Monitoring and prescription of GPS training load in elite academy soccer athletes

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A thesis submitted in partial fulfillment of the requirement of University of Brighton for the degree of Doctor of Philosophy

August 2018

Abstract

Application of global positioning system (GPS) technology is poorly understood within soccer, with limited consideration of the individual or population. The current thesis investigated an individualised approach to monitoring and prescription of training load in elite academy soccer. Study One, Study Two and Study Three focused upon individualising the training load monitoring process. Study Four and Study Five progressed the focus to the individual prescription of training load for soccer athletes.

Global speed thresholds have typically been utilised to classify high-speed locomotion, masking important information regarding the relative intensity. Study One examined discrepancies between global and individual thresholds when monitoring high-speed locomotion. GPS data was collected for 19 Premier League academy soccer athletes, over a six-week period. For each athlete and training session, high-speed running (HSR), very high-speed running (VHSR), and sprinting (SPR) distances were calculated using both global and individual thresholds. Athletes were sub-divided into high (HI_{MAS}), medium (ME_{MAS}), and low (LO_{MAS}) maximum aerobic speed groups. In LO_{MAS} athletes, individual thresholds produced higher HSR, VHSR and SPR distances compared to global. In HI_{MAS} athletes, individual analysis method produced 549m less HSR, and 341m less VHSR distance compared to global. Global thresholds produced high-speed locomotion distances significantly higher, or lower than individual thresholds for 47% of athletes, suggesting that using field tests to individualise speeds thresholds will allow accurate quantification of individual athlete intensity.

Study Two examined discrepancies between global and individual thresholds when quantifying acceleration tasks. Thirty-one elite soccer athletes were studied over a four-week period. For each athlete and training session: low-, moderate-, and high-intensity acceleration distances were calculated using both global and individual thresholds. Athletes were sub-divided into high (HI_{ACC}), medium (ME_{ACC}), and low (LO_{ACC}) maximum accelerative capacity groups. For ME_{ACC} athletes, moderate- and high-intensity acceleration distances were significantly higher utilising global thresholds compared to individual. For HI_{ACC} athletes, significantly higher distances were produced utilising global thresholds, for low-, moderate-, and high-intensity acceleration. Findings highlighted the discrepancies between

acceleration distances calculated utilising global and individual thresholds, and the variation in discrepancies between athletes of differing physical capacities.

Quantifying the physical demands elicited upon playing positions during soccer competition is vital for training prescription purposes. As a novel research question, Study Three examined total distance, high-speed locomotion, maximum speed, and acceleration demands of playing positions during competition. To provide further accuracy and insight, high-speed locomotion and acceleration thresholds were individualised, and sub-divided by intensity. GPS metrics were collected for 37 soccer athletes across 44 competitive matches. Athletes were sub-divided into five playing positions, with GPS metrics analysed between playing positions. Results demonstrated central defenders produced the lowest values for all GPS metrics. Wide attackers and wide defenders produced significantly higher sprinting, and high-intensity acceleration distances compared to all other positions. Central midfielders produced significantly higher total and moderate-intensity acceleration distances compared to all other playing positions. This study was the first to provide a holistic overview of the relative demands placed upon playing positions, demonstrating the individual nature of soccer competition.

Soccer training games are popular conditioning modalities, however research is yet to analyse training game demands relative to positional demands of competition, or differentiate between average and peak demands. Study Four investigated how different training game interventions affected the average and peak demands elicited upon soccer playing positions relative to their competitive demands. GPS and rating of perceived exertion (RPE) data was collected for 46 soccer athletes over a season. Athletes were sub-divided into five playing positions, with positional data collected for 22 matches and 39 training game sessions. Average and peak GPS metrics, and RPE were compared between training games and competition for each playing position. Findings demonstrated that although medium and large training games elicited average total distances significantly higher than competition, when comparing peak total distances, all game formats were significantly lower. This was also evident with very high-speed running and sprinting intensities. Results highlight the importance of analysing physical outputs of training games relative to peak demands of competition. Findings provide coaches the ability to prescribe game formats to playing positions specific to their positional requirements.

A novel alternative to age and weight categories for youth competition involves 'bio-banding' athletes using maturation groups. Study Five investigated physical and technical performance during bio-banded and chronological soccer competition intervention for athletes of varying maturation status, yet to be examined by literature. Twenty-five male soccer athletes, aged 11-15 years and 85-90% of predicted adult stature, were divided into early, on-time, and late developing athletes. Athletes competed in both bio-banded and chronological age group competition. Four physical performance metrics, and six technical performance metrics were analysed to determine differences between maturation statuses, competition format, and the interaction. For early developers, bio-banded produced significantly more short passes, dribbles, and a higher RPE than chronological. For on-time developers, bio-banded produced significantly more short passes, dribbles, and less long passes than chronological. For late developers, bio-banded produced more tackles, and less long passes than chronological. There were no significant differences identified for total, sprinting, or acceleration distances between competition formats. Findings demonstrate bio-banded competition increased the technical emphasis placed upon athletes of varying maturation statuses, without reducing the physical demands. Consequently, competition formats can be prescribed to athletes of differing maturity statuses, dependent upon their developmental needs.

The current thesis makes numerous original contributions to individualising training load monitoring and prescription. Findings provide significant implications for applied practitioners aiming to develop the specificity of training for professional soccer athletes. The thesis provides a strong rationale for individualising speed and acceleration thresholds to monitor the relative demands placed upon individual athletes. Field based protocols were used to determine individual thresholds, allowing applied practitioners cost and time effective methods for implementation. The thesis was the first to identify the holistic positional demands elicited by soccer competition, in addition to manipulating training game format to examine average and peak demands elicited upon playing positions relative to competition. Finally, the thesis was the first to demonstrate the impact of bio-banding on the physical and technical demands of soccer.

Publications

Peer reviewed publications arising from this course of investigation

Abbott, W., Brickley, G., & Smeeton, N.J. (2018). An individual approach to monitoring locomotive training load in English Premier League academy soccer players. *International Journal of Sports Science & Coaching, 13(3),* 421-428.

Abbott, W., Brickley, G., Smeeton, N.J., & Mills, S. (2018). Individualizing acceleration in English Premier League academy soccer players. *The Journal of Strength and Conditioning Research, 32(12),* 3503-3510.

Abbott, W., Brickley, G., & Smeeton, N.J. (2018). Physical demands of playing position within English Premier League academy soccer. *Journal of Human Sport & Exercise, 13(2),* 1-11.

Abbott, W., Brickley, G., & Smeeton, N.J. (2018). Positional differences in GPS outputs and perceived exertion during soccer training games and competition. *The Journal of Strength and Conditioning Research, 32(11),* 3222-3231.

Peer reviewed publications arising from research conducted alongside this course of investigation

Abbott, W., Brownlee, T.E., Harper, L.D., Naughton, R.J. & Clifford, T. (2018). The independent effects of match location, match result and the quality of opposition on subjective wellbeing in under 23 soccer players: a case study. *Research in Sports Medicine, 26(3),* 262-275.

