn by the individual during each training exposure. All players were well familiarised with training in the MEMS tracking device and heart rate monitor.

Immediately following the end of each 4-min trial, within the 3-min rest period, players were asked to provide differential-RPE ratings via a centiMax scale (CR100) (Borg & Borg, 2002). Each participant was asked to differentiate between local (legs; RPE-L), central (breathlessness; RPE-B), overall (overall; RPE) and technical (technical; RPE-T) rating of perceived exertion (Borg *et al*., 2010). Players were prompted for the RPE rating individually by an investigator, who provided a centiMax scale (CR100) for review and noted the response with pen and paper upon a clipboard. The players were previously familiarised with the scale.

5.3.5 Data Analysis

Following each experimental training session, data recorded on the MEMS device was downloaded on the relevant commercially available software package

(Openfield, Catapult Sports, Melbourne, Australia). As the study was designed to examine the effectiveness of MEMS accelerometer variables to effectively differentiate between the movement requirements between training conditions. PL (au), PL per minute (PL.min^{-1}; au), PL.m^{-1} (au), 2DPL (au), anteroposterior PL (PLap; au), mediolateral PL (PLml; au), vertical PL (PLv; au), inertial movement analysis efforts (IMA; au), total distance per in (m.min^{-1}; m) and TRIMP (au) were selected for analysis.

M.min^{-1} was the only variable that was calculated from GPS. The GPS variable was chosen to offer an insight into the locomotive demands of the activities and as a reference for the MEMS accelerometer based variables. PL was calculated from accelerometry data and is determined from the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (x, y and z) and divided by 100 (Boyd *et al.,* 2011). PL.min^{-1} was the PL divided by the duration of the activity and displayed relative to minutes. PL.m^{-1} was calculated from accelerometry and GPS data and is determined from PL divided by the total distance covered. It has previously been proposed that PL.m^{-1} presents a measure of a player's locomotive efficiency (Barrett *et al*., 2016). 2DPL is derived from only the accelerations in the medio-lateral and anteroposterior planes (as the vertical vector of the PL equation is removed) (Gabbett, 2015). PLap, PLml and PLv each represent the three individual component planes of PL. IMA represents the accelerations, change of direction and deceleration events greater than 2.5 m.s^{-1} based on MEMS accelerometer, gyroscope, and magnetometer data. Within the commercially available software, the original acceleration data was smoothed at a known frequency via a polynomial least squares fit then the smoothed data was overlaid onto the original acceleration trace to identify the start and end point of each event (Luteberget & Spencer, 2017). These events are displayed as a change in velocity throughout the medio-lateral and anterior-posterior vectors (Luteberget & Spencer, 2017). Heart rate was recorded every 5-sec during training. The relevant TRIMP was calculated for each training activity via the relevant commercially available software package. TRIMP was calculated from assigning an intensity of 1, 1.2, 1.5, 2.2, 4.5 and 9 to the time spent in the respective heart rate zones, 0-50%, 50-65%, 65-75%, 75-85%, 85-92%, 92-100% heart rate maximum.

All training session data was split into the separate discrete activities within each experimental training sessions. The start and end times noted during the session were verified by the velocity curves displayed within the software upon download, which allowed players' movements to be identified. This enabled the relevant period of activity associated with the training to be selected. The data was then downloaded from the software into excel (Microsoft, Redmond, USA) via CSV reports for analysis. The associated differential RPEs were assigned to each participant for each trail and added to the excel spreadsheet.

5.3.6 Statistical Analysis

The mean and standard deviation (mean ± SD) were calculated for all variables. All differences are presented as means with 95% confidence limits (mean ± 95% CL). Cohen's d effect sizes were calculated from the ratio of the mean difference to the pooled standard deviation to establish standardised differences. Effect sizes of <0.20 represented trivial, 0.21-0.50 small, 0.51-0.80 moderate, >0.81 large differences. A magnitude-based inference approach was used to interpret practical significance between group differences. The threshold for change considered to be practically important (SWC) was 0.2 multiplied by the between subject standard deviation, based on Cohen’s d effect size principle. The probability that the magnitude of change was greater than the SWC was rated as <0.5% most unlikely, 0.5-5% very unlikely, 5-25% unlikely, 25-75% possibly, 75-95% likely, 95-99.5% very likely and 99.5-100% most likely. The probability was rated as unclear if the chance of a substantially positive and negative effect were >5%.

5.4 RESULTS

The findings from each of the experimental training sessions will be described in separate sections. Similarities between the findings of each experimental training session will then be overviewed.

5.4.1 Experimental Condition 1 – Running

Table 9 displays the mean ± SD and associated mean difference ± 95% CL for LRun and SRun. Figure 26 displays the Cohen’s D effect size ± 95% CL differences and associated magnitude-based inference between LRun and SRun. PL.m^{-1} and RPE-T were most likely greater and demonstrated large effect sizes (1.93 ± 0.75; 1.07 ± 0.66 respectively) in SRun. These results suggest that players perceived greater technical demands when turning more frequently and that PL.m^{-1} may be sensitive to the different movement patterns required within each of the two activity types. IMA was possibly likely to be greater in SRun and demonstrated a small effect size (0.33 ± 0.62). No other variable appeared to be greater in SRun. M.min^{-1} was the only training load variable to be most likely lower in SRun and demonstrated a large effect size (-3.32 ± 0.94). $M.min^{-1}$, therefore, appears to be reflective of the movement requirements associated with running continuously. Variables that were very likely lower in SRun were PL and $PL.min^{-1}$, both demonstrating large effect sizes (0.82 ± 0.64; 0.82 ± 0.64 respectively). 2DPL, PLap and PLv were all likely lower in SRun with moderate effect sizes (-0.61 ± 0.63; -0.54 ± 0.63; -0.67 ± 0.64 respectively). This appears to suggest that many of the PL derived variables (PL, $PL.min^{-1}$, 2DPL, PLap and PLv) are more reflective of the demands of continuous running than change of direction. PLml, TRIMP, RPE, RPE-L and RPE-B all demonstrated unclear differences, all with the exception of RPE-B were associated with small effect sizes (-0.29 ± 0.62; -0.22 ± 0.62; 0.26 ± 0.62; 0.41 ± 0.63; 0.02 ± 0.62 respectively).

Table 9. Mean ± SD for each training load variable for LRun and SRun and the associated difference ± 95% confidence limit

	LRun (mean ± SD)	SRun (mean ± SD)	Difference ± 95% CL
$m.min^{-1}$	240.90 ± 13.85	196.20 ± 13.08	-44.70 ± 24.09
PL	82.19 ± 5.81	77.44 ± 5.82	-4.75 ± 3.91
$PL.min^{-1}$	20.34 ± 1.44	19.15 ± 1.44	-1.19 ± 0.98
$PL.m^{-1}$	0.08 ± 0.01	0.10 ± 0.01	0.01 ± 0.005
2DPL	47.09 ± 4.04	44.68 ± 3.88	-2.41 ± 3.01
Plap	32.48 ± 4.31	30.32 ± 3.67	-2.16 ± 3.09
PLml	27.44 ± 2.98	26.57 ± 3.06	-0.87 ± 2.21
PLv	60.29 ± 5.98	56.35 ± 5.73	-3.94 ± 3.74
IMA	0.03 ± 0.11	0.08 ± 0.18	0.05 0 ± 0.07
TRIMP	16.58 ± 5.98	15.35 ± 5.36	-1.23 ± 3.74
RPE	63.50 ± 9.91	65.63 ± 6.01	2.13 ± 6.97
RPE-L	66.63 ±14.03	71.25 ± 7.37	4.63 ± 8.90
RPE-B	57.88 ± 14.06	58.13 ± 9.14	0.25 ± 8.24
RPE-T	17.00 ± 5.48	25.95 ± 10.53	8.95 ± 4.82

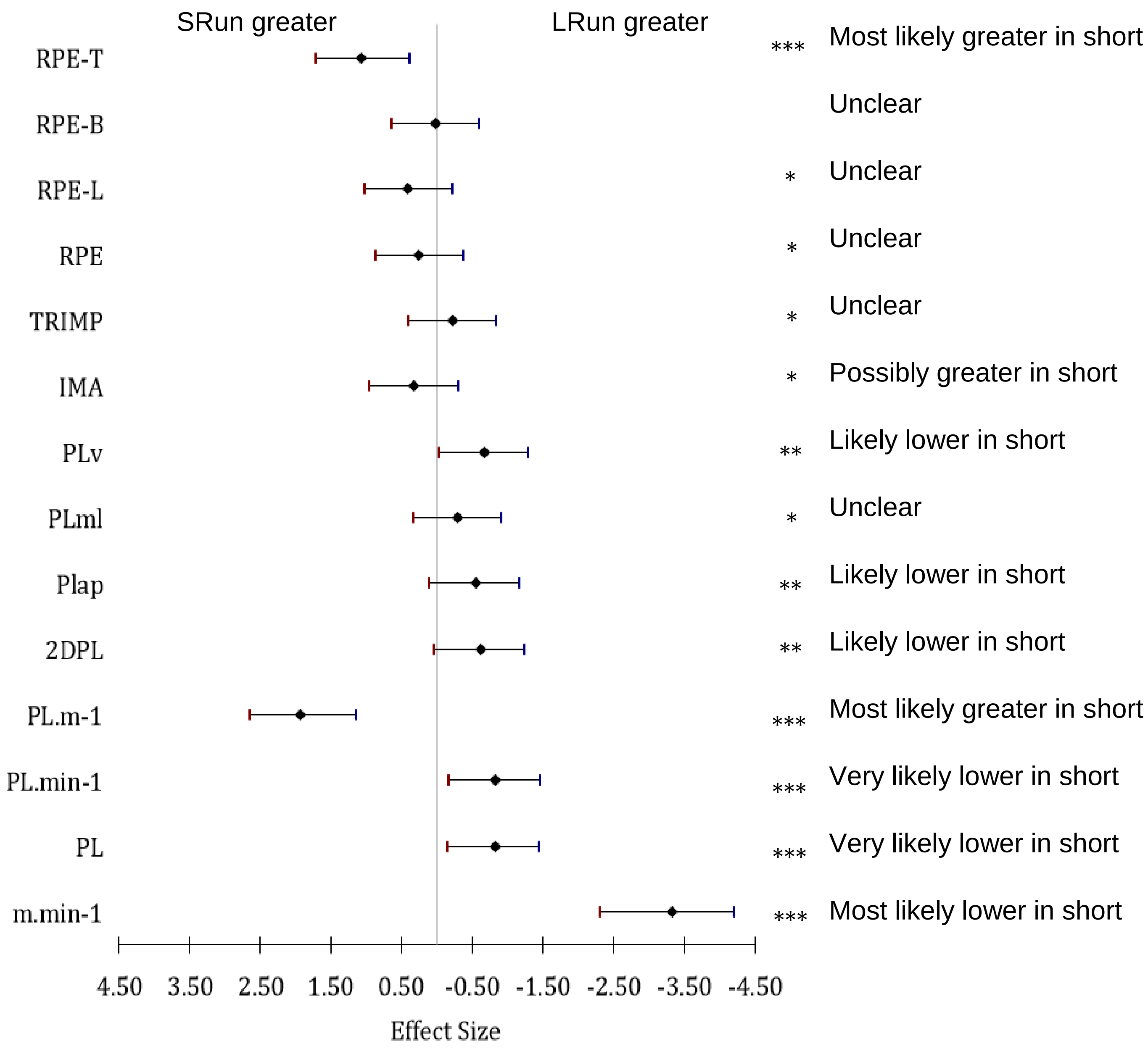


Figure 26. Cohen's D effect size ± 95% CL differences between training load variables for LRun and SRun (* = 0.21-0.50, small; ** = 0.51-0.80, moderate; *** = >0.81 large differences) (magnitude-based inference)

5.3.2 Experimental Condition 2 – Possession

Table 10 displays the mean ± SD and associated mean difference ± 95% CL for LPoss and SPoss. Figure 27 displays the Cohen's D effect size ± 95% CL differences and associated magnitude-based inference between LPoss and SPoss.

RPE-T was the only training load variable that was most likely greater in SPoss and demonstrated a large effect sizes (1.39 ± 0.69). This suggests that players perceived the technical demands association with SPoss to be greater than those associated with LPoss. $PL.m^{-1}$, IMA, RPE and RPE-L were all likely greater in SPoss and associated with small effect sizes (0.29 ± 0.62; 0.49 ± 0.63; 0.33 ± 0.62 and 0.43 ± 0.63 respectively), which suggests that the two MEMS accelerometer variables and two perceptual variables were increased as a response to the smaller pitch size. $M.min^{-1}$ was most likely lower in SPoss and associated with a large effect size difference (-0.86 ± 0.65). $PL.min^{-1}$ and PL were very likely lower in SPoss and were associated with small effect sizes (-0.50 ± 0.63; -0.50 ± 0.63). PLv was possibly lower SPoss and demonstrated a small effect size (-0.26 ± 0.62). These results again appear to support the suggestion that greater $M.min^{-1}$ appears to be associated with larger areas and that PL, $PL.min^{-1}$ and PLv appear to demonstrate larger values in the bigger pitch size. 2DPL differences were very likely trivial, PLml likely trivial and Plap and TRIMP possibly trivial. All four training load variables were associated with trivial effect sizes also (-0.10 ± 0.62; -0.02 ± 0.62; -0.18 ± 0.62; 0.17 ± 0.62). It, therefore, appears that the PLml, PLap and TRIMP were similar between SPoss and LPoss. The differences between RPE-B were unclear and demonstrated a trivial effect size (0.05 ± 0.62).

Table 10. Mean ± SD for each training load variable for LPoss and SPoss and the associated difference ± 95% confidence limit

	LPoss (mean ± SD)	SPoss (mean ± SD)	Difference ± 95% CL
$m.min^{-1}$	119.59 ± 13.40	106.68 ± 16.35	-12.92 ± 6.96
PL	46.56 ± 7.55	42.73 ± 7.81	-3.83 ± 2.06
$PL.min^{-1}$	11.67 ± 1.91	10.69 ± 1.95	-0.98 ± 0.53
$PL.m^{-1}$	0.10 ± 0.01	0.10 ± 0.01	0.00 ± 0.002
2DPL	27.14 ± 4.67	26.66 ± 4.80	-0.49 ± 0.44
Plap	17.33 ± 3.17	16.76 ± 3.14	-0.57 ± 0.69
PLml	17.27 ± 3.02	17.21 ± 3.20	-0.06 ± 0.66
PLv	32.90 ± 5.45	31.38 ± 6.15	-1.52 ± 1.11
IMA	1.08 ± 0.96	1.55 ± 0.97	0.47 ± 0.60
TRIMP	12.43 ± 4.31	13.18 ± 4.48	0.75 ± 1.21
RPE	44.74 ± 10.83	48.16 ± 9.96	3.42 ± 3.58
RPE-L	39.87 ± 10.94	44.08 ± 8.38	4.21 ± 4.21
RPE-B	44.34 ± 9.82	44.87 ± 9.70	0.53 ± 3.17
RPE-T	35.00 ± 7.77	45.39 ± 7.18	10.39 ± 5.60

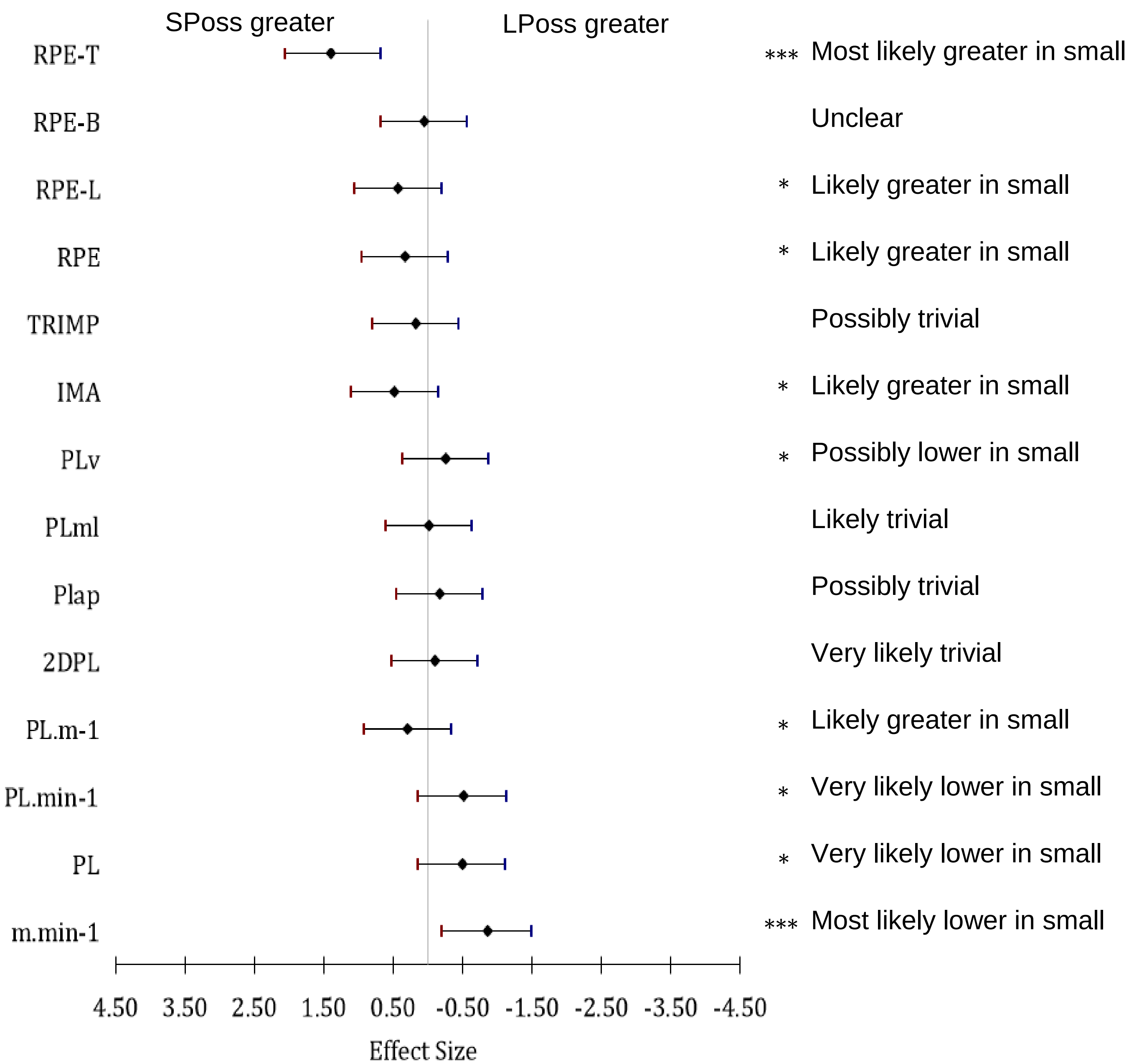


Figure 27. Cohen's D effect size ± 95% CL differences between training load variables for LPoss and SPoss (* = 0.21-0.50, small; ** = 0.51-0.80, moderate; *** = >0.81 large differences) (magnitude-based inference)

5.4.3 Experimental Condition 3 – Dribbling

Figure 28 displays the Cohen's D effect size ± 95% CL differences and associated magnitude-based inference between SDribb and LDribb. PL.m^{-1} was the only variable most likely greater in SDribb and was associated with a large effect size (1.19 ± 0.67). This appears to suggest that $PL.m^{-1}$ is the only training load variable demonstrated greater values in the shorter dimensions. $M.min^{-1}$ was most likely lower in SDribb and demonstrated a large effect size (-2.24 ± 0.79). PL, $PL.min^{-1}$, 2DPL, PLv, and PLap were all found to be likely lower in the SDribb. PL, $PL.min^{-1}$ demonstrated moderate effect size differences (-0.57 ± 0.63; -0.57 ± 0.63). These results once again support the suggestion that PL and $PL.min^{-1}$ are more likely reflective of the movements associated with bigger areas than smaller areas. 2DPL, PLv, and PLap demonstrated small effect sizes (-0.41 ± 0.63; -0.46 ± 0.63; -0.44 ± 0.63).