Clifford, T., **Abbott, W**., Kwiecien, S.Y., Howatson, G, & McHugh, M.P. (2018). Cryotherapy re-invented: Application of phase change material for recovery in elite soccer. *International Journal of Sport Physiology and Performance, 13,* 584-589.

McHugh, M.P., Clifford, T., **Abbott, W**., Kwiecien, S.Y., Kremenic, I.J., DeVita, J.J., Howatson, G. (2018). Countermovement jump recovery in professional soccer players using an inertial sensor. *International Journal of Sport Physiology and Performance, Publish Ahead of Print.*

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Abbreviations and Explanations

The following abbreviations have been defined in the text in the first instance.

GPS	-Global Positioning System
RPE	-Rating of Perceived Exertion. Utilising the modified CR10 Borg scale (Borg, 1982).
Global thresholds	-Application of the same thresholds to all athletes. This can be to quantify high-speed locomotion (Study One), or acceleration (Study Two).
Individual thresholds	-Application of individual specific thresholds to athletes. This is determined by maximum aerobic speed and maximum sprint speed performance (Study One), or maximum accelerative capacity (Study Two).
MAS	-Maximum aerobic speed.
MSS	-Maximum sprint speed.
ASR	-Anaerobic speed reserve.
$v\dot{V}O_{2max}$	-Velocity at $\dot{V}O_{2max}$.
LO_{MAS}	-Low maximum aerobic speed (< 1 *SD* from group mean). This criteria was used to sub-group athletes within Study One.
ME_{MAS}	-Medium maximum aerobic speed (± 1 *SD* from group mean). This criteria was used to sub-group athletes within Study One.
HI_{MAS}	-High maximum aerobic speed (> 1 *SD* from group mean). This criteria was used to sub-group athletes within Study One.
HSR	-High-speed running.
VHSR	-Very high-speed running.
SPR	-Sprinting.
LO_{ACC}	-Low maximum accelerative capacity (< 1 *SD* from group mean). This criteria was used to sub-group athletes within Study Two.
ME_{ACC}	-Medium maximum accelerative capacity (± 1 *SD* from group mean). This criteria was used to sub-group athletes within Study Two.
HI_{ACC}	-High maximum accelerative capacity (> 1 *SD* from group mean). This criteria was used to sub-group athletes within Study Two.

LSG	-Large training game, characterised as 10v10, 9v9, 8v8, or 7v7 plus goalkeepers. Used to sub-divide training methodologies within Study Four.
MSG	-Medium training game, characterised as 6v6, 5v5, or 4v4 plus goalkeepers. Used to sub-divide training methodologies within Study Four.
SSG	-Small training game, characterised as 3v3, 2v2, or 1v1 plus goalkeepers. Used to sub-divide training methodologies within Study Four.
Early developer	-Maturity Z-score > 1. Used to sub-group athletes within Study Five.
On-time developer	-Maturity Z-score -1 to +1. Used to sub-group athletes within Study Five.
Late developer	-Maturity Z-score < -1 Used to sub-group athletes within Study Five.
Bio-banded	-Soccer competition with teams grouped by level of maturation.
Chronological	-Soccer competition with teams grouped by age.

Acknowledgements

First and foremost, I would like to express my gratitude to my supervisors Dr. Gary Brickley and Dr. Nicholas Smeeton for their help and guidance throughout the PhD. Both of you have been invaluable throughout this process, and I have learnt a significant amount under your tutelage.

I would also like to thank my family. John, Juliet, and Steph Abbott - without your continued support I would not be in the position I currently am. This is as much a collective achievement for us all as it is for me. Kathryn Newbon – thank you for your support, your understanding, and your patience with this ongoing obsession!

Thank you to all the staff and players at Brighton and Hove Albion FC for your cooperation and participation throughout data collection. Finally, thanks to the colleagues and friends who inspired me to always challenge my beliefs and current practices, and who helped create the desire to embark upon my research journey.

Contents

1.0 Introduction

1.1 Introduction

Due to the competitive nature of soccer, both on and off the pitch, teams are constantly searching for tools to gain a competitive advantage. The significant financial incentives associated with success result in organisations placing a large emphasis on identifying tools to improve performance. Technological improvements, coupled with a continued search for competitive advantage, have led to an increased use of technology within elite soccer environments. Technology, such as global positioning system (GPS) devices, are now common within most sporting organisations. GPS devices provide a wealth of information for sport science practitioners and coaches, with the aim of improving training monitoring and prescription processes, and gaining competitive advantages. With vast sums of data available, and a number of potential methods to conduct analysis, it is vital data is collected and analysed with accuracy and validity. To accurately and effectively monitor and prescribe training load, and positively affect soccer training, the correct processes must be applied. This is increasingly important given the shift towards an individual approach to training. Emerging research acknowledges the individual nature of the training process, and consequent requirement for an individual approach to training load monitoring and prescription.

Distance travelled performing high-speed locomotion tasks (e.g. high-speed running, very high-speed running, and sprinting) has received significant attention when investigating training load (Bradley et al., 2009; Di Salvo et al., 2010). Faude et al. (2012) highlighted the importance of high-speed locomotion by stating straight-line sprinting is the most dominant action performed when scoring goals. Considering sprinting tasks are associated with impaired muscle function, and increased perceived muscle soreness, the volume of sprinting completed has implications upon recovery time and injury risk (Howatson & Milak, 2009). It is therefore important that high-speed locomotion is quantified accurately (Carling, 2013). Typically, global speed thresholds have been utilised to band high-speed locomotion in applied environments. These thresholds are suggested to mask important information regarding the relative intensity an individual is working (Hunter et al., 2015). Recently, individual speed thresholds have been developed, however many are time consuming, expensive, and require access to facilities and expertise to administer (Lovell & Abt, 2013). This creates barriers for applied practitioners working with large squads of athletes. In addition, researchers have utilised varying methodologies to test and individualise athlete's speed thresholds. Abt and Lovell (2009) utilised the second ventilatory threshold to determine ‘high-intensity’ thresholds for individual athletes. Rationale was that the threshold marked the transition from moderate to high-intensity exercise. Gabbett (2015) utilised field tests to individualise speed thresholds, incorporating athlete’s maximum sprint speed. To increase the specificity of speed thresholds, researchers have recently incorporated multiple markers of athlete’s physical capacity to individualise the monitoring process. Hunter et al. (2015) and Mendez-Villanueva et al. (2013) recently applied this to youth athletes, utilising athlete’s functional limits of endurance and sprint locomotor capacities. Unsurprisingly, differences in methodologies within previous research have led to varying conclusions, requiring further investigation.

Despite having an important role in the monitoring process, soccer training load should not focus solely upon high-speed locomotion. Doing so neglects metabolically demanding tasks such as acceleration. An athlete’s ability to accelerate quickly is suggested to be vital for on field performance, in addition to being important underlying factors for muscular fatigue (Greig & Siegler, 2009; Lockie et al., 2011). Similar to high-speed locomotion, in the majority of applied environments global acceleration thresholds are utilised to band and quantify acceleration tasks. Considering the highly individual nature of the exercise continuum, it is difficult to accurately assess the relative intensity of acceleration tasks without accounting for an individual’s accelerative capacity. Recently, Sonderegger et al. (2016) devised individual acceleration thresholds using individual’s maximum accelerative capacity. This was the first study to devise individual acceleration thresholds, and focused upon investigating acceleration values produced at various initial running speeds. The protocol utilised was field based, meaning it could be replicated with large squads, and minimal equipment. Research is yet to investigate discrepancies between global and individual thresholds when quantifying acceleration tasks, requiring further investigation.

Extensive research has focused upon quantifying the physical demands of playing positions during soccer competition (Bangsbo et al., 2006; Molinos, 2013). This is vital for training prescription purposes, with training aiming to replicate or exceed competitive demands (Hodgson et al., 2014). Research has demonstrated the physical demands elicited upon playing positions differ significantly (Molinos, 2013). Central defenders and strikers are suggested to produce the lowest total distances, with central midfielders producing the highest (Dellal et al., 2012; Guadino et al., 2010). When investigating high-speed activities, research demonstrated wide players produced the highest sprinting and high-intensity running distances, with central players producing the lowest (Carling, 2013). Research has primarily focused upon total, and high-speed distances, neglecting metabolically demanding actions such as accelerating. Additionally, previous studies focusing upon high-speed locomotion and acceleration tasks have utilised global thresholds, neglecting the relative intensity of activities produced by athletes. Previous research has also failed to sub-divide acceleration tasks dependent upon intensity. Consequently, there is rationale for thorough investigation to determine the exact physical demands elicited upon soccer playing positions. This information is vital for applied practitioners aiming to prescribe specific soccer training and improve competitive performance.

Considering the differences in physical demands placed upon soccer playing positions, an individualised approach to training must be adopted. Soccer training games are popular amongst coaches, allowing for physical, technical and tactical aspects to be trained simultaneously (Castellano & Casamichana, 2013; Davies et al., 2013). Training games can be manipulated to alter the physical stimulus elicited upon athletes. One manipulation is game size, with large, medium, or small training games suggested to alter the stimulus (Hill-Haas et al., 2011). Despite investigating the physical outputs produced during different training game formats, research is yet to relate findings to positional demands of competition. Considering the varying demands elicited upon soccer playing positions, and the consequential individual training requirements, it is vital training is assessed relative to individual's competitive demands. In addition, previous research investigating competitive physical demands elicited upon playing positions has focused upon the average demands (Domene, 2013). This has also been the case with research investigating the physical demands of training games (Castellano et al., 2013; Owen et al., 2014). Focusing upon the average demands of competition results in important information regarding the peak demands of competition being overlooked. If athletes are trained to meet the average demands of competition, they could be underprepared for the most demanding periods of play (Gabbett, 2016). Research suggests the most demanding periods of play often coincide with scoring or conceding goals (Barnes et al., 2014; Faude et al., 2012). Consequently, it is vital the peaks demands of competition and training are analysed in addition to the average demands.

In an attempt to individualise the prescription of competition, allow equal opportunity, and reduce injury risk, a number of sports have introduced age categories (Figueiredo et al., 2010). However, grouping soccer athletes by age has led to significant complexities related to inter-individual variations, termed the relative age effect (Albuquerque et al., 2012; Del Campo et al., 2010). The relative age effect relates to a high proportion of soccer athletes being born earlier in the competitive year, and has been reported in both youth and professional teams (Del Campo et al., 2010; Helsen et al., 2005; Meylan et al., 2010). The increased strength, weight, and size of relatively older athletes increase the likelihood of selection and retention within the sport (Delorme, 2014; Hirose, 2009). The relative age effect has been viewed as discriminatory against younger athletes born later in the competitive year, and is a concern for professional soccer (Edgar & O'Donoghue, 2005). An alternative, novel solution to chronological age groups, are 'bio-banded' groups of athletes with similar levels of growth or maturation (Delorme, 2014). To date, one piece of research has focused upon the effect of bio-banded competition. Cumming et al. (2018) investigated Premier League academy players' experiences of participating in bio-banded soccer competition, using qualitative data. Athletes perceived there was an increased emphasis upon technique, tactics, and teamwork during bio-banded competition. In addition, early developers perceived bio-banded competition as an increased physical stimulus. Currently, there has been no quantitative evidence as to the effects of bio-banding upon physical and technical performance during competition.

The overarching objective of this thesis was to examine an individualised approach to monitoring and prescribing training loads in professional soccer. This was addressed in five experimental chapters, which aimed to:

1.) Analyse the discrepancies between global and individual speed thresholds in monitoring high-speed locomotion during soccer training and competition.

2.) Analyse the discrepancies between global and individual acceleration thresholds in monitoring acceleration tasks performed during soccer training and competition.

3.) Quantify the physical demands placed upon soccer playing positions during competition.

4.) Examine the effect of training game format upon average and peak physical outputs produced by soccer playing positions.

5.) Quantify the effects of bio-banded and chronological competition upon physical and technical performance, for early, on-time and late developing athletes.

1.2 Organisation of Thesis

This thesis is presented in nine main chapters. The review of literature (Chapter Two) examines all available studies focusing upon the following areas:
-Validity, reliability, and use of GPS within sport.
-Individualising speed and acceleration thresholds.
-The physical demands of soccer competition.
-Effect of match outcome upon competitive physical outputs.
-Manipulation of soccer training games as training modalities.
-Growth and maturation of youth athletes.
-Application of bio-banding within sport.
Throughout the literature review, special reference is provided to individualising training load monitoring and prescription specific to individual athlete’s characteristics and requirements.

The general methods (Chapter Three) provide details on the following procedures and processes:
-Participant recruitment
-Participant exclusion criteria
-Data collection procedures
-Participant preparation and warm up procedures
-Physical and technical metrics collected
-Speed and acceleration thresholds
-Physical performance testing procedures
-Athlete groups
-GPS data analysis
-GPS data quality and accuracy
-Data exclusion criteria
-Technical data analysis
-Statistical analysis

Chapter Four (Study One) investigated the discrepancies between global and individual speed thresholds when quantifying high-speed locomotion. The aim was to determine the extent of the discrepancies between analysis methods, and whether discrepancies were uniform for athletes of differing physical capacities.

Chapter Five (Study Two) identified the discrepancies in acceleration distances produced using global and individual thresholds. The aim was to determine whether discrepancies varied dependent upon acceleration intensity, and maximum accelerative capacity.

Chapter Six (Study Three) compared the physical demands of competition for different soccer playing positions. The study also examined the effect of match outcome upon the physical outputs of playing positions. The aim was to provide position specific recommendations for training intensities.