IMA was associated with a small effect size (-0.32 ± 0.62), however, the qualitative difference was suggested to be trivial, suggesting there was little difference between the moderate to high accelerometry demands associated between SDribb and LDribb. PLml, TRIMP, RPE, RPE-L, RPE-B and RPE-T differences were all unclear and were associated with trivial effect sizes (-0.20 ± 0.62; -0.06 ± 0.62; -0.11 ± 0.62; 0.19 ± 0.62; -0.10 ± 0.62; 0.26 ± 0.62). The effect sizes referenced, therefore, suggest that the internal training loads (both perceptual and heart rate) associated with dribbling were not different in SDribb and LDribb.

Table 11. Mean ± SD for each training load variable for LDrib and SDrib and the associated difference ± 95% confidence limit

	LDrib (mean ± SD)	SDrib (mean ± SD)	Difference ± 95% CL
$m.min^{-1}$	212.60 ± 9.91	187.07 ± 12.67	-25.52 ± 13.75
PL	82.68 ± 5.78	79.39 ± 5.81	-3.29 ± 3.72
$PL.min^{-1}$	20.36 ± 1.44	19.54 ± 1.46	-0.82 ± 0.93
$PL.m^{-1}$	0.10 ± 0.01	0.10 ± 0.01	0.01 ± 0.005
2DPL	47.43 ± 3.91	45.82 ± 3.90	-1.61 ± 2.48
Plap	32.59 ± 3.38	31.13 ± 3.34	-1.46 ± 4.16
PLml	27.90 ± 3.03	27.32 ± 2.70	-0.58 ± 1.61
PLv	60.51 ± 5.91	57.87 ± 5.54	-2.64 ± 3.68
IMA	0.19 ± 0.36	0.31 ± 0.41	0.13 ± 0.21
TRIMP	16.66 ± 6.66	16.29 ± 6.50	-0.37 ± 4.33
RPE	70.31 ±6.69	69.06 ± 14.04	-1.25 ± 7.19
RPE-L	63.54 ± 9.72	65.83 ± 13.61	2.29 ± 8.29
RPE-B	65.83 ± 9.05	64.58 ± 15.61	-1.25 ± 9.24
RPE-T	39.90 ± 10.87	43.13 ±13.88	3.23 ± 8.57

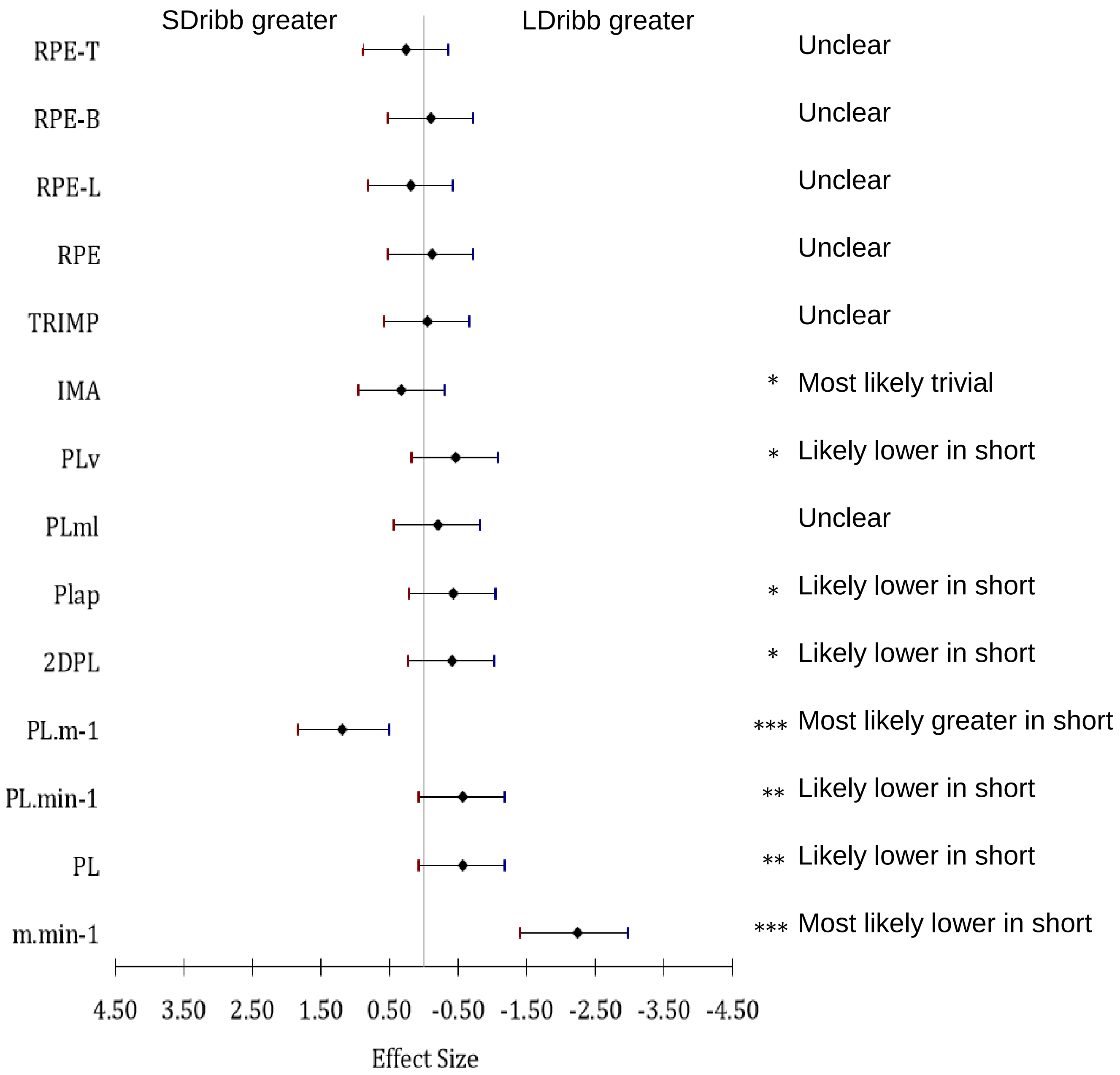


Figure 28. Cohen's D effect size ± 95% CL differences between training load variables for LDrib and SDrib (* = 0.21-0.50, small; ** = 0.51-0.80, moderate; *** = >0.81 large differences) (magnitude-based inference)

5.5 DISCUSSION

The aim of the study was to examine the sensitivity of training load monitoring methods (MEMS accelerometer, GPS, heart rate and perceptually derived variables) to changes in movement requirements. Secondly, it was hoped that effective training load variables to describe differences in movement requirements in football specific activities would be identified. It was hypothesised that MEMS accelerometers may be useful in capturing and differentiating between the training loads associated with different movement requirements as a consequence of different pitch dimensions. The results appear to partially support the hypothesis as it appears that one MEMS accelerometer variable particularly, $PL.m^{-1}$, may be effective in capturing the changes to movement. The many other training load variables that were investigated appeared, however, to offer limited utility. These finding may have important implications for applied practitioners, who may need to review and evaluate their current training load monitoring strategies in an attempt to capture the movement requirements of activity more effectively.

From the systematic manipulation of movement requirements in structured (running), semi-structured (dribbling) and unstructured (possession) training activities, $PL.m^{-1}$ was found to be the only MEMS accelerometer derived variable that appeared sensitive to changes in movement requirements across all three experimental training sessions. The variable was observed to be most likely, likely and most likely greater in the smaller condition than the larger condition in the running, possession and dribbling experimental training sessions respectively. For example, in the running experimental condition, PL.m^{-1} was highest in the shorter condition, which required players to decelerate, change direction and reaccelerate more frequently. In the longer condition, which conflictingly had a greater linear running component, PL.m^{-1} was most likely lower. This particular MEMS accelerometer variable, therefore, appears to offer insight into the movement requirements of a training activity.

Only one previous study has attempted to investigate the sensitivity of PL.m^{-1} within the applied football environment (Barrett *et al*., 2016). Although conducted in very uncontrolled circumstances, a change in the variable was observed towards the end of the first and second half of elite competitive football matches (Barrett *et al*., 2016). The previous findings may demonstrate some similarity to the present study as both propose that PL.m^{-1} may offer sensitivity to changes in movement. These observations appear sensible as theoretically, PL.m^{-1}, describes the rate of change of multiplanar accelerations for every meter travelled. It may, therefore, be suggested that PL.m^{-1} offers insight into how distance is travelled. This may, then be interpreted as the movement requirements. For example, PL.m^{-1} is higher if 5000m was covered for a PL value of 600 rather than if the same distance was covered for a PL value of 500. The greater PL for the same distance may, therefore, suggest greater multiplanar acceleratory demands per meter travelled and, therefore, a change in the movement requirements. This proposal is something that is not currently available within the literature and rarely seen utilised within the applied setting.

PL.m^{-1} was the only training load variable that was sensitive to the increased movement requirements as a result smaller pitch conditions in all three training activities. There were, however, other measures that were reflective of the increased locomotive requirements in the bigger conditions of each of the training activities. M.min^{-1}, which represents locomotive density and the MEMS accelerometer variable PL (and PL.min^{-1}), were two such variables. The results suggest that m.min^{-1} typically sits at the opposite end of the continuum to PL.m^{-1}, as the locomotive density and movement density may be inversely related for the same workload. M.min^{-1} is relatively widely used within football research (Akenhead *et al*., 2015; Anderson *et al*., 2016; Malone *et al*., 2015) and practice to capture average speed or locomotive density. It has, however, been previously suggested that it may not be sensitive to capture differences in training type as little variation has been found within a Premier League team's training week (Malone *et al*., 2015). M.min^{-1} may, therefore, demonstrate sensitivity in the more controlled testing environment of the present study where each condition represented hugely converse movement requirements due to the manipulation of pitch dimensions. Its utility, however, when the training demands were more subtly different may need to be further investigated.

The MEMS accelerometer variables, PL and PL.min^{-1}, were found to be very likely, very likely and likely lower in the smaller conditions than the larger conditions for running, possession and dribbling respectively. This, therefore, suggests that although the variables consider the rate of change in accelerations across the three planes of motion, there appears to be a strong relationship with accelerations in the vertical plane and, therefore, locomotive demands. These MEMS accelerometer variables do not, therefore, appear to offer sensitivity to the changes in movement requirements as a result of space restriction, which the present study is attempting to identify. The proposal that PL and PL.min^{-1} may be ineffective at capturing the movement requirement of training activity initially appear counterintuitive. It may have been expected that due to the greater multidirectional demands associated with the smaller pitch restrictions, the multiplanar accelerations represented by PL would be greater. The results instead imply that although there may be a greater frequency of accelerations in the multiple planes in smaller spaces, the greater ground contact impulses and, therefore, greater rate of change of vertical accelerations associated with linear running influence the total PL value to a greater extent. This suggestion is well supported from within previous research where criterion-related validity studies have found that PL shares a close relationship with external training load markers such as distance covered (Gabbett, 2015; Polglaze *et al*., 2015; Scott *et al.,* 2013) and low speed distance (Gabbett, 2015). As the association between PL and distance covered was previously understood, further MEMS accelerometer variables that attempt to dilute the locomotive bias of PL were incorporated within the present study. One such measure is PL.m^{-1}.

It appears that other than PL.m^{-1}, m.min^{-1} and PL, all other variables were less sensitive to the differing movement demands modulated by pitch dimensions. Although ineffective at differentiating between the movement requirements across all training activities some subtle inferences may be made. For example, 2DPL, appeared to be associated more closely with the locomotive requirements of the bigger conditions. Variables such as IMA and RPE-T appeared to be more reflective of the movement requirements of the smaller dimensions in certain activity types. While the other perceptual variables, PLml and TRIMP appeared unable to capture differences between the two different load requirements. It, therefore, appears that although this range of measures may be ineffective in capturing the movement demands associated with different football training activities as is required in the current study, further unpacking of the measures may be required to fully understand use in the applied setting.

Interestingly, 2DPL, which is established from only the accelerations in the medio-lateral and anteroposterior planes (as the vertical vector of the PL equation is removed) (Gabbett, 2015) may have been expected to circumvent some of the issues observed with using PL to capture movement requirements. The results of the current study do, however, challenge this. 2DPL was not found to be greater when movement requirements were manipulated by restricting space in the experimental sessions. In fact, it appears that 2DPL was likely lower in the shorter running and dribbling conditions, therefore, the measure proposed as a method to reduce the locomotive bias present in PL, appears to be associated with greater values when locomotive demands are high. This observation is further supported by previous research, which investigated 2DPL in rugby league players and found that a relationship was shared between 2DPL, PL, PL_{slow}, total distance, low speed activity and collisions (Gabbett, 2015). These findings appear to suggest that it is a little simplistic to suggest that the large impulses associated with ground contact will only be observed in the PL's vertical plane, instead being present in the mediolateral and anteroposterior planes also.

The theory that ground contact impulses associated with locomotive activity may be observed as accelerations across the three planes is further supported by the observation that PLml differences were trivial (possession) and unclear (running and dribbling) across the three experimental conditions. These findings suggest that although the variable isolates the rate of change of accelerations in the mediolateral plane, it does not mean that they are only a reflection of mediolateral activity and instead linear locomotive activity may be reflected as accelerations within this mediolateral vector. To our knowledge only one previous study has investigated the individual planes of PL in an applied real-world football environment. Barrett *et al*., 2016 explored the within match patterns of MEMS accelerometer variables and although PLml did appear sensitive to differences between 15 min periods within competitive matches, the pattern that was observed appeared similar to distance covered, therefore, demonstrating that mediolateral activity was not isolated by the variable.

Not all MEMS accelerometer variables other than PL.m^{-1} appeared to be reflective of locomotive demands though. The other training load variable that demonstrated some utility in capturing the increased movement requirements in restricted space was IMA. IMA was likely greater in the smaller possession condition, however, only possibly greater in the shorter running condition and most likely trivial differences between dribbling conditions. One explanation for the limited sensitivity of the variable across all experimental testing sessions maybe because only moderate and large accelerations (>2.5 $m.s^{-1}$) were collected and analysed. A large volume of the change of direction movement requirements associated with the smaller running and dribbling conditions may have been lower than the set threshold due to the more continuous lower intensity nature of the activities. This would, therefore, mean that IMA may not have captured the full extent of the movement requirements players were exposed to. It appears that no previous research has looked to investigate IMA in football, however, its use in women's team handball has recently been explored (Luteberget & Spencer, 2017). The study found that IMA high intensity activities, as classified in the present study, differentiated between playing positions in handball. These previous findings suggest that IMA may offer sensitivity in distinguishing between different activity demands, however, the differentiation would be the result of high intensity actions rather than classifying movement density as observed via $PL.m^{-1}$. Due to the ability of the variable to differentiate between the movement requirements in the activity that may best represent typical football training (possession), more research is required in the area.

As suggested outside of the MEMS derived variables, the internal and perceptual demands that were examined were largely similar or unclear between the large and small conditions in each experimental testing session.

The only differences captured between activities were most likely differences for RPE-T in running and possession and RPE-L and RPE in possession. These limited differences may suggest that small and large pitch dimensions do not appear to demonstrate hugely different internal and perceptual demands with the exception of RPE-T. This is a key finding as it would suggest that large areas, which may exaggerate locomotive demands and small areas, which may exaggerate change of direction demands may internally and perceptually represent a similar training load. The two varieties of load may, therefore, be equally demanding for different reasons. It may be a surprise that differential RPE did not distinguish between the different sorts of load more effectively as it has previously been found to effectively distinguish between different dimensions of effort in team sports players (Malone *et al*., 2016). The previous research did, however, examine very different training modes rather than its sensitivity to differentiate between different demands as a result of manipulated pitch dimensions. The current research, therefore, appears to suggest that although by differentiating between different dimensions of RPE has previously demonstrated utility, for the measure to be sensitive in identifying differences in effort associated with specific movement demands it may require further differentiation and refinement e.g. both high locomotive load and high movement demands may require a similarly high leg effort, however, the specific muscle, muscle action and related physiological requirement within each condition would be different. It could possibly be challenged that if the pitch dimensions in the current study were manipulated to a greater extent then differential-RPE may have demonstrated sensitivity to the differing movement demands. The pitch dimensions selected were, however, identified as they appeared to sit at either end of the movement spectrum for what is realistic and practical sizes for the applied elite football training environment.

Further, due to the elite level nature of the participants used in the present study, only a restricted amount of experimental training sessions and pitch dimensions could be investigated. This may, therefore, limit the application of some of the findings as the results may only be specific to the experimental training sessions and pitch size conditions applied and further application may require a degree of generalisation from the findings. It may, therefore, be proposed that to get a true idea of the effectiveness of the training load variables to distinguish between pitch dimensions a greater volume of training activities and pitch dimensions should be investigated in the future. It may also be suggested that although the possession experimental testing session was relatively uncontrolled, the research area may benefit from future research in a more effectiveness related scenario, which demonstrates the true applied demands of elite football training. Further areas of study that would be required to add insight in the area would be the area of physiological adaptation, investigating if the different training demands investigated stimulate different physiological adaptations as the monitoring methods proposed are fundamentally a proxy to estimate the internal demands and potential adaptive pathways.

In conclusion, it appears that PL.m^{-1} may be the only training load variable, which can effectively distinguish between the movement requirements associated with different pitch dimensions in common training activities. Although, many other MEMS accelerometer, internal and perceptual based variables are well supported elsewhere within the literature, it appears that no other measure is sensitive to the increased movement requirements associated with a restriction in relative pitch dimensions. The ability of $PL.m^{-1}$ to capture the volume of movement relative to a unit of distance leads the researchers to propose the variable to be communicated within the applied setting as ‘movement density.’ This component of training load monitoring is something that has not been promoted within previous research or widely applied within practice. $PL.m^{-1}$’s demonstrated utility now leads the researchers to propose the variable as a useful addition to a larger monitoring model. Simply put, $PL.m^{-1}$ categorises the type of movement requirement and, therefore, should by no means be implemented as the single component of a monitoring strategy. It may, however, be used alongside other variables that capture volume and intensity from an internal and external perspective across movement and locomotive requirements.

5.6 PROFESSIONAL SKILLS DEVELOPMENT REFLECTION

Management and Leadership Skills

At this stage I feel I continue to improve some key leadership skills via my role of supervisor during supervision of all WBA FC science staff (first team and academy). I regularly meet with each individual and discuss their performance and individual development plans. I felt that this is a skill set that is vastly improving. It is apparent that my personality lends itself to this role as staff appear to be open and keen to engage in the practice. I am, however, keen to continue to develop in this area via formal training as although I feel pretty natural, it is quite clear that I am finding my own way. One example of how I continue to self-lead my development in this area is my continual engagement in this kind of practice via BASES supervision, which I currently supervise three individuals. It was clear that the supervisions/ mentoring sessions that I perceive to be most successful have two things in common. Firstly, they appear to be more holistic/ pastoral and not specifically only outcome/ topic focussed but instead have a wider developmental focus. Secondly, the occasions that the supervisee and I have appropriately planned for the meeting, with both of us being better prepared, have made these occasions much more effective. Both of these things ring true also when I consider being on the other side and receiving supervision from Barry throughout this process. I would suggest that this area of supervision and mentorship is quickly becoming one aspect of my current role, which I am really enjoying and keen to continually develop.