Chapter Seven (Study Four) examined the effect of training game format upon physical outputs produced by soccer playing positions. The study assessed both average and peak physical demands of training games relative to positional demands during competition.

Chapter Eight (Study Five) investigated the effect of bio-banded competition upon physical and technical performance. Differences in performance during bio-banded and chronological competition was analysed for athletes of differing maturation status.

The general discussion (Chapter Nine) provides an overview of the thesis findings. The findings relate to an individualised approach to monitoring and prescribing GPS training load within elite academy soccer athletes.

2.0 Review of Literature

2.1 Training Load Monitoring Techniques

Training is a process of adaptation resulting from progressive and careful manipulation of training load (Guadino et al., 2010). To be successful, accurate analysis of both squad and individual training load is required (Casamichana et al., 2012; Gomez-Piriz et al., 2011). An insufficient training stimulus could result in a reduction in cardiovascular fitness, whilst an above optimum training stimulus could result in injury occurrence. Typically, methods such as session ratings of perceived exertion (RPE) and heart rate monitoring have been used to assess session intensity (Hill-Haas et al., 2011). RPE is a subjective measure of training intensity that utilises the 1-10 Borg Scale (Scott et al., 2013). It is widely adopted in team sports due to its ease to administer. RPE is inclusive of factors such as work completed, illness, injury, and psychological conditions. Heart rate monitoring has traditionally been used as a method to assess the physiological requirements of exercise. It is typically reported as the time spent in relation to maximum heart rate (Dellal et al., 2012). Research has found significant correlations between RPE and heart rate monitoring when assessing soccer session intensity (Casamichana et al., 2012; Impellizzeri et al., 2004). More recently however, questions have been raised regarding the sensitivity of heart rate in quantifying the intermittent demands of sport (Castellano et al., 2013; Domene, 2013; Hodgson et al., 2014). Scott et al. (2013) state that heart rate monitoring is a useful method for monitoring aerobic energy production, however for training methods utilising anaerobic energy production, demands are not accurately reflected. Considering soccer is a sport dominated by explosive actions, it is vital for the training monitoring process that these actions are quantified. The recent emergence of global positioning system (GPS) and accelerometer technology has offered a highly practical way of monitoring the external training load of soccer (Casamichana et al., 2012). GPS devices measure position, velocity and acceleration, of which, a range of metrics are available to quantify external load. The ability to objectively quantify external training load is suggested to be a vital aspect of athlete monitoring (Cardinale & Varley, 2016). In contrast to heart rate and RPE, GPS devices allow for soccer specific actions and movements to be quantified and recorded.

2.2 Background to GPS

Due to the competitive nature of soccer, organisations are constantly searching for tools to gain a competitive advantage. A process that has recently gained momentum in sport science is the use of technology to monitor training load. This is likely due to rapid advances in technology, and increased availability (Cardinale & Varley, 2016). Consequently, athlete tracking devices consisting of GPS and micro electrical mechanical systems are now common within most sporting organisations (Malone et al., 2017). The basic components of GPS technology provide information on total distance, speed, and acceleration, which can be utilised to quantify external workload completed by athletes. This provides practitioners with a wealth of options, including quantifying exertion and physical stress placed upon athletes, assessing positional workloads during training or competition, or monitoring changes in athlete's physical capacities (Cummins et al., 2013). The integration of GPS with triaxial accelerometers has allowed for measurement of accelerations in three axes, providing information on the direction of acceleration tasks. Figure 2.1 provides an example of how the direction and intensity of acceleration tasks can be quantified and presented using Catapult Sprint (Catapult Sprint 5.1.5, Catapult Innovations, Melbourne, Australia) software. Further analysis of speed data can be conducted by banding locomotion using activity bands. This technology allows for detailed analysis into the specific physical demands and activity profiles of competition and training (Aughey, 2011). As a consequence, specific training programs can be developed to maximise improvements, and optimise competitive performance (Cardinale & Varley, 2016). There are limitations associated with GPS technology however. Hardware and software is expensive, analysis is time consuming, and dedicated staff members are required to lead the analysis. In addition, GPS devices are unable to quantify activities such as ball striking, wrestling and grappling.

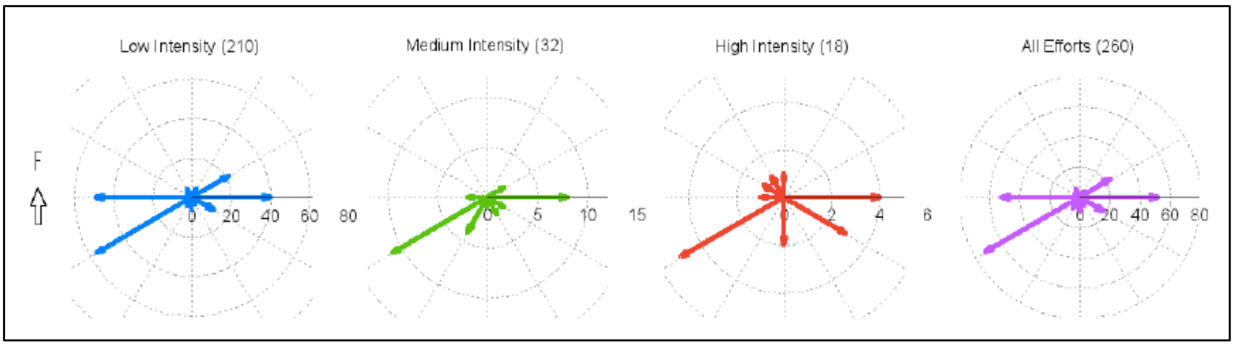

Figure 2.1. Example report quantifying the intensity and direction of acceleration tasks.

Considering its widespread use within applied sporting environments, it is vital that practitioners are aware of how GPS data is derived. This relates to how data is generated, factors affecting validity and reliability, and the impact of changing hardware and software (Malone et al., 2017). GPS is essentially a satellite navigation network, providing location and time information for the tracking devices. These were initially developed for military purposes, however are now commercially available. Satellites orbit the Earth, sending precise time information via an atomic clock to the GPS receivers (Malone et al., 2017). The duration of time taken for the radio signal to travel from the satellite to GPS receivers is used to determine distance from the satellite. Using a minimum of four satellites connected to the receiver, exact location of the receiver can be triangulated. Displacement can then be calculated to determine speed of movement (Aughey, 2011).

2.3 GPS Validity and Reliability

Athlete tracking technology is continually being developed. Advancements in technology are typically followed by validity and reliability investigations within the research. Validity of the technology relates to the ability to accurately measure the intended variables (Scott et al., 2015). In applied environments, the accurate quantification of exercise is vital to the prescription and feedback process. Reliability of technology reflects the ability to reproduce values on repeat occasions (Scott et al., 2015). This is important within applied environments as it allows for comparison between sessions, and between athletes. Often, technology is utilised within sport prior to the necessary validation and reliability information being obtained. GPS devices are manufactured with various sampling rates, which relates to the speed at which the unit gathers data. The majority of validity and reliability research has been conducted on devices with 1-Hz, 5-Hz, and 10-Hz sampling rates. Previous research has raised issues regarding the reliability of the 1-Hz and 5-Hz GPS units when measuring high-intensity accelerations, decelerations, and changes of direction (Aguiar et al., 2013; Boyd et al., 2013). In a recent review of the validity and reliability of GPS in team sport, Scott et al. (2015) state that although all devices were able to accurately quantify distance, 1-Hz devices had limitations with accurately quantifying short distance high-intensity sprinting (standard estimate of error = 9.0 - 32.4%, moderate-poor validity). Although recent research suggests 5-Hz GPS devices have overcome said limitations with short distance high-intensity sprinting, there are still issues associated with movements involving changes of direction (standard estimate of error = 9.9 - 11.5%, moderate-poor validity) (Scott et al., 2015).

However, current advances in software and the availability of 10-Hz GPS and 100-Hz accelerometer devices, have allowed for a greater accuracy and reliability when collecting data (Akenhead et al., 2013; Cummins et al., 2013). Scott et al. (2015) conclude that 10-Hz GPS devices have the ability to repeatedly report short distances at high speeds with good to moderate intraunit reliability (mean coefficient of variation = 5.1%), therefore overcoming the previous issues encountered with 1-Hz and 5-Hz units. Recent research conducted by Delaney et al. (2017) provides further evidence, stating 10-Hz devices exhibit coefficient of variation of 1.2 - 6.5% when assessing acceleration and deceleration. As a consequence, it is suggested that the latest 10-Hz devices produce sufficient accuracy to quantify acceleration, deceleration, and constant velocity movements within team sports (Scott et al., 2015; Varley et al., 2012). Therefore, current literature has demonstrated the vast majority of activities and tasks associated with soccer can be accurately quantified, and training load calculated. An issue that remains however, is that of inter-unit reliability. Research has demonstrated that intra-unit reliability of devices is higher than inter-unit reliability. Therefore, it is recommended that athletes wear the same device when tracking over multiple sessions, to reduce the associated error.

2.4 High-speed Locomotion in Soccer

During soccer competition, only 1 - 4% of locomotion distance is spent 'sprinting'. The mean distance of an individual sprint is 10 – 20 metres, with a mean duration of 2 – 3 seconds (Spencer et al., 2005). Despite its infrequent nature, it typically occurs during the most significant moments of competition (Barnes et al., 2014; Faude et al., 2012). For example, scoring a goal, or preventing a shot on target (Guadino et al., 2010). To summarise athlete locomotion, activities are banded using speed thresholds. These are typically attributed subjective descriptions of movement and designated a specific speed band. Examples are walking, jogging, running, high-speed running, very high-speed running, and sprinting (Akenhead et al., 2013; Carling, 2013). Presently there are no consistent definitions for speed bands, making comparisons between research difficult (Dwyer & Gabbett, 2012). In addition to inconsistent speed thresholds used throughout research, another issue is the application of global thresholds to athletes of varying ages and maturation. Global refers to the application of the same speed thresholds systematically to all athletes. Although global speed thresholds allow coaches to compare absolute workload completed by athletes, they are suggested to mask important information relating to the relative intensity an individual is operating

(Hunter et al., 2015). Each individual's internal response varies for the same external demands, and result in differing degrees of adaptation. Individual variations are even more pronounced when monitoring athletes of different ages and maturation levels (Gabbett, 2015). Due to inherent physiological, biomechanical, and metabolic differences during exercise, speed thresholds based upon post-pubescent athletes may not be suitable for pre-pubescent athletes (Cummins et al., 2013). For example, post-pubescent athletes are demonstrated to have increased muscle mass when compared to pre-pubescent athletes, resulting in greater levels of maximal strength, power output, and sprinting performance (Meylan et al., 2010). The highly complex and athlete-specific factors influencing locomotion mean that there is the potential for large error in training load calculation when using global speed thresholds (Lacome et al., 2014). As a consequence, application of global speed thresholds may result in an inadequate reflection of training load for the majority of athletes within a squad (Abt & Lovell, 2009; Cummins et al., 2013).

Having identified the disadvantages associated with global speed thresholds, researchers attempted to individualise thresholds using various physical performance markers (Abt & Lovell, 2009; Hunter et al., 2015; Mendez-Villanueva et al., 2013). For example, previous research has used gas ventilatory thresholds (Abt & Lovell, 2009; Hunter et al., 2015; Lovell & Abt, 2013), or maximum sprint speed (Gabbett, 2015) as methods to individualise locomotion for individual athletes. For applied practitioners, the identification of gas ventilatory thresholds provides an issue. With access to facilities, equipment, and staff necessary to accurately administer the tests, this proves expensive, time consuming, and infeasible to many practitioners. Another limitation of previous research is that only single performance markers were used to determine individual thresholds, reducing the accuracy of thresholds. In contrast, Hunter et al. (2015) and Mendez-Villanueva et al. (2013) used athlete's aerobic and anaerobic locomotor capacities to individualise speed thresholds. Both studies used field tests to determine maximum aerobic, and maximum sprint speeds, providing applied alternatives to laboratory testing. Research by Mendez-Villanueva et al. (2013) was conducted using youth soccer athletes however, limiting application of the results. Direct application to elite adult soccer players may be limited due to biomechanical and physiological differences caused by maturation. Hunter et al. (2015) presented research as a case study, with limited participants. Therefore, results may not be applicable to large squads of athletes demonstrating varying physical capacities. When critiquing the data analysis, both studies focused solely upon competition, and did not include training within their analyses. Given that the majority of training load is accumulated during training scenarios, there is significant rationale for including training within the monitoring process. Currently, no research has focused on the use of field tests to individualise training load in an elite adult soccer population. As a consequence, there is rationale for further research into high-speed locomotion training load. Due to the reported inaccuracies associated with global speed thresholds, and the highly individual nature of athlete locomotion, an individualised approach is often recommended to improve the training monitoring process for individual athletes.

2.5 Acceleration Manoeuvres in Soccer

Despite having an important role, soccer training load should not focus solely upon monitoring high-speed locomotion. Focusing upon high-speed locomotion neglects metabolically demanding tasks occurring at low speed, for example acceleration (Akenhead et al., 2013; Osgnach et al., 2010). To highlight the frequency and importance of acceleration, research reported a three- to eight-fold greater number of accelerations compared to sprints during competitive match-play (Varley & Aughey, 2013; Dalen et al., 2016). With the average sprint during soccer lasting approximately two-seconds, an athlete's ability to accelerate and reach high speed quickly is suggested to be vital for on-field performance (Lockie et al., 2011). In addition, Greig and Siegler (2009) suggest sprinting and acceleration tasks are important underlying factors for muscular fatigue, given the high neuromuscular demand associated. Epidemiological injury data suggests there is a higher occurrence of muscular strain injuries towards the latter stages of competition, likely the result of fatigue. Considering the neuromuscular demand associated with acceleration tasks, quantifying acceleration within the training load monitoring process would have large consequences for recovery.