One of the key management principles that has stuck with me from my wider reading and engagement around the area is knowing what strategy is most effective to get the best out of different individuals. One simple concept, which I have pinched from somewhere and then further refined it is illustrated in the figure below:

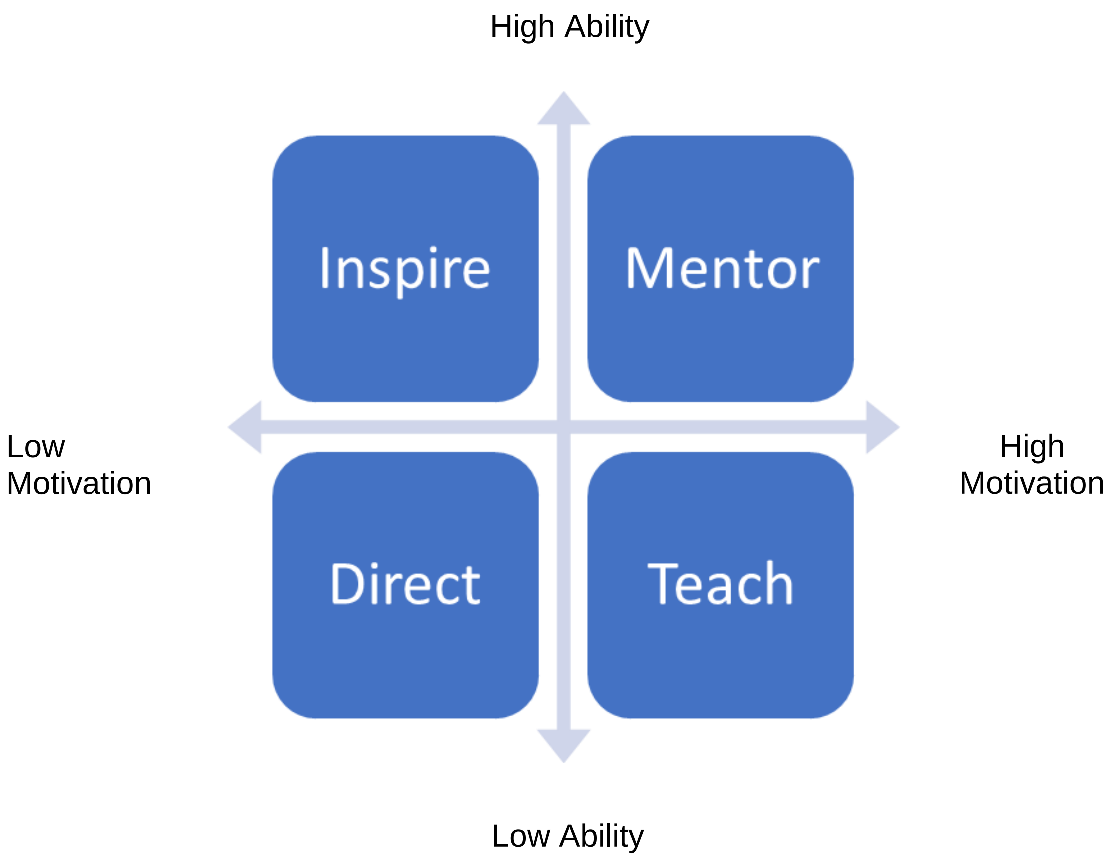


Figure 29. Conceptual management model that I have amended slightly for my context (unknown original source)

The figure suggests that you categorise each individual upon a scale of motivation and ability. You then form the best managerial strategy based on these factors e.g. if the individual has high ability but low motivation, they need inspiring, if they have high motivation and high ability they should be mentored etc. This appears to work well in theory and as a conceptual model. As I look at many of the good leaders I have worked with over the years, I feel they have the ability to switch between each of the methods when most appropriate. This method is something that I currently attempting to apply within my role when I am in supervisory roles with individuals.

Research Skills

Since starting the professional doctorate, I have spent a large amount of time appraising the current departmental practice and strategy. One major outcome of this process is that if we are to further refine and develop our practice we need to secure more bespoke and specific academic support. This departmental appraisal has motivated me to begin discussions with Barry regarding establishing an academic link between WBA FC and LJMU. This relationship would allow us to answer relevant performance questions, refine our scientific processes, have access to internationally recognised experts and secure a better developmental practitioner programme. Interestingly, this departmental development would require me to refine all of the professional development skills that were outlined within my previous self-audit within my training plan (appendix 9.1) and subsequent aims of this thesis.

The academic link and collaborative research projects have since successfully been established. Some of the tasks that I have completed have required me to develop relevant research skills such as preparing research applications, research design, analysis, interpretation and dissemination. The link has also required me to demonstrate managerial capacity as I have been required to manage a collaboration between the club and a university, develop a research strategy and manage and mentor internal research students. The collaboration has further allowed me to develop professional networks and vehicles to disseminate some of our good practice and research. The academic collaboration, therefore, appears to have been the perfect project for the department and me personally at this point in our evolution.

Interestingly, as the developing academic link between the club and university is progressing, I am currently taking on further advisory responsibility for two PhD students/ projects that had been set up. One around immunity and the other around feedback methods. I am clearly still at the very early stages of understanding effective practice in these kinds of positions but feel that due to the other expertise within the supervisory groups, my role should be shaped as one of a professional compass. Due to my experience within the environment and due to my involvement in forming the research question collaboratively with colleagues it appears sensible for me to be the one who could advise both members of staff around the professional challenges and applications of the work within the complex environment. This is certainly an area of the role I continue to really love (both the research and the mentoring), maybe because it is such a new challenge and I am experiencing such a steep learning curve especially with its direct relevance to my professional doctorate and my own personal development journey.

Dissemination & Networking Skills

At this stage of the project I feel that I am continuing to work towards developing the skills related to networking and dissemination, which I set my self at the self-assessment stage of the professional doctorate. A reflective extract below demonstrates some of the lessons that I have recently learnt in this area as I reach the later stages of my professional doctorate journey:

I have organised two speed development for team sport masterclasses. Four world leaders in the area will present to delegates on evenings at the Hawthorns. The reasons for committing to get these events over the line is multifactorial. Firstly, it has been great to make professional networks with the speakers and have the opportunity to engage in discussion around research and its application, discussing performance problems really relevant to the club and department. Secondly, it has been great for me to develop my administration and organisation skills, as I was required to master a number of clerical tasks that I would have not have been previously exposed to. Further, it is brilliant for me to provide something of real value to the profession and look to develop knowledge in the area. It is beginning to be really clear that the development and education of other practitioners is an area I really enjoy. Finally, it is also a great wider networking opportunity for me and the department, raising our national and international profile.

I am extremely pleased that the concept appears to have been so well received. I am excited to get the evenings going now, however, a little apprehensive as it is a huge step up in profile for the department so I hope we do a good job. I am particularly excited about the format of the evenings, where we plan to have a really high level practitioner and researcher who are each current and relevant to the elite football environment on the same bill so they can engage in some healthy discussion around the application of the research to the applied *environment. Professional development is an area I am really keen on and it has given me a real taste for the area in more detail. I can envisage it being a key area in my future career.*

CHAPTER 6

LESSONS FROM DISSEMINATION – SHAPING THE RELEVANT FINDINGS FOR DIFFERENT GROUPS

6. LESSONS FROM DISSEMINATION – SHAPING THE RELEVANT FINDINGS FOR DIFFERENT GROUPS

6.1 RESEARCH ORIENTATION

The outcomes of the study will hopefully allow a novel model of monitoring to be proposed. The goal of any sport scientist should be to apply scientific principles to their applied environment to positively influence development or performance. It, therefore, appears appropriate that the proposed model should, therefore, improve training review and prescription for the better. I have strong beliefs that a lot of the commonly utilised models in practice across Premier League football simply describe training demands. If training variety and limiting monotony is an important part of maximising readiness and avoiding staleness then utilising a variable that may be able to categorise training along a continuum of movement requirement, therefore, appears attractive. The following chapter should, therefore, explore this concept further.

What training information is important for a coach and other performance staff to acquire to inform practice? This is probably the first question that we should all ask as practitioners, however, it may often be omitted. Instead we may frequently lean towards what is currently being collected or what commercial companies may suggest, molding our feedback strategies to suit. I believe that my findings offer some real challenge to the later. It surely appears inappropriate to solely capture how far someone has run and how much high-speed work they have completed. This type of information, however interesting, does not appropriately describe the totality of training load that a player is exposed to. I am hugely passionate about the fact that science practitioners should not collect data for data's sake and instead should have a clear rationale for all the player interactions and data collection processes that they complete. I think that the model I am proposing in the current presentations appropriately rationalise a suitably distilled model of monitoring for football, which provides coaches with all the relevant information that they require to inform the training process. The more I reflect on this conceptual model of 'volume', 'intensity' and 'type', the more comfortable that I am with its appropriateness. The 'type' is the measure that I don't think I have done very well previously and where the utility of my findings may be. I think that this concept of 'type' is probably done rather subjectively or with less precision, whereas, I hope that my proposals may add some clarity and comprehension to the concept. Making it easier to digest for scientists and coaches alike.

6.2 INTRODUCTION

One of the key aims of the thesis was to propose and disseminate an effective model of monitoring for elite football training. This chapter, therefore, firstly attempts to evaluate the key findings from the previous studies, which will then inform the formulation of a revised model of monitoring for training load in elite football. This proposal will then be disseminated to key stakeholders in the training process. The effectiveness of this dissemination will then be evaluated and reflected upon for future refinement.

Typically, two key groups of stakeholders within the planning, delivery and reviewing processes around elite football training are the coaches and the science and fitness practitioners. Often these two groups will work collaboratively throughout the training process with the science and fitness practitioners supporting the coach throughout each phase. The two different staff groups do, however, characteristically come from two different experiential and educational backgrounds with separate technical expertise. It is, therefore, important to recognise these individual differences when communicating to each specialist group.

As many of the key findings from within the previous three studies are relevant to both groups, an audience specific approach to dissemination should, therefore, be considered. The current study, therefore, overviews the dissemination strategy chosen for each a group of coaches and a group of science and fitness practitioners. The coaching dissemination was to two separate groups of academy coaches enrolled upon the Premier League Elite Coach Apprenticeship Scheme. The workshops were delivered as part of the Physical Principles module. The science and fitness dissemination was a presentation delivered as part of a Catapult Southern workshop. The following sections will be split into two parts; Part A – Coaches and Part B – Science and Fitness Practitioners. The methods section will overview the planning phases, the results will display the PowerPoint slides along with associated notes, videos of the presentations and feedback from the attendees. Finally, the discussion section will overview reflections of each presentation.

6.3 METHODS

6.3.1 Part A – Coaches

In preparation for the coach dissemination presentation, a planning document (Table 12) was completed containing all the relevant information to inform the presentation design.

Table 12. Coach dissemination planning document

ECAS Residential Plan
Date:
19th and 20th February 2018
Title:
Sport Science & The Coaching Process
Topic:
An integrated model of the coaching process – What is the role of sport science within the process. A fair appraisal of its ability/ inability to support the coach.
Abstract:
Due to the evolving physical demands associated with PL football, it is imperative that clubs and their coaches embrace the benefits that sport science can offer in maximising performance via player preparation, recovery and the training process. As these are the changing requirements at the end

of the pathway within First Team PL football, it is important that players within academy phases are developed with these demands in mind. The level of integration between sport science and coaching, however, appears to be very varied between clubs and teams within PL academies. The reasons for this are of course multifactorial. It may, however, be considered that the misunderstanding/ miscommunication of the utility and limitations of sport science by sport scientists and coaches alike may play a major role. The current workshop hopes to tackle some of these issues allowing coaches to consider, discuss and appraise the current and future utility of sport science. A real-life training load monitoring case study (my professional doctorate) will be utilised to demonstrate some of the wider issues presented and discussed.

Objectives**:**

1.Discuss what current sport science support looks like in the coaching process

2.Understand the utility and limitations of sport science

3.Share findings of professional doctorate specifically around the coaching process at the end of the pathway

4.Evaluate the application of professional doctorate findings to PL academy football

Take home message:

Sport science can effectively inform the coaching process if its utility and limitations are truly understood

Audience**:**

Two groups of around 20 ECAS coaches currently employed within Premier League Academies

Duration**:**

1h30min

Delivery methods:

Presentation

Small group discussions

Small group tasks

Individual tasks

Materials needed:

Five flipcharts and pens

Post-stick notes and pens

Video recorder

Plan**:**

1.Discuss what current sport science support looks like in the coaching process (15 min)

- Present slide and overview the coaching cycle

- Task – Coaches have 5-min to write down which of the stages of the coaching cycle sport scientists are currently involved in within their coaching role

- Group discussion around the coaches' current exposure and experiences of sport science support within their coaching cycles

2.Understand the utility and limitations of sport science (20 min)

- Present slide on the history and evolution of sport science support in football
- Increased physical outputs by players in matches
- Increased positions at clubs
- Increased scientific outputs at clubs
- Increased courses and graduates
- Present slides and overview utility and limitations of sport science
- Propose potential areas of utility of sport science in football
- Evidence based practice proposal
- …., however, does research ask the right questions (Houston, we still have a problem – Martin Buchheit), do practitioners interpret and translate the most appropriate evidence into applied practice, do practitioners overplay their part in the process, generalisation of research out of context, communication concerns (caveman perception slide)
- Examples of sport science data collection – what they can rather than should – inform practice – add insight

10-minute break

3.Share findings of professional doctorate specifically around the coaching process at the end of the pathway (20 min)

- Present slide and overview Impellizzeri model of monitoring training and identify the area of my research via introducing rationale and background
- Frame as asking the right question to inform practice. Previous TL monitoring doesn't appear to do all the things we need…..Quantity of training is well described but how about quality & organisation elements?
- Play Study 1 GoAnimate video
- Present slides around study 2 design and findings
- Present slides around study 3 design and findings

4.Evaluate the application of professional doctorate findings to PL academy football (25 min)
- Present slides around what the findings may mean for informing coaching practice
- Present slide and overview the coaching cycle again, however, now discuss where the findings of my research may inform practices across the cycle
- Task - Coaches have 10-min in three small groups to discuss and write down how the findings presented may inform session design for two different drills with the same outcomes except one should possess low movement demands and the other high movement demands

Feedback Method**:**

Upon completion of the session coaches will be asked to fill in two post-stick note. On one they are to write down what they liked about the session and on the other they are to write what they think could be improved

Upon completion of the session a couple of PL staff who observed the session will be asked to give some more detailed feedback around the session to video Please outline the what you felt were the key messages to come out of the workshop? - Was the content suitable for the audience? Please clarify answer - Was the content delivered effectively? Please clarify answer - What did you particularly like about the workshop? - What could be improved about the workshop? - Anything else you would like to add?

Following the planning phase, the PowerPoint slides were constructed. These slides are displayed at the relevant link below. The link displays the relevant slides and the associated notes to add further context to areas of discussion.

https://www.dropbox.com/s/aw5ydbmqnsl9on3/Coach%20Dissemination%20-%20ECAS%20Residential.pptx?dl=0

Following construction of the PowerPoint slides, the presentations were completed and the information disseminated to the relevant groups of coaches. The link displays the relevant video footage of the coach dissemination presentation.

https://www.dropbox.com/sh/w1t3v1bu91gx8uk/AACo97TibyFwSQ35tbAzK3KNa?dl=0

6.3.2 Part B – Science and Fitness Practitioners

In preparation for the science and fitness practitioner dissemination presentation, a planning document (Table 13) was completed containing all the relevant information to inform the presentation design.

Table 13. Science and Fitness dissemination planning document

Catapult Workshop Overview Date**:** 12th March 2018 Title**:** All that Glitters is not Gold - Time to Review Training Load Monitoring in Football? Topic**:** A review of the effectiveness of current external training load variables to accurately capture the multidirectional loads associated with elite football training. A contemporary proposal of training load monitoring will be discussed. Abstract**:** The monitoring of training load within elite football is widely utilised. The processes are important as they allow coaches and support staff to gather information, which may inform practices around optimising training for development, performance or to reduce the risk of injury. In current elite

football training load monitoring, an emphasis is placed on traditional GPS based variables. Due to footballs' intermittent and multidirectional nature it appears counterintuitive for such an emphasis to be placed on the locomotive distances gathered from GPS, as the associated physiological demands of these activities will be underestimated. Due to the apparent limitations of GPS devices to accurately and reliability capture the full range of change of directions demands associated with football, other technological solutions have been investigated. Triaxial accelerometers, which have been incorporated alongside GPS within MEMS devices are one such technology. Due to the absence of research utilising accelerometers in real world elite football training scenarios, their utility is unknown. It may, however, be hypothesised that the technology may be appropriate to differentiate between different training activities and relative pitch sizes. The current presentation, therefore, will discuss the findings of three studies from a professional doctorate project, which aimed to firstly establish the sensitively of current GPS related training load variables to capture the multidirectional demands associated with elite football training and further investigate the utility of accelerometer variables to describe the demands associated with different types of training activity and relative areas per player. Finally, an effective training load monitoring model will be discussed.

Objectives:

1.Demonstrate the insensitivity of traditionally utilised GPS related training load variables

2.Provide evidence of scientific investigations into the appropriateness of accelerometer variables in capturing the multidirectional demands associated with elite football training

3.Critique the findings around the utility of accelerometers for elite football training monitoring

4.Propose and discuss a contemporary training load monitoring method for elite football training

Take home message:

Measure what we should, not what we can – What is important?

Audience**:**

A group of around 30 sports science practitioners working within elite football

Duration**:**

25 min presentation and 20 min panel Q&A

Delivery methods:

Presentation

Panel Q&A

Materials needed:

Post-stick notes

Video recorder

Plan**:**

- Introduction

Introduce myself, concept of the professional doctorate and, therefore, the background and rationale for the research area

- Demonstrate the insensitivity of traditionally utilised GPS related training load variables

Play and discuss Study 1 GoAnimate video

Present slide and overview Impellizzeri model of monitoring training and introduce the specific research problem

- Provide evidence of scientific investigations into the appropriateness of accelerometer variables in capturing the multidirectional demands associated with elite football training AND Critique the findings around the utility of accelerometers for elite football training monitoring

Present slides around and discuss study 2 design and findings

Present slides around and discuss study 3 design and findings

- Propose and discuss a contemporary training load monitoring method for elite football training

Feedback Method:

Upon completion of the session coaches will be asked to fill in two post-stick note. On one they are to write down what they liked about the session and on the other they are to write what they think could be improved

Upon completion of the session a member of PL Elite Performance staff who observed the session will be asked to give some more detailed feedback around the session to video

- Please outline the what you felt were the key messages to come out of the workshop?
- Was the content suitable for the audience? Please clarify answer
- Was the content delivered effectively? Please clarify answer
- What did you particularly like about the workshop?
- What could be improved about the workshop?
- Anything else you would like to add?

Following the planning phase, the PowerPoint slides were constructed. These slides are displayed at the relevant link below. The link displays the relevant slides and the associated notes to add further context to areas of discussion. https://www.dropbox.com/s/djqht2phzw4k22g/Science%20%26%20Fitness%20Dissemination%20-%20Catapult%20Southern%20Workshop.pptx?dl=0

Following construction of the PowerPoint slides, the presentation was completed and the information disseminated to the relevant group of science and fitness coaches. The link displays the relevant video footage of the science and fitness dissemination presentation. https://www.dropbox.com/s/khch3kmit63gbw9/Science%20%26%20Fitness%20Dissemination%20-%20Catapult%20Southern%20Workshop.mp4?dl=0

6.4 RESULTS

6.4.1 Part A – Coaches

The detailed feedback captured from a member of Premier League Elite Performance staff is displayed within the link below. The link displays video footage of the relevant answers to the questions posed.

https://www.dropbox.com/s/brdgrilrup0xasf/Coach%20Dissemination%20Feedback.MTS?dl=0

The coach feedback that was captured via the immediate post session post stick feedback is displayed in the two tables below (Table 14 and 15). Column 1 overviews the comments associated with what the coaches liked about the presentation and column two displayed comments associated with areas for development.

Table 14. Post stick note feedback from coaches post session

Monday 19th February	
Positive	Negative
Integration within coaching cycle	More focus in FP and YDP
Specific detail regarding individuality	More context
Measure what you should not what you can	Would be interested in how you went about the 'softer skills' to enable you to get your points across
Movement load v distance covered	Improve sport science provision within academies

Insightful and engaging	Provide clear and basic process to apply in sessions
Acceleration and decelerations v distance	Very complicated and does not take into account how players feel or their individual needs
Challenge S&C/ sport science to pan weekly loadings individually when planning sessions with coaching staff	More relevance to actual sessions that we could maybe implement
Allow young inexperienced sport science staff to develop and learn	Slightly lost in the science but thought you explained it well and got there eventually
Video presentation	Content was mainly geared towards PDP
S&C present on match days	Examples of good practice with S&C and coach collaboration process linking to the cycle
Measure what you should not what you can	
Movement load is important not just duration trained	
Depth – detail of information	
Insight into S&C	
Ideas around the load linked to coaching	
Movement load understanding	

Good use of slides – short, interesting, not overkill	
Good evidence	
Interesting to see balance of workload to volume of session	
The understanding of volume and type	
To start to have open discussions and involve clear preparations to sessions - communicate	
Options to increase and decrease training load and understand timings ideal to/ for match preparation	
Enjoyable and thought provoking	
Some very discussion of real issues	

Table 15. Post stick not feedback from coaches post session

Tuesday 20th February	
Positive	Negative
Good use of video and applied research	Info in the video relevant?
I enjoyed the session – very informative – good stats and data	More examples from real life situations would be helpful
I like that you delivered in an honest manner with a lot of understanding	Invite S&C coaches from clubs to the day

and respect for coaches	
It has made me think about my sessions in greater detail	The animation video went too fast
Collecting what each club in room collects in regards to sports science	More video footage
Good detail	More first hand experiences
Good balance between theory & live example	More work around communication
Measure what we should rather than what we can	Limited relationship with FDP
Football based so was engaging	Football related practices (video) of high/ low movement load
Measure what we should rather than what we can	Examples of data from above sessions or data in general
Work linked to practical sessions	Long winded way to talk about movement load – didn't need study
Better understanding of outcomes from training type and load	Could session design task be added to beginning and take from there – coach example
At my club we have 35 sport scientists	
I enjoyed listening to the research you conducted	
The data is useful information and we should considerate it when planning	

sessions	
Link to work done at clubs	
Knowledge	
Link to football	
Enjoyed the why we do it	
Detail of the data we are given/ measuring	
What is actually important?	
Interesting and engaging of how it applied to the game	
Emphasis on a football led programme which sports science impact on and improve with their expertise	

6.4.2 Part B – Science and Fitness Practitioners

The science and fitness practitioner feedback that was captured via the immediate post session post stick feedback is displayed in the table below (Table 16). Column 1 overviews the comments associated with what the practitioners liked about the presentation and column two displayed comments associated with areas for development.

Table 16. Post stick not feedback from science and fitness practitioners post session

Monday 12th February	
Positive	Negative
Interesting metric to look at	How does it influence training drill prescription?
Like the concept of PL/m	How to implement this
Use of PL/m	More concise on the research
Application via use of case studies	Difficult to inform coaching process with large drill library
Identifying new metrics to monitor training load	Too many graphs
Honesty of talk	Maybe the graphs could be presented in a more interesting way?
Movement demand continuum	Doesn't tale positional differences into account
Good to highlight metrics v duration	Is the change in PL sensitive or just because smaller distance?
PL/m metric	Abbreviations used without thorough explanation
Interesting	How was information used – did it inform decisions? Did it improve/ effect physical output?
Movement demand continuum	Movement demand feedback data obvious for kind of session put on

Quantification of drill demands	Would find it interesting as to whether any speed (high speed running / sprinting distance) or rate of change (acceleration/deceleration) metrics would better differentiate between days of the microcycle or between managers?
Provides a way of quantifying something that otherwise be missed	Additional information around differences in position, age, match importance etc.
Taking the analysis of data forward	Additional information between the relationship of PL/m to internal and subjective measures
Thorough research and pushing boundaries	Physiological adaptations associated with different movement load interventions?
Movement demand	An understanding of the positional differences and normal ranges would be good
Good way of quantifying 'cost' of session – not just distance covered	
Better insight into quantifying movement demands using accelerometers	
Simple	

Really interesting to see the differences (or lack of) in PL and Total Distance metrics between managers.	
Interesting to see days within the training cycles of a similar density, and that it's only really duration of activity that differentiates the days.	
The use of PL/m	
The choice of statistics used	
The categorisation of different drills	
The proposed continuum of drills	
Objectively supports perceptions of drills via a metric coaches can relate to	

6.5 DISCUSSION

6.5.1 Part A – Coaches

Following the delivery of each coach dissemination sessions, personal reflections were captured via reflective accounts. Each of the relevant extracts for the associated coach dissemination events are displayed below. The reflective extracts overview the key interpretations of each of the dissemination occasions.

Reflective Diary

Date: 19.02.2018

Scenario: ECAS Delivery – Study 4 Dissemination to Coaches

- Description – what happened?

I presented a 2hr presentation to PL academy coaches around the involvement of sport science within the coaching process, including some of my professional doctorate findings. The first half of the session discussed the current uses and limitations of science within football. The second half used my research to illustrate some of these findings, specifically proposing the concept of movement load. I videoed the session and asked for feedback from coaches and a member of the PL Elite Performance team. The video, feedback, reflections and supporting document will form study 4.

- Feelings – What were you thinking & feeling?

In the days leading up to the presentation I was feeling a little apprehensive about if the presentation content was appropriate for the audience. I also commonly feel that I may lack clarity when trying to illustrate some of my points so felt some concern that this may once again be evident. I was a little surprised that in the hour or so ahead of the presentation I did not feel as nervous as I expected, not only because of the setting and presenting (I always feel a little discomfort in the environment) but probably because it is a topic that is so important to me and that I 'own' a little bit.

During the presentation, I felt pleased about how it was being received, I was happy with the level of engagement and lines of discussion with coaches and felt that I satisfied all of the relevant questions that were posed. Once the workshop was over I was certainly content with how it went. It was pleasing to have several coaches come and thank me for the talk and highlight specific areas that they felt were particularly useful. When reviewing the post stick note feedback from the coaches I felt that a lot of the feedback was fair and again very happy that there appeared to be a lot of positive comments regarding the content, application and delivery of material.

- Evaluation – What was good & bad?

I thought that the level of engagement, interest in the area and current perceptions of the coaches towards their sport science staff was positive and refreshing. I anticipated there may be a slight air of cynicism but this was certainly not the case. Instead there appeared to be some mutual respect between the disciplines.

I felt that my general delivery was good, varying delivery style and pace throughout. I do, however, still feel that I may lack clarity at points but will watch the video back to get further context on that assumption. I thought the video was a good addition and felt that the coaches could follow its flow and rationale.

I felt that I could have managed time a little better. I felt that the first half of the presentation went on a little longer than expected, which in turn meant that the second half was a little quicker paced than I may have hoped, which may have made the concept a little harder to understand. I do feel, however, that this was largely due to the fact that there was such good discussion in the first half, which I perceived as beneficial and let play out naturally as there was some good relevant content. The design of the first task was not effective and led to some of this delay in the first half. I rotated around flip charts and asked for examples of collaboration between coaching and science within the coaching cycle. Although beneficial I should have come up with a much better design of the task.

- Analysis – What sense can you make of situation?

I think that my level of preparation and passion for the area allowed the session to run a little bit more relaxed than some of my previous experience of this work. I feel that because I have really good experience as a researcher and practitioner in this very specific area it allowed me to really challenge and discuss at length some of the concepts. I also felt I could add context to a lot of the detail and discussions, however, could maybe have even done this further.

I certainly feel that this is an area that there is a real requirement for. It appears that coaches are really welcoming of the collaboration with science, however, need support facilitating it. It appears that science needs championing little in academies and provisions in some areas increased. One of the most insightful discussions was around how we help the development of science staff, specifically around 'softer skills' and contextual intelligence. This is certainly a key area for us to investigate in the future.

I certainly do feel uncomfortable when presenting. I still am not quite sure if this is just something I should respect and keep exposing myself into this area to develop or if this is because it is an area that my character may not lead itself well to and, therefore, should look to invest my dissemination and communication methods in other areas. I guess that either way it is inevitable that in my current role I will regularly be exposed to these methods and should look to maximize my performance, which will inevitably by excellent preparation and only offering myself to do it in areas that I am passionate about and truly understand well.

- Conclusion – What else could I have done?

I could have certainly made more explicit references to how some of the concepts apply to FP and YDP coaches as most in the room were from that setting. I think I could have sold my investment in the area and narrative around my experiences a little bit further (although I am a little uncomfortable dong this). The first task should definitely have been structured differently. Finally, I think I could elaborate a little and give context in a few of the areas that I eluded to, which I could have got reference from the coaches by involving a little bit more Q&A and interaction if time allowed.

- Action plan – What would I do next time?

As I am delivering the same presentation tomorrow, I will look to change the following:

- More narrative around my role in the process, both club and research
- More contextual examples of collaboration, softer skills, coaching examples, coaching sessions etc
- Restructure the first task to be more effective with time
- Try and be a little more explicit with FP and YDP examples/ transfer
- Following the evening's tactical periodisation talk, try and link some of the concepts between the two areas together

<u>Reflective Diary</u>

<u>Date: 20.02.2018</u>

<u>Scenario: ECAS Delivery – Study 4 Dissemination to Coaches</u>

- Description – what happened?

For the second consecutive day, I delivered a workshop around ‘sport science and the coaching process.’ The content was the same as yesterday, however, I changed the structure of the first task – I did not scribe and got a colleague to note down the comments. I also tried to frame some of the examples and discussion specifically around FP and YDP as this was flagged from the previous day’s feedback. I also tried to build a little more on the narrative around the coaches I worked with and my role within the process. As a result of the coaches receiving a session tactical perioidsation the day before I also linked some concepts from that methodology in with the content of the workshop

- Feelings – What were you thinking & feeling?

I was a little disappointed with the session on the whole. I thought the coaches engagement in the first half of the session was not as strong as yesterday’s session. I found it difficult to deduce if this was due to my delivery, the group’s make up or the fact that it was the last session on the second day as opposed to the first on the first day. The level of questioning was not as considered. I had to work hard to stimulate some worthwhile conversation. I did, however, feel that the second half went better once I got into the football specific content. I was happier than yesterday that I managed to deliver a more academy focused model with better reference to the younger ages.

- Evaluation – What was good & bad?

I thought that I tackled the FP and YDP application a little more effectively that yesterday's session and added a little bit more context around the coaches and my role within that process. I do, however, feel that this may have been at the expense of some of the better content around relationships, communication and staff development from the previous day. The engagement and discussion around the topic was certainly not as rich as yesterday. I do feel that the initial task was a strength of the sessions. I felt I could have developed some of the conversations/ observations further to try and draw the coaches into a discussion with one another, comparing practice.

- Analysis – What sense can you make of situation?

I felt that the 'graveyard shift' element of the session had a bearing on the outcome. Both for coaches' engagement and my performance. I also feel it is evident that I take my energy from the group, which should not be the case – I should provide energy for the group. Although the material was the same as yesterday I felt that I probably didn't 'sell' it as effectively. I still question if presenting is a healthy uncomfortable for me or uncomfortable as I am not hugely effective at it. I feel I could have utilised some of the questioning methods that I have recently learnt on the mentoring course. I think that because limited questions came from the coaches I found it hard to demonstrate some of my authentic tacit knowledge, therefore, I have to develop to do this naturally. One real positive is that the final task demonstrated that they had a good understanding of the area as the outcomes were all of a high level and probably higher than yesterday's group. I think that this may have been because they were entering the session at a higher level due to all the content they had been exposed to over the previous two days. I also think that this may have explained some of the reduced impact I feel the workshop was having – it was probably not as novel to this group, which meant that I did not hook them into the journey as effectively.

- Conclusion – What else could I have done?

I feel I could have developed the first task into some further discussion even though it may have been at the expense of sharing some of the later content at that stage. I should not be precious about how the information and content is discussed – just because I have it prepared in slides it doesn't mean it could not be discussed in advance of this if the conversations steer it this way. A lot of the feedback suggested that some video content illustrating some different varieties of sessions would be a useful addition, however, as they are coaches I feel this is their domain and shouldn't necessarily need to be spoon fed this type of information. I could have been more measured and skilled in developing discussions with reasoned questioning.

- Action plan – What would I do next time?

I would consider the time of the day that the session is being delivered and, therefore, manipulate content and deliver style to reflect the most effective method for that group at that time. I certainly feel that my manner suits preparing minimal content and simplicity in slides, which then allows me to engage the group in further conversation and use my applied experience to offer insight and examples authentically rather than deliver a very prepared wooden presentation.

6.5.2 Part B – Science and Fitness Practitioners

Following the delivery of the science and fitness dissemination session, personal reflections were captured via a reflective account. The relevant extract for the associated practitioner dissemination event is displayed below. The reflective extract overviews the key interpretations of the dissemination occasion.

<u>Reflective Diary</u>

<u>Date: 12.03.2018</u>

<u>Scenario: Catapult Delivery – Study 4 Dissemination to Scientists</u>

- Description – what happened?

I delivered a 25-min presentation and Q&A around my professional doctorate findings entitled ‘All that glitters is not gold: Time to review training load monitoring in football?’ The content was essentially the same as what I delivered to the coaches in the month before. I was, however, under significantly greater time restrictions with a 25-min slot. I, therefore, prioritised delivering the research design and findings rather than the more experiential elements around supporting the coaching process and my observations around the limitation of the application of science within football.

- Feelings – What were you thinking & feeling?

As always following these experiences I have mixed feelings. I certainly felt I could have delivered it a lot better. I felt pretty uncomfortable during the presentation and afterwards felt a little disappointed with my delivery of the content. To be completely honest I don't know if this is a misconception or not as it is generally the way I feel after every talk I give. I will watch the video back to make a more objective evaluation. I think my underpinning feelings are a reflection of how I think the audience are perceiving the content rather than my own perceptions. I did feel that the audience possibly perceived the content to be a little 'science' heavy and seem to be most engaged during the anecdotes around my experience rather than the research.

- Evaluation – What was good & bad?

I felt that I outlined the performance problem relatively well and my manner was positioned in the right place – honest and asking some uncomfortable questions of myself and indirectly of the wider science population. I do feel, however, that some of my messages were maybe a little too subtle and possibly should have been more explicit with some of the limitations of current monitoring practice. I felt that the group although scientists were very ‘fitness/ strength coach’ dominant and maybe my content was a little dry and academic at times. I think I knew this would be the case and was a purposeful tactic to try and make them slightly uncomfortable with the detail and get them to ask questions of themselves…not sure I did it effectively enough though.

I also felt that time was a big constraint I probably had an hours material altogether to do it real justice and add a lot of the narrative around each study. It was, therefore, a little rushed with some of the really interesting application and my experiences taken out. I did this purposely as because it was a dissemination piece for my professional doctorate I kept the research in but in reflection I think that I use the research to sell the wider message – like I did for the coaches workshop. The time constraint also affected my delivery style as I feel I rushed the material and didn’t appear as composed as I would have liked.

Some negative feedback centered around the individual and positional differences that exist, which I feel is a really good observation and something that I should certainly look to engage with in my future directions and felt that the attendees craved application, which I understand but instead I biased it towards the underpinning theory and left the application up to them – they are the practitioners after all. It was also a purposeful tactic to try and drag the practitioners to critical appraise current practice and encourage some of these scientific skills that they may commonly neglect.

- Analysis – What sense can you make of situation?

One key observation in this area is I certainly feel more effective and comfortable delivering in an interactive environment (Q&A etc.) than a dry PowerPoint presentation. I think it allows me to draw upon my experience and tacit understanding more so. I think that this is a reflection of my personality as I am generally more comfortable in informal settings. This should certainly be a consideration for future delivery methods.
In regard to research I feel I should get into the detail more in the future. How are my proposals effected for by age, position? What is the impact on performance, injury risk when prescription is link to the movement demand concept?

- Conclusion – What else could I have done?

I feel I could have framed it more around the training process rather than the research as I perceive that is what the group craved. I do, however, think the group should have been in the detail as the danger is lots of assumptions may be made without true scientific interrogation. Irrespective of the content I certainly could have delivered it in a better way, maybe not particularly different, maybe just sharper. This could have been achieved by removing some of the material, so it was paced slower and more composed.

- Action plan – What would I do next time?

I think that following the three recent dissemination pieces and feedback I have a real understanding of the utility of my research and where to pitch it for different groups. I certainly feel there is lots of the story to tell using the research as a vehicle as opposed to shared just the research. I think the key element for me to learn though is to put less material in presentations, interact with the audience and sell the story not just the data.

6.6 PROFESSIONAL SKILLS DEVELOPMENT REFLECTION

I have recently made a large professional change. I chose to leave my role at West Bromwich Albion to join the Premier League as Elite Performance Manager. The decision was certainly not an easy one as I was still really enjoying the role at WBA FC. It was one made with an understanding of what was best for my development and a decision that could not and would not have been made if I had not been engaged on the professional doctorate. The new role is roughly split into two major responsibilities; firstly, to support and challenge Elite Performance practitioners (science, S&C, physio, performance analysis, psychology, talent ID) and their processes within PL academies. The second responsibility is largely split again into two main areas. Firstly, managing and developing the national projects (I am responsible for national benchmark fitness testing and BASES accreditation). Secondly, organising and delivering professional development events and educational pathways. Astonishingly, therefore, the three key areas of my role are crucially underpinned by the key professional skill areas that I have been aiming to develop.

Research Skills

One of the key responsibilities in my new role is the management and delivery national Premier League projects. I, therefore, believe that many of the recently developed skills in the area of research are vitally important. Already since I have been in post I have been required to review large data sets, review current processes, propose refinements and discuss future research strategy. I am excited to continue to engage in this area of practice, however, I do have reservations as I still have limited experience of this area outside of the rigid framework of completing research within an academic qualification. I do, however, feel that this is one area that has one of the greatest scopes to be developed within my role as fundamentally we are required to facilitate and support the development of Premier League Elite Performance staff to world leading. This can only happen if we can establish and share good practice and look to drive the standards forward via innovation.

Management and Leadership Skills

I am really enjoying the club support element of the role. I love utilising the supervisory skills that I have developed to help support staff across clubs helping them establish how they may develop themselves, their processes and their practice. This has also been one of the most challenging parts of the role as it is clearly dependent upon relationships, which due to the embryonic stages of the role may not be firmly established. It also takes time to appropriately establish where I feel I can add value to individuals and their programmes. I am required to support staff across a really broad landscape of Elite Performance disciplines too. I cannot, therefore, rely on being able to share technical expertise with all individuals and instead have to invest in them as people and professionals to maximise their development. I do strongly feel though that as the role evolves this is where we can have real impact. I will, however, have to utilise the full range of mentorship, management, supervisory and advisory techniques I have developed throughout the professional doctorate process to establish appropriate bespoke models of support for each of the clubs and their relevant practitioners.

Dissemination and Networking Skills

This is especially important due to my new role where I am exposed to these kinds of responsibilities very frequently. I have recently delivered educational workshops to staff, presentations to clubs and provided internal updates to colleagues. One thing that is clear from this dissemination is that the skills I wanted to develop in this area are still very much in progress. I feel that I need to be a lot more composed, concise with my thinking and delivery and keep the narrative strong throughout with up to only three key headlines. I am always certainly well planned and prepared. I do not, therefore, feel that this is a limiting factor. I would, therefore, suggest that the only way to really develop these skills in the way I hope, would be to continue to expose myself to these opportunities. Like everything there is clearly a skill component to being effective in the area. It is, therefore, up to me to explore strategies to enhance this.

CHAPTER 7

SYNTHESIS

7. SYNTHESIS

The purpose of the following chapter is to articulate the research and professional outcomes achieved as a consequence of the professional doctorate process. The key results and interpretations will be described along with a meta-reflection, which hopes to capture some of the theoretical and conceptual elements of the journey. Initially an evaluation of the original aims and objectives will be conducted.

7.1. ACHIEVEMENT OF AIMS AND OBJECTIVES

7.1.1 Research

The overall aim of the research contained within the thesis was:

To investigate the relevance of indicators of external load for the evaluation of the movement requirements in elite football

The above aim was achieved by the investigations conducted in chapters three, four and five. Further detail around the specific results that fulfilled this achievement are outlined in the objectives below.

The above aim was initially proposed to be fulfilled by the following objectives:

1 – To evaluate if current external training load monitoring methods in Premier League football effectively differentiate between different coaching methods

Achievement of objective one was demonstrated in chapter three. The training load patterns between four different Premier League coaching groups within an in-season training week were compared. The training load patterns observed between coaching groups were very similar. Differences were, however, present between the volume of TD, PL and TRIMP observed between the coaching groups. There was, however, little difference between the values of $m.min^{-1}$ observed between three of the four coaching groups. The observed training load patterns between the four coaching groups appear to suggest that the elite football training loads observed were largely modulated via duration. These findings suggest that the training load monitoring methods widely used within elite football may be ineffective in capturing the true differences in coaching methods, especially with reference to movement requirements.

2 – To evaluate the effectiveness of MEMS accelerometers to describe differences in movement requirements between a range of football training activities

Achievement of objective two was demonstrated in chapter four. The PL and $PL.m^{-1}$ associated with different football training activities were compared. PL did not clearly distinguish between the movement requirements associated with the training activity. $PL.m^{-1}$, however, was found to be an effective external training load measure for describing differences in movement requirements between different training activities.