As with high-speed locomotion, it is important to acknowledge individual capacities when quantifying acceleration tasks. It has been demonstrated that acceleration demands elicited upon playing positions during competition vary significantly (Dalen et al., 2016; Ingebrigsten et al., 2015). Dalen et al. (2016) identified that wide defenders and wide attackers produced a higher frequency of accelerations when compared to central midfielder and central defender playing positions. Ingebrigtsen et al. (2015) provided similar conclusions, stating wide players produced significantly more accelerations than central players. However, a limitation associated with previous research investigating acceleration occurrence in soccer, is that global thresholds have been utilised to band acceleration tasks. Within the current literature, no consistent global acceleration thresholds exist for soccer. Aughey (2010) utilised a single threshold of 2.78 $m.s^{-2}$ to quantify acceleration occurrence. Akenhead et al. (2013) divided thresholds by intensity, with acceleration rates of 1 - 2 $m.s^{-2}$ for low-intensity acceleration, 2 - 3 $m.s^{-2}$ for moderate-intensity, and > 3 $m.s^{-2}$ for high-intensity. Bradley et al. (2010) also divided accelerations by intensity, but utilised different thresholds, with moderate-intensity defined as 2.5 - 4 $m.s^{-2}$ and high-intensity defined as > 4 $m.s^{-2}$. Although global acceleration thresholds allow for comparisons in external workload completed by athletes, they fail to acknowledge individual's maximum accelerative capacities, and relative intensity of the stimulus placed upon individual athletes. The dose-response relationship is highly individual, with athletes' internal responses to the same external stimulus varying, and resulting in differing degrees of adaptation (Impellizzeri et al., 2005) Consequently, without an individualised approach to monitoring acceleration, it is difficult to determine the intensity of an individual's acceleration.

Sonderegger et al. (2016) were the first to individualise acceleration thresholds, incorporating individual's maximum accelerative capacity. Results demonstrated a large range in maximum accelerative capacities within highly trained junior soccer players, with values ranging from 4.5 - 7.1 $m.s^{-2}$. Large variations in individual accelerative capacity provide further rationale for an individualised approach to quantifying acceleration tasks. Akenhead and Nassis (2016) recently investigated current training load practices and perceptions amongst applied practitioners. Despite compelling physiological rationale, results demonstrated infrequent use of individual thresholds within applied sport. Considering the advantages of an individual approach to monitoring acceleration, and the vast literature currently utilising global acceleration thresholds, rationale exists for investigation into the discrepancies between global and individual acceleration thresholds.

2.6 Individualising Athlete Training Load

The importance of training load prescription and monitoring is frequently cited within the literature (Gomez-Piriz et al., 2011; Jennings et al., 2010). From an injury prevention perspective, Piggott et al. (2009) concluded that 40% of injuries could be linked with a preceding spike in training load. When focusing upon performance enhancement, a large emphasis is placed upon developing the physical performance of soccer athletes (Carling, 2013). Coaches aim to challenge the physical boundaries of athletes, without exceeding what can be tolerated (Bowen et al., 2016). This increased focus upon physical performance is likely the result of the increasing physicality of modern-day soccer (Barnes et al., 2014). To develop the physical attributes of soccer athletes, training load must be carefully manipulated (Hill-Haas et al., 2008). There is a fine balance between applying an appropriate training stimulus to promote adaptation, and applying an above optimal training stimulus resulting in an increased risk of injury. Recent research has focused heavily upon associations between training load and injury occurrence. Gabbett (2016) utilised the acute:chronic workload ratio as a tool to identify injury risk, citing a 'sweet spot' of optimal training load associated with a reduced probability of injury. Training loads higher or lower than the prescribed ratio were associated with an increased risk of injury. When utilising workload ratios to calculate injury risk, it is of the upmost importance that valid representations of load elicited upon the athlete are presented. Inaccuracies in the calculation of training load could lead to athlete overtraining, an insufficient training stimulus, or injury occurrence. All of these eventualities have a negative effect upon individual and team performance (Casamichana et al., 2012). Considering the high energy cost required for high-speed locomotion (e.g high-speed running, very high-speed running, and sprinting) and acceleration tasks, it is particularly important that these activities are quantified accurately.

It is vital for practitioners to acknowledge how different training loads affect different athletes. Training load is extremely individual in nature, with athletes responding differently to training loads dependent upon a number of internal and external variables (Casamichana et al., 2012; Scott et al., 2013). A major limitation of previous research focusing upon the demands of soccer training and competition, is that the same training load thresholds have been used for all athletes (Bradley et al., 2009; Di Salvo et al., 2010). This is despite athletes having different physical capacities, and differing responses to physical stimuli. Similarly, when coaches employ soccer training sessions, the majority of athletes are subject to the same methods (Bloomfield et al., 2007; Di Salvo et al., 2007). This is despite the individual roles of athletes varying significantly during competition. To be effective, training must replicate situations that athletes encounter during competition. It is therefore essential to gain a detailed understanding of the frequency, intensity, and direction of specific physical actions and movements performed by individuals during competition (Bloomfield et al., 2007; Russell et al., 2013). Once collated, this information can help attribute specific activity profiles to playing positions or individuals (Di Salvo et al., 2007). A high occurrence of specific actions and activities may overload certain muscle groups, and have implications for how training load is monitored, and how individuals are conditioned. Furthermore, individualised conditioning programs can be developed to replicate and overload positional demands during competition (Bloomfield et al., 2007; Di Salvo et al., 2010).

2.7 Competitive Demands of Soccer

Soccer athletes typically cover 9 - 13 kilometres during competition (Domene, 2013). 60 - 70% of the total match duration is spent at low-intensity, either walking or jogging. However there is typically a high-intensity burst of activity every 72-seconds (Bangsbo et al., 2006; Di Salvo et al., 2007). High-intensity activity is suggested to constitute ~12% of total distance, with a maximal sprint effort occurring every four-minutes (Di Salvo et al., 2010; O'Donoghue et al., 2005). In addition, frequent changes of direction, alteration of activity, technical actions, and unorthodox movements also occur (Bloomfield et al., 2007; Drust et al., 2007). It is critical for the training analysis process that movement demands of competition are recorded. This allows practitioners to assess the effectiveness of training sessions relative to the demands of competition. To accurately prescribe training, it is vital that research stays current, as the physical outputs produced during competition are constantly evolving. Barnes et al. (2014) analysed English Premier League match data from the 2006-07 season to the 2012-13 season. It was demonstrated that although total distance covered remained relatively consistent, high-intensity running distance (21 - 24 $km.h^{-1}$) and sprinting distance (speed > 24.1 km^{-1}) increased by ~35% throughout the same six-year period. Maximal running speed also increased significantly during the time period, demonstrating an increase in physical demands associated with high-level soccer competition (Carling, 2013; Dellal et al., 2011a).

The majority of research investigating demands of soccer competition has focused upon characterising total distance, and high-speed distances (Bradley et al., 2009; Di Salvo et al., 2010). Despite previous research (Lovell & Abt, 2013) demonstrating the significant errors associated with global speed thresholds in comparison to individualised, the majority of research has used global speed thresholds when analysing competitive demands. Considering the differing physical capacities of soccer athletes, results achieved using global speed thresholds must be approached with caution. Despite the focus upon high-speed distances, it has been suggested the demands of soccer cannot solely be described by speed parameters. Focusing primarily upon speed parameters results in metabolically demanding activities, performed at low absolute speeds being overlooked, and training load underestimated (Akenhead et al., 2013; Scott et al., 2013). Research by Osgnach et al. (2010) demonstrates acceleration and deceleration tasks are of a greater energy cost than moving at a constant speed (Castellano & Casamichana, 2013; Hodgson et al., 2014). With the vast majority of previous research focusing solely upon the high-speed demands of soccer, further research investigating the holistic demands of soccer competition is warranted. Of the limited studies including acceleration within their analyses, global speed thresholds were used to determine acceleration intensity (Dalen et al., 2016; Ingebrigsten et al., 2015). A limitation of global thresholds is that they fail to account for individual factors, and consequently cannot acknowledge the intensity an individual athlete is operating (Hunter et al., 2015). Considering the limitations surrounding the use of global speed and acceleration thresholds, rationale exists for further investigation into the demands of soccer competition.

The physical demand placed upon athletes during soccer competition differs significantly dependent upon playing position (Domene, 2013). Research by Dellal et al. (2012) demonstrates significant differences in high-intensity running, number of sprints, headers, tackles, and total distance between different positional roles. Carling (2013) provided further evidence, stating that running at a range of speeds, as well as the number of changes in speed, varied significantly dependent upon playing position. Significant differences have been identified between playing position for total distance travelled (Dellal et al., 2012; Guadino et al., 2010), high-speed distances (Bangsbo et al., 2006; Bradley et al., 2009), and the number of accelerations and decelerations performed (Ingebrigtsen et al., 2015; Terje, et al., 2016). Specifically, Guadino et al. (2010) found central defenders and strikers produced the lowest total distance during competition, whilst central midfielders produced the highest total distances. For high-speed activities, wide attacking and defending players produced the highest distances, whilst central players produced the lowest (Carling, 2013). Research investigating the occurrence of accelerations between different playing positions followed the same pattern, with wide players producing higher acceleration values than central players (Ingebrigtsen et al., 2015; Terje et al., 2016). Despite a number of studies analysing positional differences in individual GPS metrics, research is yet to conduct a collaborative study analysing the total distance, high-speed locomotion, maximum speed, and acceleration demands of soccer playing positions during competition. Such research would aid coaches to determine the content of their training sessions. With this information, coaches could design training sessions specific to the demands of individual athletes, improving competitive performance. Consequently, there is strong rationale for further, and more accurate, investigation into the physical demands elicited upon soccer playing positions during competition.

2.8 Physical Outputs and Match Outcome

In an attempt to positively influence the match results, a number of studies have examined the relationship between physical outputs and match outcome (Carling, 2013; Castellano et al., 2014). Research divided match outcome (i.e. won, drawn and lost), and compared the physical outputs produced by outfield players during the match. Despite significant attention, the relationship between match outcome and physical outputs produced still remains unclear. Mohr et al. (2003) identified the ability to produce high physical outputs during competition to be a differentiating factor between playing standard. Players of a higher competitive level produced higher physical outputs during competition compared to moderate level players. A review by Carling (2013) concluded that less successful teams in both England and Italy produced higher overall and high-speed distances when compared to their more successful counterparts. Castellano et al. (2014) suggest the relationship between physical output and soccer success is complex. Concluding that producing lower physical outputs does not ensure success, with success likely being linked to technical and tactical strategies. Past research investigating the effect of physical outputs produced during different match outcomes has failed to differentiate between playing positions. Differentiation between the physical outputs produced by attacking and defending players in matches of differing outcome would provide further insight into the discussion. In addition, previous research has conducted analysis upon numerous teams within English and Italian leagues. No research has focused upon a single team, and investigated the effects of positional physical outputs upon match outcome for a competitive season. Further investigation into the relationship between positional physical outputs and match outcome would provide valuable insight to applied practitioners.

2.9 Soccer Training to Develop Competitive Performance

To improve competitive performance, coaches employ team training sessions with the aim of developing the technical, tactical, physical and psychological ability of athletes (Bloomfield et al., 2007; Di Salvo et al., 2007). When focusing upon the physical ability, if the principle of specificity is considered, effective training must replicate and overload the physical demands an athlete encounters during competition. With significant variations in positional requirements, it is important that training addresses each athlete's individual needs (Dellal et al., 2012). It is vital the same training techniques are not used for all athletes, in a 'one size fits all' approach. Instead, different playing positions require an emphasis on distinct physical components relative to their competitive requirements (Terje et al. 2016).

When investigating the different training methodologies used within soccer, training games, also known as small-sided games, are frequently cited within the literature. Training games are popular amongst coaches, as they allow the ability to improve technical, tactical and physical aspects of soccer simultaneously (Castellano & Casamichana, 2013; Owen, Twist & Ford, 2004). Advantages of this training modality are that training time, and therefore risk of injury, are reduced, athlete motivation is high, and specificity of training is achieved (Castellano et al., 2013). Research has demonstrated the intensity of certain training game formats to be higher than competition, providing an overload stimulus relative to competitive demands (Boyd et al., 2013; Hodgson et al. 2014). For example, Dellal et al. (2011a) stated sprint activities ranged from 1.8 - 2.6% of total distance during competition, compared to 13.6 – 16.3% of total distance during small training games. During training games, coaches have the ability to alter training game characteristics and manipulate the physical load placed upon athletes (Casamichana et al., 2013; Dellal et al., 2012). Factors include the number of players, individual playing area, number of touches, inclusion of goalkeepers, durations and rest periods, and coach encouragement (Hill-Haas et al., 2011).