3 – To examine the sensitivity of MEMS accelerometer, GPS, heart rate and perceptually derived variables to changes in movement requirements in football specific activities

Achievement of objective three was demonstrated in chapter five. The systematic manipulation of movement requirements was completed via changing relative pitch dimensions in commonly completed training activities. The findings suggest that $PL.m^{-1}$ may effectively distinguish between changes in movement requirements modulated by relative pitch dimension. The measure was found to be greater when pitch dimensions were smaller, suggesting the variables may be sensitive to increases in multidirectional activity. $M.min^{-1}$ also demonstrated sensitivity between movement requirements, however, conversely to $PL.m^{-1}$, the variable appeared to capture the greater locomotive activity associated with larger pitch dimensions. The other accelerometer, internal and perceptual based variables did not demonstrate the sufficient sensitivity to distinguish between the movement requirements associated with changes in relative pitch dimensions.

4 – To propose and disseminate an effective model of monitoring elite football training

Achievement of objective four was demonstrated in chapter six. An appropriate conceptual training load model as a result of the findings from chapter three, four and five was devised. The thesis findings along with the theoretical and conceptual proposals were then disseminated to two different stakeholder groups; coaches and science and fitness practitioners. This was achieved by the delivery of workshop presentations. Feedback and reflections from these events were also captured.

7.1.2 Professional

The professional development aims of the associated with the professional doctorate process were:

1 - *To develop relevant research skills*

2 – *To develop skills related to management and leadership*

3 – *To develop appropriate dissemination and networking skills*

The above aims were achieved by the investigations conducted in chapters three, four and five, the dissemination outlined in chapter six and further professional development outlined throughout the reflective pauses. Further detail around the specific outcomes that fulfilled the achievements are outlined in the objectives below.

1 – *Further develop an understanding and application of different practical analytical and visualisation approaches relevant to the elite football environment*

Achievement of objective one was demonstrated in chapter three, four and five. Within each of the investigations outlined, the results were interrogated, analysed, visualised and disseminated in a variety of methods. Skills around the use of practical statistics (magnitude-based inferences), an understanding of mixed models and relevant statistical software (R), techniques around data visualisation (PowerBi) and methods of innovative dissemination (GoAnimate) were all developed.

2 *- Disseminate research findings via a broad dissemination approach. In turn, develop formal and informal research dissemination skills via regular engagement in scientific writing and the exploration of novel dissemination methods*

Achievement of objective two was demonstrated in chapter three, four, five and six. Throughout all chapters of the thesis there is evidence of scientific writing. This skill improved greatly throughout the process due to continual engagement and development. Chapters three and six also demonstrate the use and development of more informal dissemination techniques such as video animation and presentations. As a result, the skills required for these methods of information sharing were refined and it is hoped that a broader audience may be reached.

3 *– Develop a club research strategy along with formal academic collaboration*

Achievement of objective three was demonstrated in the reflective pause of chapter five. The doctoral enrolment of two of the departments full time staff, plus the recruitment of two full time PhD studentships demonstrate completion of this objective. The research focus of these higher research degrees was collaboratively established between club and university as part of the academic agreement.

4 *– Facilitate greater exposure to managerial, supervisory and mentorship responsibilities*

Achievement of objective four was demonstrated in the reflective pause of chapter four, five and six. Throughout the professional doctorate process, the identified responsibilities were developed with more management, supervisory and mentorship established.

5 – *Engage in further reading and courses around important managerial and leadership skills*

Achievement of objective five was demonstrated in the reflective pause of chapter five. Great amounts of performance management material have been personally read and contextually interpreted throughout the process. Enrolment and initial engagement upon the European Mentoring and Coaching Council Accreditation has been completed.

6 – *Regular exposure to public speaking and presenting to a variety of different audiences*

Achievement of objective six was demonstrated in chapter six and the reflective pause of chapter three and six. Many formal presentations and workshops have been completed to scientific (Science & Football conference, Catapult workshops), medical (FMA), academic (Doctorial Conference) and coaching (ECAS) audiences.

7 – *Organisation and implementation of high standard scientific workshops, which aim to link research to practice in a variety of football specific areas*

Achievement of objective seven was demonstrated in the reflective pause of chapter five. A masterclass series was established, which delivered workshops on topics such as speed, power and aerobic development for team sports. Internationally recognised researchers and practitioners were involved throughout the series.

7.2. GENERAL DISCUSSION OF FINDINGS

The current training load monitoring landscape within football has been widely discussed in chapter two. It appears that clubs, coaches and practitioners must see real value in the practice as it is widely adopted across the globe. The results outlined in chapter three do, however, suggest that the processes adopted may not be as effective as possible. It appears that variables such as duration, TD, TRIMP and PL appear to capture the same volume component. There does appears to be a duration bias present across the GPS, MEMS accelerometer and heart rate values mentioned. Questions may, therefore, be posed if all of these measures are required and if they demonstrate sufficient sensitivity to capture what is really happening in football training. The measures appeared ineffective to differentiate between the different coaching methods observed between different coaching groups, although subjective observation would imply that there was large difference in the methods utilised, especially in reference to the movement requirements of football training. It should, therefore, be questioned if the methods that are commonly utilised in training load monitoring in football are actually effectively measuring what we hope and think that they measure. As we appear to be approaching a data tipping point in elite football, we should look to be efficient in the data collected and ensure anything captured is so for a purpose. It may, therefore, be time to review the current training load monitoring processes in football.

The review of the literature in chapter two appears to suggest that MEMS accelerometer measures may offer a solution to the limitations around capturing movement requirements. The second investigation within chapter four, therefore, attempted to explore the effectiveness of the MEMS accelerometer variables of PL and $PL.m^{-1}$ to capture the differences between football training activities. Even when PL was normalised for duration it still did not appear to clearly distinguish between these activities. It, therefore, appears that although PL appears to be widely utilised in practice and is well supported within the literature, it appears ineffective at differentiating between the different movement requirements of different training activities. The same investigation did, however, suggest that $PL.m^{-1}$ may offer insight into the movement requirements desired. The variable measures rate of change in accelerations captured by the multiplanar MEMS accelerometer technology for every meter travelled. Theoretically, therefore, this measure appears to represent movement density as it attempts to capture the accelerometer load relative to the distance covered.

The sensitivity of $PL.m^{-1}$ that was observed in chapter four was then tested and further investigated along with other variables of training load in chapter five. Once again, the findings suggested that $PL.m^{-1}$ may be effective at distinguishing between the movement requirements. Although, many other accelerometer, internal and perceptual based variables are well supported elsewhere within the literature, it appeared that they do not clearly distinguish between the movement requirements associated with changes in relative pitch dimensions. This component of training load monitoring is something that has not been promoted within previous research or widely applied within practice.

The findings of the studies herewith (chapter three to five) and the relevant review the literature (chapter two), enable the lead researcher to make a conceptual proposal for a monitoring model in football (figure 30), which hopes to direct future research. It appears that the volume component of training may typically be duplicated across traditional monitoring models and, therefore, it may be suitable to instead only use one variable that captures this value. Intensity may be proposed as the second key component of the model. Due to the large variation in physiological response to intensity of different training modalities, it appears suitable to potentially include both a locomotive and change of direction based measure for the component of training load. The final piece of the conceptual model that should be further investigated is a measure that captures the movement requirement of the activity, which may, therefore, inform the type of training load.

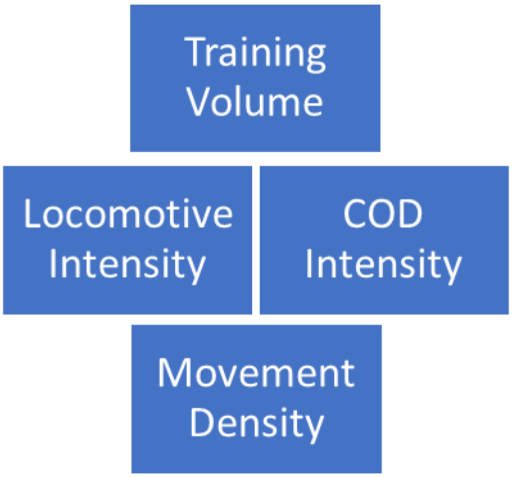


Figure 30. Conceptual proposal of an external training load monitoring model for football

PL.m^{-1}'s demonstrated utility now leads the researchers to propose the variable to be a useful addition to the larger proposed conceptual monitoring model, with further research into its utility as the movement density measure required. Simply put, PL.m^{-1} may help categorise the type of movement requirement. It should, therefore, by no means be implemented as the single component of a monitoring strategy. It may, however, offer potential when used alongside other variables that capture volume, change of direction intensity and locomotive intensity. The measure is, therefore, proposed within a theoretical external training load model below along with other appropriate variables (table 17). Further research, along with practical contextual experience is, however, required to ensure that the most appropriate training load variables are selected within the model ahead of implementation.

Table 17. Theoretical proposal of an external training load monitoring model for football

	Movement	Locomotive
Volume	PL	
Intensity	Max Acc/ Dec	Max V
Density	$PL.m^{-1}$	

It may be a little over simplistic to portrait the measure of movement density purely as a value. In fact, conceptually, the measure works a lot more effectively when considered as a continuum as displayed in figure 31. The continuum proposed may be influenced by many training design factors. As found in chapter four and five it would appear that the training activity and relative pitch dimensions would be two key principles that underpin the position of a selected training activity upon the continuum. Further research may, however, be required to establish what other training factors may influence the position of a training activity upon the movement requirement continuum.

Figure 31. Conceptual proposal of a continuum of movement requirements

7.3 META-REFLECTION

I have consistently reflected throughout my professional doctorate programme. I would suggest that even before embarking on the journey, I was a relatively reflective practitioner. In fact, I feel that at times I can over reflect. I often dwell on issues and micro-analyse. I presume this is heathy in some regards, however, I feel that at times it is detrimental as I may make misperceptions due to unpicking proceedings to the finest details and misread what is really important. One thing that I had previously been poor at was documenting and recording my reflections (thinking in ink). Throughout the last 27-months I have used multiple methods to capture these accounts each with varying success.

Initially, I started formally documenting all key occasions and experiences, typing up accounts that included key descriptions, feelings, evaluations, analyses, conclusions and action plans. I found that this method was really effective at capturing appropriate detail and the structured layered approach ensured that I clearly unpicked the event from tangible descriptions to the more abstract aspects of feelings and evaluations. The method did, however, require a big allocation of time and as this was usually a luxury that was in short supply, my compliance waned. Instead, I continued to reflect but at this I time used my iPhone to capture voice recordings about daily events and moments of interest. This was much more convenient, easily capturing details on the move. Similarly, however, the method did not last the test of time as I found it difficult to meta-reflect as it was difficult to quickly jump back in to reflect on specific feelings and details without listening to the library of reflections that I had built. I, therefore, settled on a semi-structured method that appeared to suit my routine but also allowed me to quickly meta-reflect on common themes throughout my previous reflections. This method involved my using an A4 diary, which I would keep with me and quickly jot key information, descriptions, feelings, evaluations etc when I thought relevant. Yes, it did still require a significant allocation of protected time to clearly think and record my thoughts, however, it had much more flexibility than the formal reflective diary that I would record on the laptop. I guess the testament is that this is the method that appears to have stood the test of time. I did, however, appear to go through spells of engagement when I would effectively integrate reflective practice into my routine and other periods where I had limited engagement. My levels of engagement were often dependent upon my combined professional and academic workload, when my reflective practice tended to be the first thing to diminish when exposed to time constraints.

Whatever method I was utilising to reflect, I typically engaged in reflective practice towards the end of my working day or as soon as I returned home for work. I felt this had enough proximity to the events to be accurate but enough space between so that they were not too driven by in the moment emotion. I must admit I do quite enjoy reflecting and feel it offers me closure to certain events or directs me to suitable actions that are required. I am also pretty comfortable with sharing my thoughts and feeling around these events with colleagues and peers. This would always be verbally though and I did not share any of my written reflective accounts with anyone throughout the professional journey. I assume this may have been a limitation, however, I do feel I have been open and honest throughout, consistently sharing my thoughts and feelings with relevant others. One thing I think I could do better and more consistently is review my reflections. As I have suggested the method used typically dictated the effectiveness of this but even so I don't think I did this as often as possible.

From reviewing my reflections throughout my period engaged on my professional doctorate, it is clear that I am very development and process focused. Most my reflections were tightly framed around processes rather than outcomes. I was often appraising the effectiveness of the methods that were in place within the department, the relationships that existed and the interactions between people or their practice. In regard to the developmental aspect, a lot of my time was spent analysing and evaluating how myself and the department were or were not progressing and growing. Were we reactive to change? Were we positively evolving? Very little content from my reflections were around outcomes and even fewer around things that I personally could not effect, which seems to make sense to me. I presume that reflective practice should be engaged in to inform change and teach the individual lessons for future practice. It, therefore, appears counterintuitive to be reviewing areas outside of my control as I cannot legislate for them in the future. One thing that I think I have learned from reviewing my reflections is that I certainly pay a lot of attention to people focused aspects of my professional life. I appear to be pretty perceptive and often try and see things through the lens of others. A definite limitation to my reflective practice is that I probably take these perceptions too far and over analyse the affect that my behaviour and actions may have on others, trying to interpret their thoughts and perceptions, even though at times this may not be relevant. I can often dwell on pretty insignificant events if I perceive that I could have done more or acted more effectively rather than reacting promptly and moving on. Maybe because of the personal, qualitative aspect of reflections I tend to bias them around personal, qualitative elements rather than more mechanistic areas of practice.

As I sit here at the end of the professional doctorate journey it is incredibly evident from the reflections I have captured that the process of research and professional development has certainly had a huge impact on my personal practice. It is self-evident that the engagement on the academic course has been the single most impactful professional development period of my career. I have learnt and developed so much in so many areas and on route towards achieving all of the relevant aims and objectives that were set out in the introduction of the thesis. I have certainly evolved and developed as a practitioner, researcher and manager and feel that my dissemination skills are far more refined with much more sophisticated practical and academic networks. I guess the greatest evidence of my development in these areas is the change in role that occurred towards the later stages of the programme. Without the professional development that the professional doctorate engagement facilitated I would not have either considered or been appropriately skilled in the relevant areas to be considered for my new role. As I approach submission and engage in a time of personal reflection it is the development of these key professional skills, which I am equally as proud of as the research that has been produced.

A further major benefit of the professional doctorate mode of study, has been the importance of identifying the wider impact of my academic journey. Throughout this period, the strategies of dissemination and potential impact have always been high on the agenda. Study one and study four, therefore, were designed as applied studies with a specific purpose to maximise the impact of the research via targeted modes of dissemination. Study one utilised a novel form of video dissemination to be shared via social media, while study four was a combination of two presentations, one to a group of academy coaches and the other a group of sport scientists. It is hoped that the integrated dissemination methods within the thesis have demonstrated a variety of approaches of how the research can be shared and the wide application the findings may have. It is too early to evaluate the impact that these events may have on applied practice in football, however, I feel that these occasions have demonstrated that there appears to be to be a gap in the knowledge base around this theme and, therefore, there is an appetite for coaches, practitioners and researchers to learn more in the area. The dissemination strategy for sharing the findings of the current thesis does not, therefore, finish at the time of submission of these applied studies but instead their utilisation as prospective scoping exercises informs a wider future dissemination strategy to achieve impact. I hope to continue to present the findings of the research via multiple methods to mixed groups. Formal sharing of this may form formal peer-reviewed research, semi-formal research reports and semi-formal conference presentations.

The level of impact of the research findings will not be limited to the formal dissemination processes either. Due to the role I was employed in at the start of my professional doctorate journey and now at the end of the pathway, I also have obligations and opportunities to share informally within different settings too. As previously suggested the research was born out of applied performance problems that colleagues and I at WBA FC were facing on a daily basis. I have, therefore, began to disseminate the information formed with the relevant staff employed at the club. This will continue on an ongoing basis and shared via mixed methods to the various stakeholder. It is hoped, therefore, that this will have a direct impact upon practice at the identified club and tackle the challenges that were faced when I was in post there at the formation of the project, during data collection, data analysis and data interpretation stages of the research. More recently my current role requires me to support Premier League academy Elite Performance practitioners. This support may come in the form of club visits or organised professional development events. Whatever the scenario it is important that my colleagues and I share good practice and attempt to raise national standards in the area of Elite Performance. I will, therefore, ensure that the new knowledge formed from the findings of the thesis plus its application for the elite football environment are appropriately shared within my current role to inform training design and monitoring processes.

7.4. FUTURE RECOMMENDATIONS

7.4.1 Research

The conclusions in this thesis have provided novel findings around the monitoring of elite football players, with special reference to the movement requirements. In achieving the aims of the thesis, however, several other research questions were established and, therefore, recommendations for future research are proposed. This section details those recommendations in relation to each specific chapter of the thesis.

Suggestions arising from chapter three:

1 - It is recommended that further investigations comparing training loads and patterns between coaching groups explore a wider range of external training load variables such as sprinting and further accelerometer-based measures.

2 - It is recommended that a similar comparison is made between different coaching groups at different clubs. It would be important to explore if club contextual factors may be an influencing factor.

3 - It is recommended that future research attempts to establish if differences between coaching groups is present across other training periods such as preseason or across in-season mesocycles.

Suggestions arising from chapter four:

1 - It is recommended that further investigations explore a wider range of external training load variables, especially other accelerometer-based

measures. The retrospective nature of the current study did not make this possible.

2 - It is recommended that future research should investigate how the movement requirements of different playing positions are influenced within different drills and how the coach delivering the drill may impact upon the movement requirements. Both of these areas would provide great insight into the specifics of training design.

3 - It is recommended that research should look to identify how the external demands of training activities relate to the internal requirements and, therefore, the possible physiological adaptation. This would, therefore, enable the planning and delivery of training to take a truly informed approach.

Suggestions arising from chapter five:

1 - It is recommended that a greater variety of training activities and pitch dimensions should be investigated in the future.

2 - It is recommended to investigate if age (chronological and biological) has an influence on the movement requirements observed between training activities. This would be of specific interest for players who are at or approaching peak height velocity.

3 - It is recommended that future studies should look to quantify the movement requirements in each training activity. This dependent variable was systematically manipulated within the current study but was not directly measured.

Suggestions arising from chapter seven:

1 – It is recommended that future studies should look to test and challenge the conceptual proposal of an external training load monitoring model for football. The limitations of the model should be established and it should be investigated if there a more effective conceptual model for monitoring football training.

2 - It is recommended that future studies should look to test and challenge the theoretical proposal of an external training load monitoring model for football. It should be established if the most effective training load variables are proposed with the current proposed model.

3 – It is recommended that future studies look to establish what other training factors other than training activity and pitch dimensions may influence the movement requirement of football training.

7.4.2 Professional

Throughout the thesis, the key themes of professional development have been revisited throughout. These have specifically centred around research skills, management and leadership and dissemination and networking skills. As suggested these skills have all been significantly developed throughout the professional doctorate journey. There is, however, certainly further room for improvement. The following section outlines the recommendations in relation to each specific area.

Research skills:

1 - Continue to actively engage in research; refining skills in data collection, analysis, interpretation and dissemination.

2 - Establish a research strategy within current role.

Management and leadership skills:

1 - Continue to evolve key supervisory and mentorship skills. Initially complete mentorship accreditation.

2 - Continue to develop knowledge and understanding around key principles of performance management. Establish a personal high-performance philosophy and effective framework.

Dissemination and networking skills:

1 - Refine skills around formal and informal research and good practice dissemination by the continual planning, organisation, delivery and reflection of relevant events.

2 - Establish a strategy to innovatively disseminate research and good practice to the wider Elite Performance practitioner group.

CHAPTER 8

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8. REFERENCES

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CHAPTER 9

APPENDICES

9. APPENDICES

9.1 TRAINING PLAN

Professional Doctorate Training Plan

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DSportExSci2016

May 2016

<u>Self Audit</u>

Introduction/background:

The ability to self-audit is a key trait that any practitioner or academic should strive to develop. As outlined within the vitae research development framework (vitae, 2016), 'in order to engage effectively with your career planning, it's important to expand self-awareness'. The framework goes on to suggest that it is important for a student to appreciate the foundation of capabilities and expertise that they possess entering the doctorate, which will aid the creation of a development plan. It appears impossible to be able to accurately complete a self-audit without engaging in elements of formal and informal reflection. Reflection has been defined as 'a purposeful and complex process that facilitates the examination of experience by questioning the whole self and our agency within the context of practice' (Knowles *et al.,* 2014). Following a self-audit it is imperative that a detailed development plan is put in place. When constructing such a plan it is worth noting that the development of expertise is often acquired via a combination of professional knowledge based programs and practical experience (Knowles *et al.,* 2001).

The Professional Doctorate in Sport and Exercise Science aims to create and interpret new knowledge associated with professional practice as well as developing the skills required to carry out safe independent practice as an Applied Sport ands Exercise Science practitioner. It would, therefore, appear rational for the trainee to identify a method of self-evaluation that would review each of these two key areas in order to establish desired outcomes for personal and professional development.

Approach to the self-audit:

The method utilised to establish current competency as a researcher, was the vitae researcher development framework (vitae, 2016). While, the BASES accreditation competency profile (BASES, 2016) was utilised to establish competency as a practitioner. These approaches appear as appropriate tools, as they outline the skills required within each environment. Each method allows the practitioner to grade their current competencies against a structured framework. This process exposed some clear areas of development. Many of the formal research skills outlined throughout the sections are where my limited exposure and expertise were highlighted. While many of my strengths appear to be narrowly focused around the more applied traits within the environment and setting of my current practice.

I feel that my academic and professional background has ensured that I have a good knowledge base that ensures my professional judgments are underpinned with sound scientific reasoning. I feel, however, that my generalist applied role; along with my limited high-level research exposure has resulted in no true expert knowledge status within any singular area. I possess a healthy skepticism for analysing literature. If I am to be truly critical, however, I probably only scratch the surface and rarely dig specifically deep to complete a comprehensive synthesis. The application of my knowledge and my ability to interpret information via an applied lens are key strengths. I feel that my experience and understanding of the delivery environment helps facilitate this.

I believe I possess an initial understanding and appreciation of the theory and application of research methods as I utilise data via a wide range of methods within my professional setting. I feel, however, I lack an in depth knowledge and would struggle to give rationales and alternatives to commonly used methods. This lack of sophistication is not isolated to data analysis and I am fairly rigid in my professional practice approach. As I continue to develop, however, I believe I approach problems more imaginatively and conceptualise solutions more efficiently. I am an open and honest researcher-practitioner who invests time to talk to colleagues within multiple fields of expertise, demonstrating the desire to challenge and be challenged on many conventional approaches. I approach discussions in the right manner, however, I feel that I must strive to improve the sophistication of my approach and attempt to get my points across concisely and succinctly. This development need is echoed within my written work. I feel that my writing style is too ‘fluffy’ and lacks a concise approach. Again, my limited experience of publication in print may provide a rationale for this flaw.
I am also starting to gain increasing managerial responsibilities, although I am relatively inexperienced in this area. I have self-appointed myself responsible for staff development and look to improve them as practitioners via reading, education and discussion. Once again one area that may be my downfall is the lack of promotion of research within the department and the development of this skill set within the other staff.

The environment I work in is very transient. This ensures that I have to be very responsive to change and adapt within its context. I feel that engaging in self-reflection aids my efficiency. My reflective practices, however, are fairly informal, lack consistency and relatively unrefined.

I am very thorough in the organisation of my continued professional development opportunities. I regularly attend relevant conferences and workshops. I have also recently gained experience of presenting within these settings. Although I regularly attend these forums, I do not have any previous experience of organising any seminars, workshops or conferences that would help disseminate knowledge and research. Although, I am regularly in attendance at industry events, I am generally very poor at networking. I have very strong networks with individuals and colleagues who I am familiar with but not with those whose path I have not crossed out of necessity. Along with networking, I also devote very little time to career planning or management and tend to cruise through my career progression rather than consciously mapping my developments.

Outcomes:

I feel that the self audit has helped identify a clear development plan for the following two years of the course. My development needs can largely be split into three areas:

- Research skills

- Management skills
- Networking and dissemination skills

I am sure that my professional development associated with the professional doctorate course will go along way in alleviating some of my concerns, however, there will clearly be some unassociated development projects that I will need to encounter to ensure I develop across all three areas.

The large emphasis of the doctorate to create and interpret new knowledge associated with professional practice will ensure that many of the research skills I have identified will be honed throughout the course. It is my opinion that I currently need to complete research within a formal qualification to ensure that I have the motivation, pressure and necessary expertise associated with a structured academic project to aid completion. It is important that I am exposed to a wider range of research methods and statistical approaches that I would usually come across professionally. This improved interpretation of data along with enhanced skills involved in sophisticated synthesis of the scientific literature are areas that the doctorate will challenge my development. It is hoped that this enhanced research ability will enable me to make more informed judgments regarding the appropriateness and effectiveness of my professional practice. These skills along with the development of my scientific writing ability into a more concise and sophisticated language will hopefully ensure that I can conduct high impact research that is worthy of publication within a high standard scientific publication.

I feel that due to my lack of recent research experience I do not demonstrate much expertise within research management. The professional doctorate along with the formation of a formal collaboration between Liverpool John Moores University and West Bromwich Albion Football Club will positively impact upon my exposure to this skill set. This professional collaboration will also ensure that I am exposed to additional academic administrative tasks such as securing research funding and other governance tasks. I have to risk manage on a daily basis within my applied role, however, it has been a long time since I have had to do this formally within a research setting. I will need to develop the relevant skills to ensure that I do this within currently recognised procedures and document with the relevant paper trail.

Management skills are an area I am very keen to develop over the coming two years. This is a development gap that I have identified as I am relatively new to this position of responsibility. I feel my supervisory skills are good, however, become neglected once my workload increases. One weakness I may have is that I do not delegate work comfortably but would rather over allocate within my own workload rather than require others to complete some tasks. I really enjoy this area of my role, especially supervision of less experienced staff and hope that through completing further research myself it will improve my skill set to be a successful supervisor and mentor. It is important that I identify professional development opportunities away from my professional doctorate studies to enable me to advance in this area, as I feel that the doctorate and my professional experience may not contain enough formal development within this area. One method that may help in this area is if I look to develop an openness and courage to seek advice and guidance from more established and managerially experienced professionals within my industry and elsewhere. Secondly, I will direct a lot of my reading around the subject, highlighting keys texts and completing reflections upon my development within my reflection and training log. Thirdly, I will explore the possibility of completing an online course in the area.

In regards to my networking and dissemination skills, there are large developments to be made over the coming two years. I am keen to improve in public speaking, as it is a method of communication I will need in order to share my research findings to colleagues and peers internationally. To ensure I can participate in these experiences successfully I may need to look for development opportunities in the area of public speaking and presenting, an area I am currently widely reading around. I believe that I am also fortunate enough to have the facilities, resources and access to the expertise to organise and deliver high standard seminars and workshops. This is a further key networking and dissemination goal I will achieve over the coming 2-year period.

Appendix:

Figure one outlines my career development from 2006 to 2016. The details above the time line represent all of my most notable professional development and academic achievements. My most notable professional achievements are displayed below the timeline.

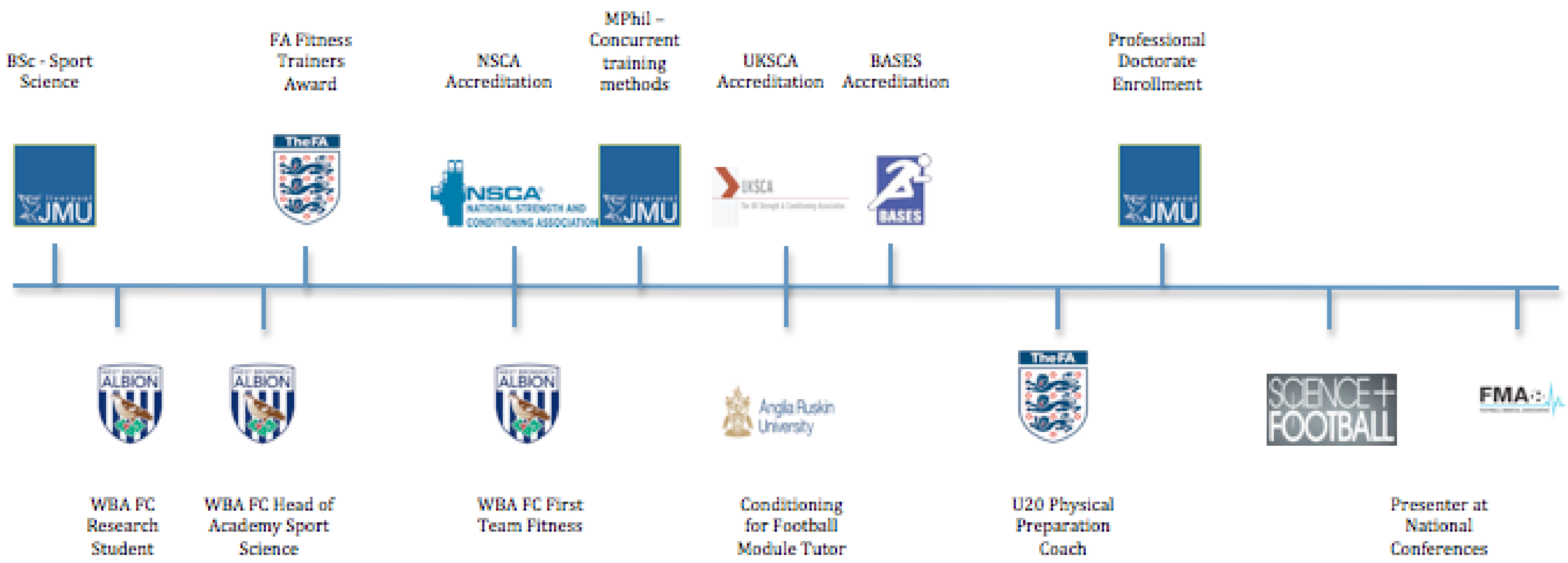
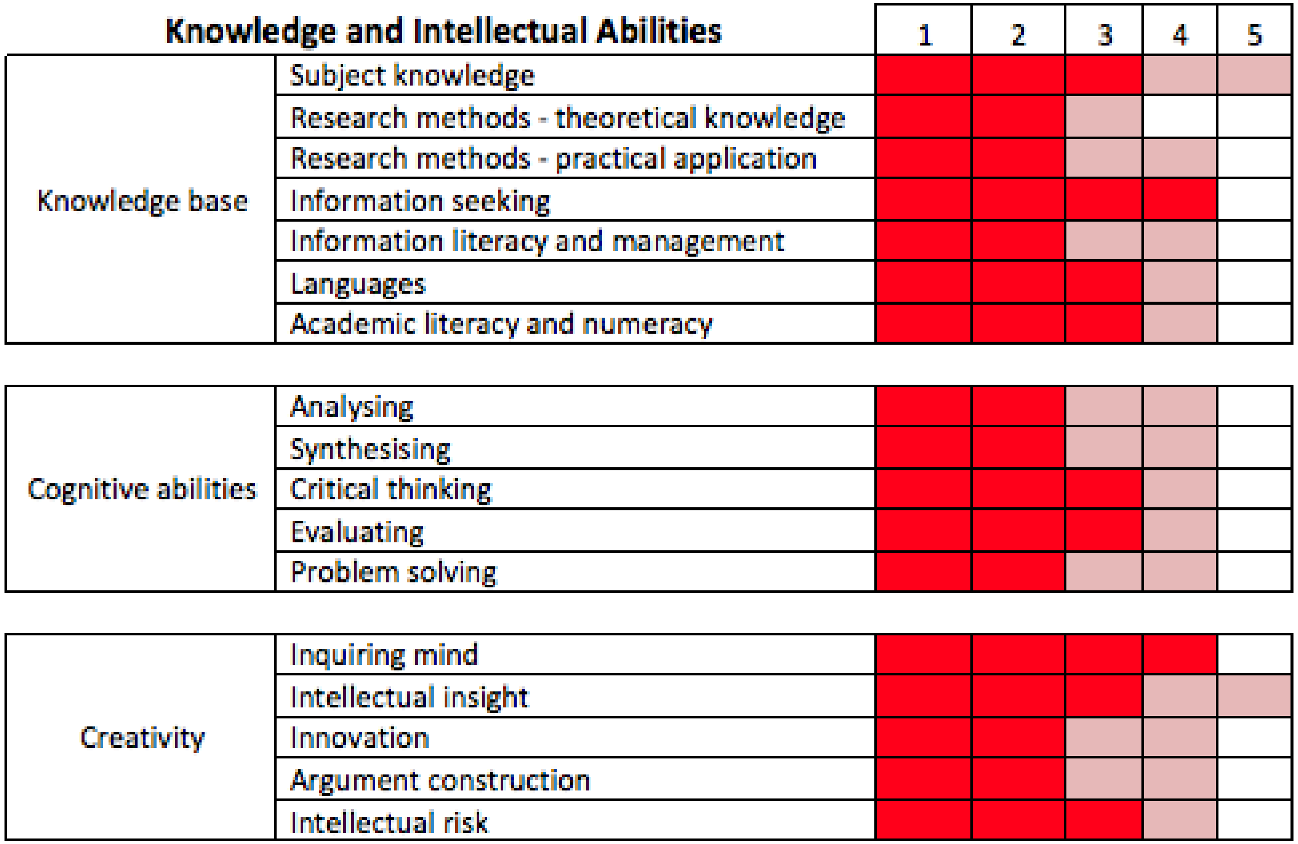


Figure 1. Career timeline (2006-2016)



Evidence

- BSc Sport Science
- MPhil Concurrent training
- Completed BASES supervised experience
- Regularly attend workshops and conferences
- Regularly complete case study and case conference approach to problem solving in the applied environment
- Use of basic descriptive statistics to interpret training and testing data
- Regularly complete literature searches and subscribe to key journals
- Use data and information to make informed decisions on a daily basis
- Professionally supervise junior staff
- Attend daily multidisciplinary team meetings
- Conduct a biweekly journal club with other members of the department
- Regularly introduced innovation procedures to department practice

Figure 2. Knowledge and intellectual abilities (vitae). Current and desired proficiencies.

Personal Effectiveness		1	2	3	4	5
Personal qualities	Enthusiasm					
	Perseverance					
	Integrity					
	Self-confidence					
	Self-reflection					
	Responsibility					
Self-management	Preparation and prioritisation					
	Commitment to research					
	Time management					
	Responsiveness to change					
	Work-life balance					
Professional and career development	Career management					
	Continuing professional development					
	Responsiveness to opportunities					
	Networking					
	Reputation and esteem					

Evidence

- 8.5 years applied experience
- Professionally supervise junior staff
- Attend daily multidisciplinary team meetings
- Conduct a biweekly journal club with other members of the department
- Regularly attend workshops and conferences
- Regularly engage with self-reflection
- Completed BASES reflection workshop
- Senior role, which requires leadership of other members of staff and department processes
- Complete own daily time management processes
- Operated with around 8 different managers
- Continuously engage in CPD activities
- Initial exposure to presenting at national conferences

Figure 3. Knowledge and intellectual abilities (vitae). Current and desired proficiencies.

Research Governance and Organisation		1	2	3	4	5
Professional conduct	Health and safety					
	Ethics, principles and sustainability					
	Legal requirements					
	IPR and copyright					
	Respect and confidentiality					
	Attribution and co-authorship					
	Appropriate practice					
Research management	Research strategy					
	Project planning and delivery					
	Risk management					
Finance, funding and resources	Income and funding generation					
	Financial management					
	Infrastructure and resources					

Figure 4. Research governance and organization (vitae). Current and desired proficiencies.

<u>Evidence</u>

- Experience of ethical submissions
- Completed BASES ethics workshop
- Accredited via UKSCA, BASES & NSCA
- Opened communication regarding a department research strategy
- Initial exposure to funding applications
- Responsible for department budget requisitions and resources

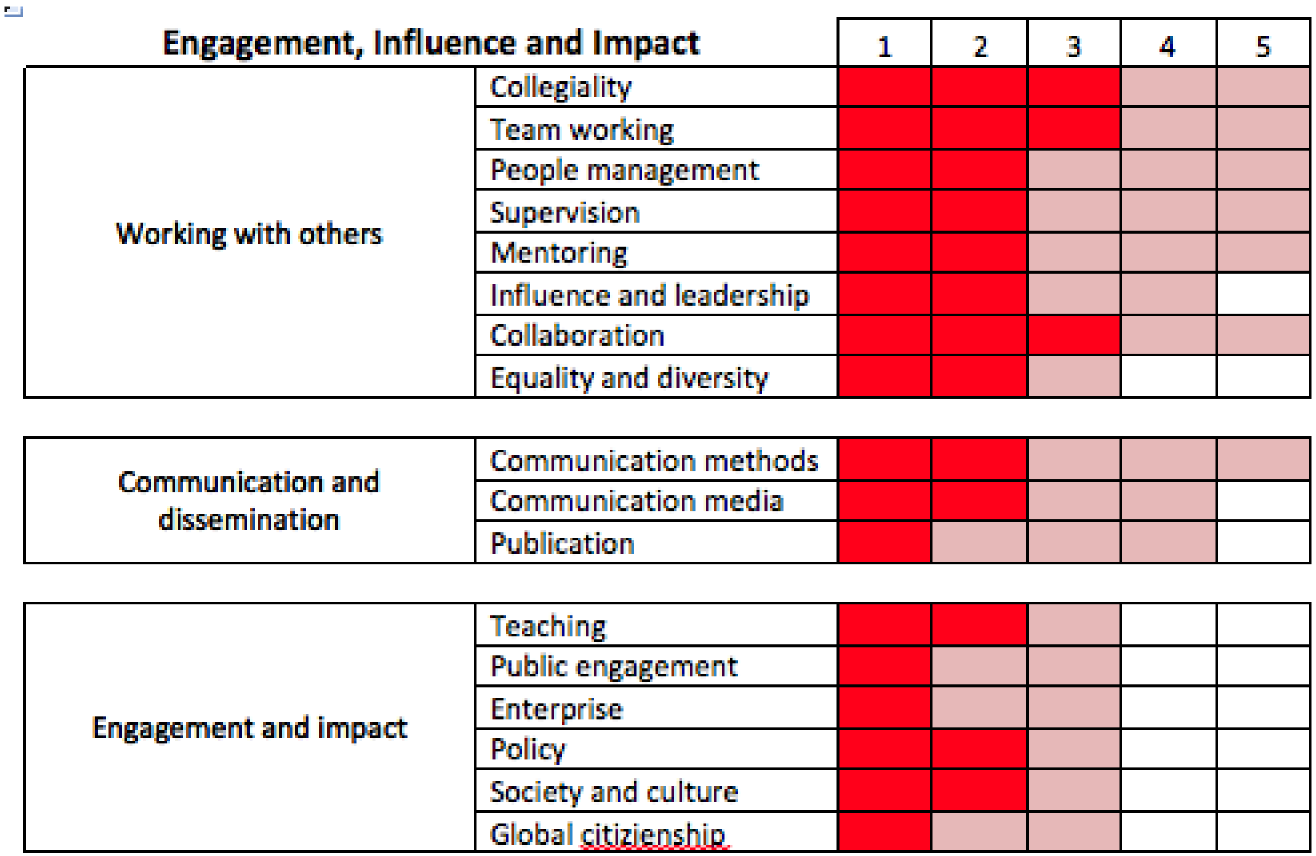


Figure 5. Engagement, influence and impact (vitae). Current and desired proficiencies.

<u>Evidence</u>

- Professionally supervise junior staff
- Operate as part of a multidisciplinary team
- Attend daily multidisciplinary team meetings
- Conduct a biweekly journal club with other members of the department
- Senior role, which requires leadership of other members of staff and department processes
- Operated with around 8 different managers
- Supervise x 2 students upon BASES supervised experience
- Initial exposure to formulating a collaborative agreement between the department and an academic institution
- Initial exposure to presenting at national conferences
- Engage in daily encounters with players and other members of staff and are confident in the interactions
- Regularly use a variety of communication methods when engaging in encounters with players and other members of staff
- Very limited publication experience, one lead author on poster and conference proceedings and second author on one article
- Developed 'conditioning for football' module and teach at ARU

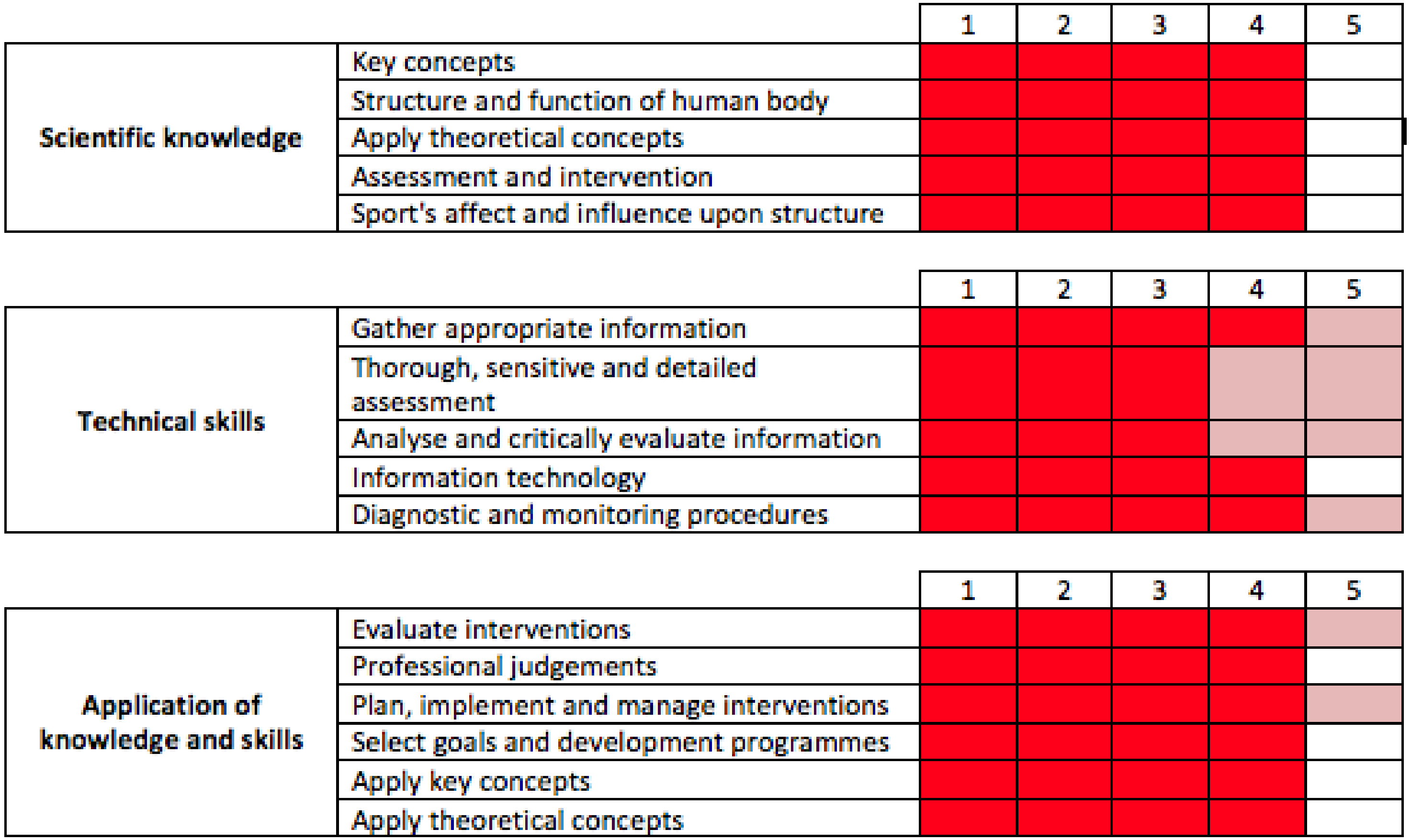


Figure 6. Scientific knowledge, technical skills and application of knowledge and skills (BASES). Current and desired proficiencies.

Evidence

- BSc Sport Science
- MPhil Concurrent training
- Completed BASES supervised experience
- Regularly attend workshops and conferences
- Regularly complete case study and case conference approach to problem solving in the applied environment
- Use of basic descriptive statistics to interpret training and testing data
- Regularly complete literature searches and subscribe to key journals
- Use data and information to make informed decisions on a daily basis
- Regularly introduced innovation procedures to department practice
- 8.5 years applied experience
- Complete daily monitoring and testing procedures

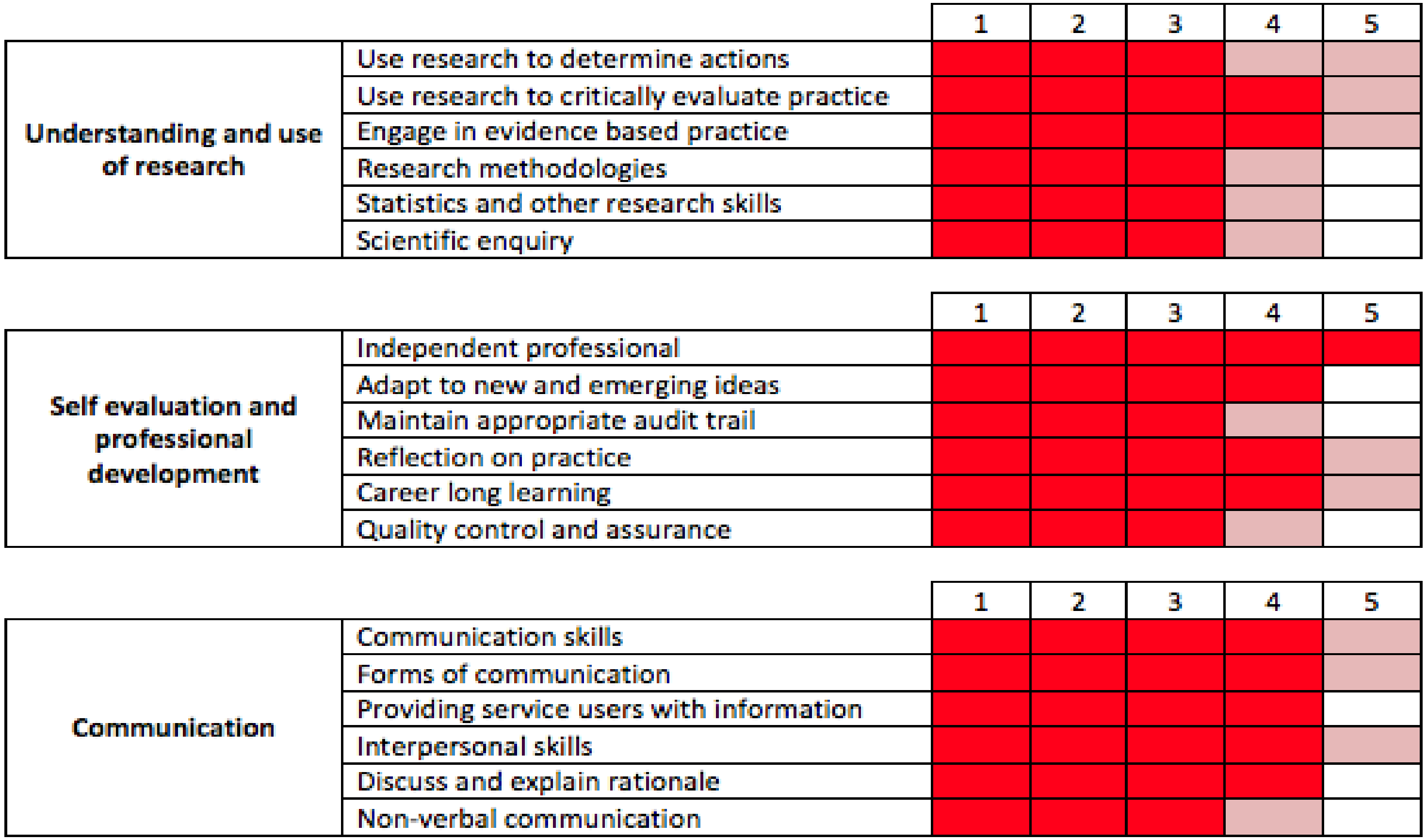


Figure 7. Understanding and use of research, self evaluation and professional development and communication (BASES). Current and desired proficiencies.

<u>Evidence</u>

- Professionally supervise junior staff
- Operate as part of a multidisciplinary team
- Attend daily multidisciplinary team meetings
- Conduct a biweekly journal club with other members of the department
- Senior role, which requires leadership of other members of staff and department processes
- Operated with around 8 different managers
- Supervise x 2 students upon BASES supervised experience
- Initial exposure to formulating a collaborative agreement between the department and an academic institution
- Initial exposure to presenting at national conferences
- Engage in daily encounters with players and other members of staff and are confident in the interactions
- Regularly use a variety of communication methods

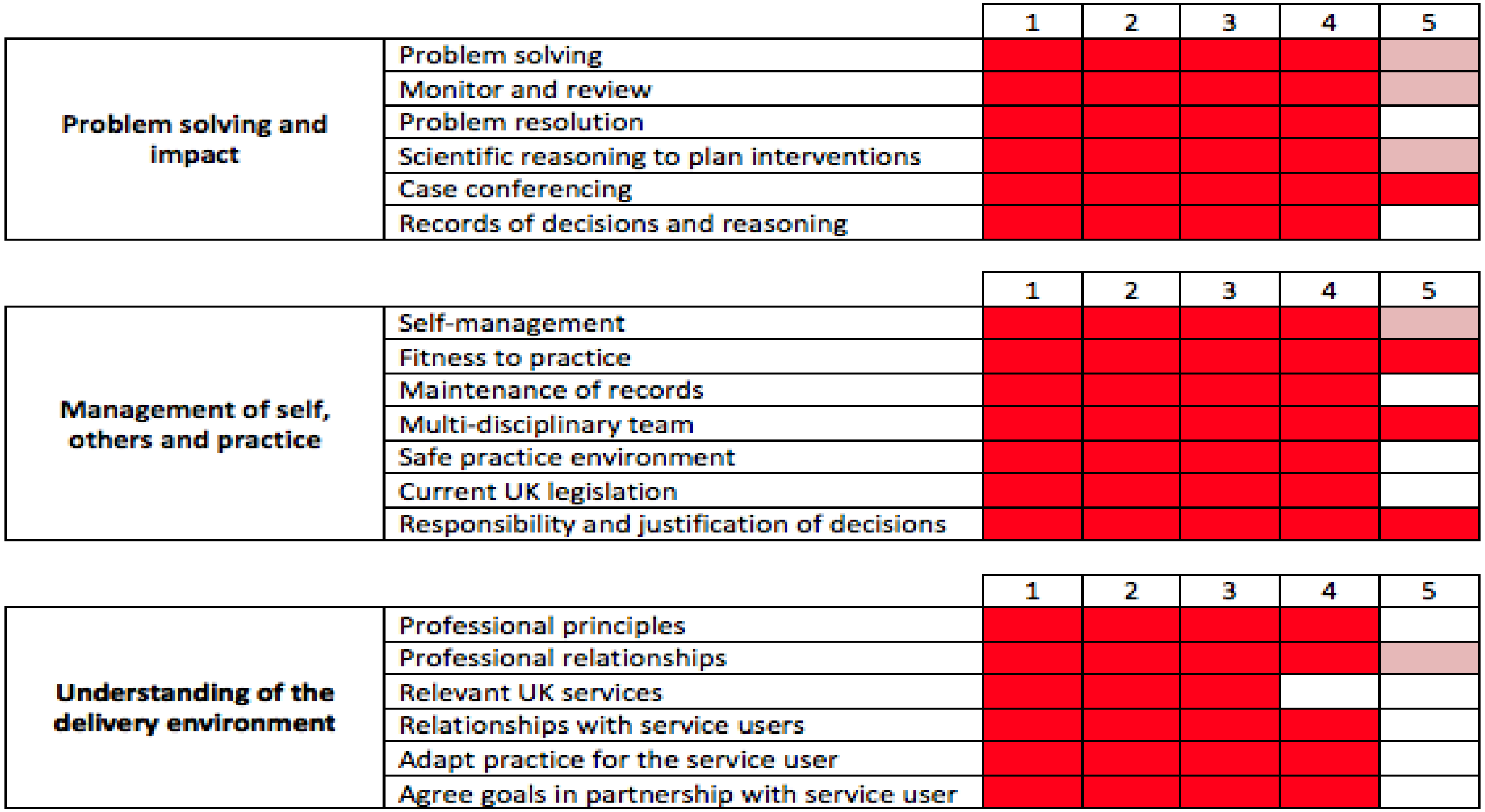


Figure 8. Problem solving and impact, management of self, others and practice and understanding of the delivery environment (BASES). Current and desired proficiencies.

Evidence

- Accreditation from UKSCA, BASES, NSCA
- Regularly complete case study and case conference approach to problem solving in the applied environment
- Use of basic descriptive statistics to interpret training and testing data
- Regularly complete literature searches and subscribe to key journals
- Use data and information to make informed decisions on a daily basis
- Regularly introduced innovation procedures to department practice
- Operate as part of a multidisciplinary team
- Attend daily multidisciplinary team meetings
- Senior role, which requires leadership of other members of staff and department processes
- Engage in daily encounters with players and other members of staff and are confident in the interactions
- 8.5 years applied experience

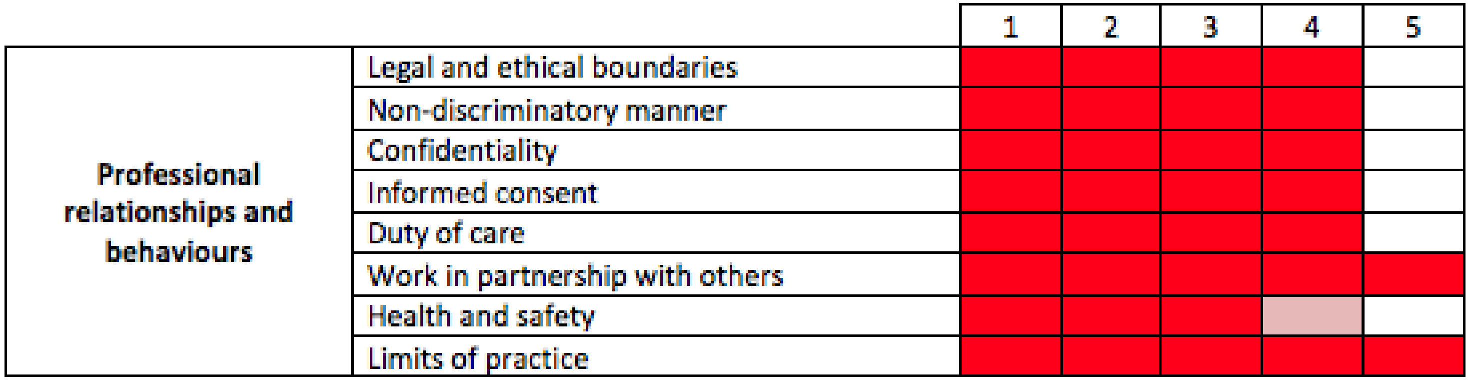


Figure 9. Professional relationships and behaviors (BASES). Current and desired proficiencies.

<u>Evidence</u>

- Accreditation from UKSCA, BASES, NSCA
- Operate as part of a multidisciplinary team
- Attend daily multidisciplinary team meetings
- Senior role, which requires leadership of other members of staff and department processes
- Engage in daily encounters with players and other members of staff and are confident in the interactions
- Experience of ethical submissions
- Completed BASES ethics workshop
- Initial exposure to formulating a collaborative agreement between the department and an academic institution

Research Proposal

Title:

The relevance of indicators of external load for a physiological evaluation of training in elite football

Background:

Football constitutes intermittent exercise in which the high intensity efforts are acyclical and therefore unpredictable (Reilly, 2005). It possesses high metabolic demands, with between 1200 and 1500 kcal (Bangsbo, 1994; Ekblom 1986; Mohr et al., 2005; Reilly & Thomas, 1979; Stolen *et al.,* 2005) reported as the energy required. It is estimated that 90% of this energy cost of soccer match play is from aerobic metabolism (Bangsbo, 1994), although, key match events, such as sprints, tackles and shots are supported by anaerobic activities (Hoff & Helgerud, 2004). It is recognised that match decisive moments are often preceded by a short, high intensity sprint in the range of 10-30m or 2-4sec (Spencer *et al*., 2005). The importance of these actions is demonstrated by the increased frequency and volume of sprints over recent years in the Premier League. Bush *et al.,* (2015) reported that over a six year monitored period from 2006/07 – 2012/13, sprints had increased by 50%, with the most substantial increase occurring in explosive sprints (125-171%).

The ability to achieve these high speeds along with the capacity to repeat

high-intensity exercise (Dellal *et al.,* 2009) and change direction while sprinting (Hader *et al.,* 2015) has been proposed as essential components of physical performance in team sports. It has been suggested, however, that a player's ability to repeatedly complete shorter accelerations, rather than reach maximal speeds, is the priority in competitive matches (Schimpchen *et al.,* 2016). This is largely supported within the previous literature, where it has been proposed that players complete between three (Bradley et al., 2009) and eight more accelerations than sprints (Varley & Aughley, 2013) during a match. These accelerations are often preceded with a deceleration to undertake changes of direction. It has been found that players complete more than 700 changes of direction in Premier League football matches (Bloomfield, 2007). Change of direction ability, therefore, has been shown to be a key determinant of team sport performance (Brughelli *et al*., 2008).
The demands of football matches appears to be generally well understood as the majority of time-motion research appears to centered around match play demands. If the gross training load that players experience is to be well understood, however, the associated internal and external training load relating to training demands must be comprehended. Football training rather than match play is associated with the largest portion of a players' total weekly training and match play time. It has been reported that it may be as high as 70% (Green *et al.,* 2013) to approximately 80% (Bangsbo *et al.*, 2006).

Of all training activities, it appears that training games such as possessions and small-sided games are the most common, with 33% of all weekly training and match play time associated with these activities (Green *et al.,* 2013). From the wide amount of small-sided game literature available it is apparent that this training format represents a common form of conditioning in football (Gaudino *et al.,* 2014). There are, however, many differences between the physical demands of this form of training and match play. Small-sided games are recognised to involve a greater amount of accelerations, decelerations and changes of direction compared to match play, however, match play is known to elicit greater max speeds and repeated sprint bouts (Hill-Haas *et al.,* 2011; Halouani *et al.,* 2014; Gaudino *et al*., 2014; Hodgson *et al.,* 2014). Due to the high volume of a player's time spent on the training field it is assumed that performance can be maximised with the application of scientific principles to training planning and structure. Due to these principles, the use of technology to monitor training load has grown exponentially (Malone *et al.,* 2015). Monitoring training load in players is essential to prevent fatigue related injuries (Ehrmann *et al.,* 2016) at the same time as maximising performance (Brink *et al.,* 2010). Impellizzeri *et al.,* (2005) proposes a conceptual model that explains that the outcome of training is the consequence of both internal and external stimuli. The external stimuli or training load is referred to as the totality of mechanical or locomotive stress generated by an individual when undertaking a bout of activity (Barrett *et al.,* 2014). The internal training load is the individual physiological response to the external training stressor (Booth & Thompson, 1991).

It is the methods to quantify external training load specifically that has progressed significantly in recent years. This has occurred as a consequence of the development of athlete tracking systems within team sports. In football, teams typically employ a combination of semi-automated multi-camera systems, local positioning systems and global positioning systems (GPS) to analyse external load (Malone *et al*., 2015). GPS based measures of total distance (TD), average running speed and distance covered above specified speed thresholds have been used to quantify physical performance in intermittent team sports (Scott *et al.,* 2013). Research suggests, however, that the reliability of GPS measured distance is decreased at high speeds (Scott *et al.,* 2013). The approach has also been suggested to be insensitive to the totality of mechanical stresses associated with team sports (Barrett *et al.,* 2014) due to its inability to quantify activities such as jumping, slide tackling and accelerating or decelerating (Ehrmann *et al*., 2016).

The commonly used GPS technologies are regularly accompanied with tri-axial accelerometer. Accelerometers may offer a measurement system that circumvents some of the limitations that exist with this method as it has a higher sampling rate and offers the potential to represent gross fatiguing movements, not just the locomotive activity (Boyd *et al.,* 2011). The most commonly utilised accelerometer based variable by practitioners is PlayerLoad. PlayerLoad is an arbitory unit that is derived from 3-dimensional measures of instantaneous change of acceleration (Barrett *et al.,* 2014). 2D PlayerLoad reflecting the mediolateral and anteroposterior directions has also been utilised within the literature as a marker of lateral changes of direction and stopping hard (Davies *et al*., 2013).

Unlike external training load, which is becoming easier to quantify due to advances in technology, internal training load remains difficult to measure in the applied environment of an intermittent sport (Desgorces *et al.*, 2007). Internal training load monitoring methods that are commonly adopted by football clubs are heart rate and perceptual monitoring methods. Two seminal heart rate monitoring methods proposed are HR-based training impulse (TRIMP) (Banister, 1991) and summated-HR-zones equations (Edwards, 1993). The perceptual questionnaire method, session-RPE (sRPE), proposed by Foster *et al*., (1995) is currently the only subjective measure of internal training load to have been widely adopted in team sports (Scott *et al*., 2013).

Internal and external methods of quantifying training load should not be utilised in isolation. The influence of one on another can be very informative to a practitioner and help inform a coach's decision. The concurrent utilisation will enable an indication of individualised training response, coping abilities, and training progression to be gathered (Scanlan *et al.,* 2014). Collecting these measures in combination enables a sport science practitioner working in football the ability to understand how the manipulation of training session's impact upon the physiological stress encountered by each player. Using internal and external training load models together might also ensure that a full picture of the training stress is gathered without monitoring method bias. It has been suggested that locomotive demands are not accurate for small-sided games (Gaudino *et al.,* 2014) and that heart rate alone appears to underestimate the intensity of short duration small-sided games (Ade *et al.,* 2014). Therefore, it may be proposed that locomotive, cardiovascular and mechanical load representing accelerations and decelerations needs to be taken into account (Gaudino *et al*., 2014).

It appears that the mechanical load quantification referenced is still in its infancy. The development of wearable tracking devices may allow the previously poorly reported metric to be measured practically and conveniently during football training sessions. It is well established that changing direction may alter the external load placed on players (Hewitt *et al*., 2011). External load monitoring methods such as GPS and metabolic power measurement are, however, constrained and there is an inability to monitor the taxing activities such as impacts, jumps and changes of direction (Barrett *et al.,* 2015). Due to these deficiencies, mechanical and metabolic responses to change of direction during football training remain unclear. A better understanding of the energy demands of unorthodox movement patterns, which categorise changes of direction, would therefore, be useful. The specific effect that different changes of direction angles and frequencies have on running performance and the associated physiological and perceptual responses have been poorly described (Buchheit *et al.,* 2012). It may be hypothesised that the progression of accelerometery technologies may allow the musculoskeletally demanding activities associated with change of directions and velocities to be more accurately measured to physiologically evaluate elite football training more accurately and efficiently. It is imperative that once established, the scientific principles founded are applied to the real life football environment to impact upon practice and performance. This will enable a more precise assessment of the external demands that currently occur in elite football and allow the proposal of a recommended model of perioidsation that could improve training structure and planning, therefore, maximising research implementation.

Aims & Objectives:

The current project aim is to examine the most relevant indicators of external load for developing an understanding of the physiological and musculoskeletal demands of elite football training.

Study 1 – To identify the relationship between external training load variables and the physiological responses to football training activities

Study 2 – To identify the relationship between external training load variables and the physiological responses when controlled football training activities are systematically manipulated

Study 3 – To determine the musculoskeletal demand periodisation strategies implemented within elite football

Study 4 – To propose a novel model of periodisation for elite football training

Project Proposal:

Study 1

Training data collected within the 2015/16 competitive season from a Premier League club will be analysed. The training data for all senior first team outfield players' (n=25) will be examined. All sessions were monitored with microelectromechanical systems (MEMS) tracking devices, which include GPS, accelerometer, gyroscope and magnetometer technology (Catapult S5, Australia) and heart rate monitors (Polar T31, Finland). Analysis was conducted with purpose built software (Catapult Openfield, Australia). The physical requirements of each drill completed will be studied using locomotive determinants (total distance, high intensity distance (>50% max velocity), sprint distance (>90% max velocity)), number and distance of GPS derived acceleration/ decelerations (>2m.s /<2m.s), heart rate (time> 85%HRmax, training impulse (TRIMP)), player load (PL) and its derivatives (3D PL, 2D PL, PL each plane, %PL within each plane) and other accelerometer based metrics (accelerations, decelerations). The physical determinants of each drill will be normalised for duration. The type (possession, SSG, technical, tactical, match play etc.), dimensions, number of players, pitch size per player and work: rest, were all uncontrolled, however, noted for each drill by a football coach and sport scientist.

The training data collated will be explored for associations between the internal training load (heart rate) and the external training load variables (locomotive, GPS derived acceleration/ decelerations and acceleratory derived metrics). A multiple correlation statistical analysis will be completed to attempt to identify, which external training load variables have the biggest impact upon internal training load in elite football training activities.

Study 2

An experimental study investigating how the systematic manipulation of external training variables may impact upon the internal training load. Elite under 21 outfield football players (n=20) from a Premier League club will participate in the study. The study will involve one initial testing day and two separate experimental occasions. The initial testing occasion will involve the completion of the 30:15 intermittent field based test (Buchheit, 2008). The termination velocity for each individual completing the test will inform the velocity based individualisation and prescription during experimental occasion 1.

Experimental occasion 1 will involve high intensity aerobic interval training bouts. The number and angle of the change of direction demands will be systematically manipulated. Locomotive based variables involving speed and distance will be controlled. Speed will be controlled using a high pitch audio signal that will be played every 10-seconds. This feedback along will provide participants with an indication of where they were required to be at a given time during the run. A 2-meter deceleration zone will be marked at every change of direction. Participants will be directed to only decelerate within the marked area.

Experimental occasion 2 will involve football specific aerobic interval training bouts. The type and pitch size of the drills will be systematically manipulated. The number of players, rules, coach encouragement and work: rest durations will be controlled by the investigator.

Each experimental condition will be monitored with GPS/ accelerometer devices (Catapult S5, Australia) and heart rate monitors (Polar T31, Finland). The training data will be analysised with purpose built software (Catapult Openfield, Australia). The physical requirements of each drill completed will be examined using locomotive determinants (total distance, high intensity distance (>50% max velocity), sprint distance (>90% max velocity)), number and distance of GPS derived acceleration/ decelerations (>2m.s /<2m.s), heart rate (time> 85%HRmax, training impulse (TRIMP)), player load (PL) and its derivatives (3D PL, 2D PL, PL each plane, %PL within each plane) and other accelerometer based metrics (accelerations, decelerations). Ratings of perceived exertion (RPE) will also be collected post each drill. This subjective rating will be multiplied by drill duration to provide a session-RPE (Foster *et al.,* 1995).

The training data collected will be explored for associations between the internal training load (heart rate and session-RPE) and the external training load variables (locomotive, GPS derived acceleration/ decelerations and acceleratory derived metrics). A one-way repeated measures ANOVA will be used to determine the effect that each testing protocol had on the dependent variables.

<u>Study 3</u>

A descriptive study of the seasonal external training load encountered by a Premier League football team across five previous competitive seasons. Study 1 and 2 will have informed the most relevant indicators of external load for developing an understanding of the physiological and musculoskeletal demands of elite football training. This study, therefore, will quantify the periodisation strategy employed by an elite professional football team for the identified training load indicator, across an annual season.

All senior first team outfield players' (n=25) data for each season will be analysed. All sessions were monitored with GPS/ accelerometer devices (Catapult S4/S5, Australia). Training data will be examined with purpose built software (Catapult Openfield, Australia). The data collected will be used to describe the mean weekly training load (microcycle) distribution across the whole season (macrocycle). The mean microcycle training load of each phase (mesocycle), preseason, early season, midseason and late season will be described. The external training load encountered within each microcycle (MD -1, -2, -3, -4, +1, +2 etc.) will be further described.

Several different coaching groups have been involved in the Premier League Club across the observed seasons. These different approaches to the programming of musculoskeletal demand across each season will, therefore, be discussed. In order to offer insight into the different approaches, examples of the types of drills delivered within each season will be displayed with the typical characteristics of these drills discussed.

Statistical analysis will be completed to attempt to identify how the external training load metric identified differs between seasons and within seasons. Data will be analysed using mixed linear modeling applied to the repeated-measures data. Particular attention will be given to the structure of the different microcycles adopted within each season. The statistical differences between weeks and days will be identified.

<u>Study 4</u>

An applied study, which will propose a novel model of periodisation for elite football training. The model will utilise the most relevant external load indicator of musculoskeletal demands identified from previous studies. The proposed model will provide a strategy to safely progress the musculoskeletal demands identified. The novel model of periodisation may be adapted to inform many football training practices. It is hoped that the model will aid the design of inseason training microcycles, preseason training progressions and field based rehabilitation, return to play schedules.

An applied document will be produced to inform microcycle design and prescription. An efficient weekly inseason loading pattern for preparedness on a matchday will be displayed. The content and prescription of each training day should be clearly outlined with a rationale and drill examples included. The report should be produced to ignite discussion between coaching, science and medical staff when planning inseason training.

<u>Facilities available for the investigation:</u>

All of the data collection will occur at West Bromwich Albion Football Club Training Ground. The equipment used to collect and analyse training data is owned and will be provided by West Bromwich Albion Football Club.

<u>Supervision:</u>

Director of studies:

Professor Barry Drust - *Professor in Applied Physiology, School of Sport and Exercise Sciences, Liverpool John Moores University*

Gantt Chart

Task	Activity	06/16	07/16	08/16	09/16	10/16	11/16	12/16	01/17	02/17	03/17	04/17	05/17	06/17	07/17	08/17	09/17	10/17	11/17	12/17	01/18
Systematic Review	Literature Search	■	■	■																	
	Literature Survey		■	■	■																
	Literature Report		■	■	■																
	WU Lit Review				■	■															
Applied 1	Operationalising				■	■															
	Data Collection						■	■													
	Data Analysis						■	■													
	WU Introduction						■	■													
	WU Methodology						■	■													
	WU Results								■												
	WU Discussion																■	■			
	WU Conclusion																■	■			
Study 1	Operationalising							■	■												
	Data Collection									■											
	Data Analysis									■	■										
	WU Introduction									■	■										
	WU Methodology									■	■										
	WU Results											■									
	WU Discussion																■	■			
	WU Conclusion																■	■			
Study 2	Operationalising											■									
	Data Collection												■	■							
	Data Analysis												■	■							
	WU Introduction												■	■							
	WU Methodology												■	■							
	WU Results														■						
	WU Discussion																■	■			
	WU Conclusion																■	■			
Applied 2	Operationalising											■									
	WU Introduction														■	■					
	WU Model														■	■					
	WU Discussion														■	■					
	WU Conclusion														■	■					
Thesis	WU Synthesis																		■	■	
	Complete Thesis																				■
Teaching & Training	Research Skills	■	■	■	■	■															
	M’ment Skills						■	■	■	■	■										
	Networking											■	■	■	■	■					
Professional Skills Log	Skills Log	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	WU Skills Log																			■	
Reflective Commentary	Reflections	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	WU Reflective Log																			■	
Viva Voce	Assessment																				■

Project Plan

My immediate project goals are to thoroughly search the literature, complete a detailed literature report and begin to formulate my systematic literature review. Although, I have begun these processes, I plan to take a step back and plan the process systematically. I will research how to complete a systematic review and critique a research paper in the correct manner and then progress the process from there. During this same period I plan to research various statistical approaches, ensuring that I am well informed when I come to plan the research design of each project. Throughout these steps I will maintain my regular reflections and skills log entries. I plan to front load my research skill development tasks so they can help inform the following research process.

Following these initial steps I then plan to spend the following 12-months planning and completing my data collection and analysis. I will work through each of my projects chronologically and systematically. This is because the results of each investigation will help inform the design of the following. I am aware that I have a busy inseason professional schedule so I have been generous with the time allocation I have attributed to each stage of the investigations. I have suggested that I will complete the writing of my introductions and methods alongside the data collection of each project. The rationale for this is two-fold. Firstly, it will ensure that I am writing continuously throughout the two-year period, which I feel is important for the development of these research skills that are currently unrefined. Secondly, as it will ensure that the research methodology has been efficiently formalised ahead of each data collection occasion. Following the completion of each investigation I will also write up my results while they are pertinent.

Alongside this 12-month research period I will also complete my management, networking and dissemination development tasks. I believe it is important that I look to progress my management proficiencies as soon as possible as they are skills that can improve my practice straight away. My networking and dissemination development will occur following this period as these traits are most relevant following the completion of my project work. It is important that I hone these skills before completion of my projects, however, as they will maximise my ability to gain impact from the sharing of my findings.

I plan to complete the writing up of each project discussion and conclusions towards the end of the two-year period. I feel that this will ensure that my writing skills have been well developed and that I can deliver my final findings succinctly and engagingly. Following these tasks I will collate all of work into a thesis and add the synthesis chapter, skills log and reflective log, ready for submission. I will continually complete the two logs throughout the two-year period so the accomplishment of these two elements will be straightforward at this stage. The final task I will face will be completion of the viva voce.

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9.2 THESIS TIMELINE

Task	Activity	06/16	07/16	08/16	09/16	10/16	11/16	12/16	01/17	02/17	03/17	04/17	05/17	06/17	07/17	08/17	09/17	10/17	11/17	12/17	01/18	02/18	03/18	04/18	05/18	06/18
Literature Review	Literature Search	■	■	■	■	■	■	■	■	■	■	■	■													
	Literature Survey	■	■	■	■	■	■	■	■	■	■	■	■													
	Literature Report	■	■	■	■	■	■	■	■	■	■	■	■													
	WU Lit Review				■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
Study 1 (Applied)	Operationalising					■	■	■																		
	Data Analysis								■	■	■	■	■	■	■	■										
	Produce Video																		■	■				■		
	WU Chapter																				■	■	■			
Study 2 (Scientific)	Operationalising								■	■	■															
	Data Analysis											■	■	■	■	■	■	■	■							
	WU Chapter																			■	■	■				
Study 3 (Scientific)	Operationalising									■	■	■														
	Data Collection												■													
	Data Analysis													■	■	■	■	■								
	WU Chapter																		■	■	■	■				
Study 4 (Applied)	Operationalising																			■	■					
	Plan Presentation																				■	■				
	Present																					■	■			
	Collect Feedback																					■	■			
	WU Chapter																							■	■	
Thesis	WU Synthesis																							■		
	Complete Thesis																								■	
Reflective Commentary	Reflections	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	WU Ref. Pauses																						■	■		
Viva Voce	Assessment Prep																								■	■

9.3 VIVA REFLECTIVE DIARY EXTRACT

Reflective Diary

Date: 14.08.2018

Scenario: Professional Doctorate Viva

- Description – what happened?

Today I completed my Professional Doctorate viva. The examiners were Mark Robinson (internal) and Tony Strudwick (external) and chair Barry Drust. It lasted two and a half hours and was broad discussion around my thesis, Professional Doctorate journey and wider themes. Mark framed a lot of his questioning around the scientific processes and biomechanical rationales to the thesis, while Tony took a broader applied angle, asking 'bigger picture' style questions. Some of the earlier questions were framed around my applied experience and rationale for the Doctorate engagement and related project. The questions then got into the detail of the studies and their dissemination. The final section largely revolved around the 'what next' and how I envisage sport science, monitoring and my research evolving in future years.

Following the completion of the viva, I was asked to leave the room while the examiners discussed my performance and their related feedback. I then got invited back into the room and each examiner gave me some feedback. Tony started by saying that although contextual, he thought that a lot of the performance problems that I identified were relevant across the industry. Tony suggested he would have no concerns in me discussing the content at level 8 level with a group of scientists or it within an applied setting to coaches, which demonstrated the breadth of my understanding. Tony also commented that I did a good job of consistently bringing the conversation back to applied context. Mark suggested he agreed with all Tony said and that I had a good balance of defending my work in the right manner, staying relaxed when under scrutiny and challenging some wider themes with my answers. Further Mark did highlight that for me to complete the work that I have, at the level I have alongside my professional roles within the tight timeframe was exceptional. The one improvement that Mark did identify is that although my rationale was clear from my research orientations, I didn't flow too well from my introductions into my aims in each study and if I was to go into peer review I would have to look to refine this.

Following getting some food and a drink Barry gave me some feedback too. Generally, he was very positive saying I did a good job. He suggested that all were really impressed with my breadth of knowledge saying that I demonstrate '70%' knowledge and understanding across the whole range of content. He did comment, however, that I could have looked to frame more of the discussions around scientific models and attempted to take a more conceptual view at times.

- Feelings – What were you thinking & feeling?

I was not as nervous as I anticipated. This may have been due to the fact that I was familiar with both assessors and I had a short amount of time with each of them informally ahead of the viva. I certainly felt as if I was composed and comfortable, enabling me to give as good an account of myself and of the research as possible.

Throughout the viva I felt I managed the situation well and it felt more like a critical discussion rather than an assessment or grilling, which must be a compliment to the environment created by Barry and the two assessors. I never felt particularly uneasy or unable to discuss the topics that were being proposed. This said it still was healthily challenging throughout. The time flew by and I was shocked when Barry gave us a time check of the last 30-min towards the end.

Following the end of the viva, my initial thoughts were that I had given a fair account of my project, knowledge and understanding, being relatively pleased with how it had panned out. This was cohobated further once I had received the feedback from the assessors. In fact, I was a little disappointed that I didn’t get something more constructive to improve the project and my performance. This then probably came when Barry offered his insights, as this delved a little more specifically into how I could have improved things.

- Evaluation – What was good & bad?

The environment and atmosphere created was a big plus, I thought it had a really good balance. I think this was largely the result of the two assessors chosen as both were very knowledgeable of their areas, fair and understood the difference between a PhD and Prof Doc. This was largely due to the work of Barry identifying appropriate individuals and then briefing them suitably of the expectations. The fact that one was an industry leader from the applied setting and the other a leading academic with a specific research background in accelerometers enables it to be a great combination and one that related to the Professional Doctorate rationale really effectively.

All of these factors allowed me to be happy and comfortable in the setting and, therefore, give a good account of the project and myself, which was really good. I think I, therefore, was able to talk openly around all themes posed. My clear communication style further enabled this.

It appeared that the feedback from the examiners specifically around the final dissemination study was really positive. They liked the structure of it and the fact that I captured feedback from attendees was a big plus.

I would, however, suggest that there was definitely areas that I could of improved on. These would largely be around the theoretical underpinning to some of the discussions and I could have hung comments around the available conceptual models a little more effectively rather than attempting to give applied examples. At times my applied experience and broader knowledge allowed me to feel I was giving good integrated responses but on reflection, probably at the expense of some real scientific detail. I think this was maybe largely due to the fact that the line of questioning was pretty broad and, therefore, I opted for broad responses instead of recognising when to zoom into the detail and give a more precise response before recognizing how this then linked to the broader contextual picture.

- Analysis – What sense can you make of situation?

Overall, I think the scenario gave me some confidence that the project was thematically well orientated and that I have developed personally so much in many aspects during the course of the program. There was a huge difference between how I critically analysed and articulated discussions compared to how I would have two and half years ago. I was also really pleased that lots of the content of the thesis stood up to the scrutiny of the examiners and it has encouraged me that some of the content may be suitable for peer review scientific publication. It was also good to get some clear direction around how I still need to develop as a researcher-practitioner, especially around my scientific writing and ability to zoom in and out of scientific details when in discussions of this nature. It appeared clear that I could have given myself a better opportunity to do this if I would have tried to established further clarification around some of the questioning and taken time to consider my thinking and responses more carefully before answering.

- Conclusion – What else could I have done?

I don't feel I could have prepared any more effectively. I do, however, feel I could have improved my performance in the viva by taking more time to clarify some of the questioning and taken further time to clearly map out my responses before beginning my response as it was evident I was at times thinking while speaking. I could also have had some key theoretical scientific models in mind that would have allowed me to hang some concepts and applied examples to more effectively.

In regard to the thesis I could have improved the flow and scientific writing specifically around the introductions to each study. I could have also improved the study design of study three by controlling for speed in running and dribbling conditions.

- Action plan – What would I do next time?

The two key areas I would look to improve upon would be trying to understand and clarify the question more effectively along with considering my response in advance of relying. Secondly, I would have considered and shared more scientific models when talking about specific principles and applications. I think these two factors would have allowed me to zoom in and out of each theme, getting a good balance of seeing the big picture at the same time of getting into the detail of an area.