Of the factors affecting the physical load placed upon athletes, the number of players used within training games is of particular interest to practitioners. Increasing the number of players within the training game, whilst maintaining a constant pitch size decreases the physical load (Halouani et al., 2014). In contrast, increasing pitch size whilst maintaining player number increases the load (Da Silva et al., 2011). Considering an additional aim of training games is to obtain tactical outcomes, it is important to maintain a relative playing area consistent with competition in order to ensure ecological validity (Owen et al., 2014). Whilst maintaining a constant relative playing area, research suggests different sized training games elicit differing physical loads (Hill-Haas et al., 2011). There is evidence that large training games (10v10, 9v9, 8v8, 7v7) result in higher total distances travelled, and high-speed running distances when compared to medium (6v6, 5v5, 4v4) or small training games (3v3, 2v2, 1v1) (Aguiar et al., 2013; Brandes et al. 2012; Dellal et al., 2012). It was concluded that small training games are characterised by a higher frequency of change of direction, acceleration and deceleration manoeuvres when compared to medium and large training games (Davies et al., 2013; Koklu et al., 2012). Maximum speeds observed during small training games were found to be significantly lower when compared to large training games (Hill-Haas et al., 2009; Koklu et al., 2012).

Although the influence of training game size has been investigated previously, research has failed to analyse the physical demands relative to demands of competition. In order to effectively assess the training stimulus, it is necessary to analyse the demands of training games relative to an athlete's positional demands for competition. Previous research investigating the effect of training game formats used global speed thresholds, with the majority ignoring acceleration tasks and focusing upon total and high-speed distances. Consequently, rationale exists for further investigation into the effects of manipulating training game size for athletes of different playing positions, relative to their competitive demands. This would provide coaches and conditioning staff with the ability to accurately prescribe training game formats to playing positions in conjunction with their physical needs, improving training specificity (Hill-Haas et al., 2010).

2.10 Training for Peak Demands of Competition

When planning and analysing physical outputs for soccer training, it is recommended for practitioners to do so relative to physical outputs produced during competition. The rationale for this is two-fold, firstly it provides context for the technical coaches, allowing for a greater understanding of the data being reported. Secondly, it allows for the demands of training to be assessed relative to the demands of competition. This allows coaches and sport science practitioners to assess whether the physical aims of training have been achieved, and whether training is preparing athletes for the demands of competition.

Previous research investigating the physical demands placed upon soccer playing positions during competition has focused solely upon the average competitive demands (Domene, 2013). This is also a limitation of research investigating the demands of training games relative to competition (Castellano et al., 2013; Owen et al., 2014). The disadvantages of analysis focusing upon the average demands of competition are that vital information regarding the peak demands of competition is masked. Additionally, if athletes are only ever prepared for the average demands of competition, this could leave them underprepared, and at a higher risk of injury, during the most demanding periods of play (Gabbett, 2016). The most demanding periods of play often coincide with when goals are scored or conceded (Barnes et al., 2014; Faude et al., 2012), so it is vital the peaks demands of competition are acknowledged and prepared for during soccer training.

2.11 Relative Age Effect in Soccer

The majority of sports utilise age-related cutoff criterion to group young athletes for competition (Albuquerque et al., 2015). The aim is to allow appropriate development, and equal competition and opportunities for athletes participating. However, age-related cutoffs can lead to complexities related to inter-individual variations, referred to as the relative age effect (Albuquerque et al., 2012; Del Campo et al., 2010). Grouping athletes using age cutoffs invariably result in significant cognitive, physical and emotional differences between individuals (Helsen et al., 2005). For example, Albuquerque et al. (2015) demonstrated a cutoff date of 1st January would result in an individual born on 1st January being grouped with individuals born on 31st December of the same year. This provides the individual with a 12-month advantage, or 364 days of extra cognitive and physical development. 12-months additional physical and cognitive maturation, and life experience, is a significant duration for youth athletes (Edgar & O'Donoghue, 2005). Relative age effects are even more pronounced when age categories comprise two consecutive years (Delorme et al., 2010). Due to the rapid growth and development rates evident during adolescence, older individuals are typically taller and heavier than those born later in the year (Meylan et al., 2010). The result is often a manifestation of increased strength, speed and power, all of which are advantageous in most sports, and attract the attention of coaches and scouts (Malina et al., 2007a; Till et al., 2010). Malina et al. (2007b) suggest the consequence is an over representation of individuals born in the first quarter of the selection year.

The relative age effect is prominent in both educational, and sport environments (Cobley et al., 2009; Del Campo et al., 2010). In sport, it has been reported in baseball, ice-hockey, netball, rugby, soccer and tennis (Mujika et al., 2009a). Conversely, in sports where physical attributes are not as important (e.g dance, gymnastics), there is no relative age effect observed

(Delorme, 2014). In soccer, asymmetries in birth date distribution have been reported for both youth and professional teams, with an increased incidence as the standard of play increases (Del Campo et al., 2010; Helsen et al., 2005; Meylan et al., 2010). Musch and Hay (1999) analysed birth dates of the highest professional soccer leagues in countries, reaching the conclusion that the highest percentage of players were born in the first quarter of the year. Additionally, when Australia moved the cut-off date for junior soccer competition from January to August, there was an eventual corresponding shift in the distribution of birth dates in senior professional players. This phenomenon has significant effects upon both the immediate and long-term participation in soccer (Delorme, 2014).

The relative age effect is commonly viewed as discriminatory for younger players born late in the competitive year, and is a large issue for professional soccer (Edgar & O'Donoghue, 2005). Relatively older players, possessing advantages such as increased size, weight, and strength, are considered talented and of higher perceived potential to coaches and scouts. This increases their likelihood of selection, and retention within the system (Delorme, 2014; Hirose, 2009). In contrast, as a result of their less advanced physical maturity, relatively younger players experience greater amounts of failure and interiority within their practice, coupled with less playing opportunities (Delorme, 2014). The reduced playing time and low perceived competence experienced by relatively younger players results significantly higher dropout rates for these individuals (Delorme et al., 2010). Although the relative age effect declines from childhood to the end of adolescence, with less variance in physical maturation, this phenomenon still continues to have an influence (Albuquerque et al., 2012). By the end of adolescence, relatively older players have already received greater exposure to competition and training. As a result, relatively older players have had the opportunity to enhance psychological, technical and tactical skills to a greater extent when compared to their younger counterparts (Albuquerque et al., 2015). The volume of time participating in soccer specific practice and play has been demonstrated as a differentiating factor between those progressing to professional level at adulthood, and those who do not (Ford & Williams, 2012; Ford et al., 2009). Separate from the short-term issues previously discussed, there are several long-term issues associated with the relative age effect, and selecting individuals based upon their superior physical characteristics. Following maturation, the physical advantages once experienced by relatively older individuals are no longer present, with technical ability becoming a larger determinant of success. Consequently, the majority of these early developers will fail to progress at the same rate. Their later developing counterparts who have persisted with the sport will catch up in size, speed, strength and power. This provides rationale for a reduced relative age effect in some senior professional sports (Meylan et al., 2010). However in the majority of cases, by this stage, large amounts of potential talent have been lost from the sport (Helsen et al., 2005).

2.12 The Effect of Maturation Upon Physical Performance

The relative age effect is not the only discriminatory factor for talent identification within youth sport, with the maturity status of individuals providing another difficulty (Albuquerque et al., 2012; Cumming et al., 2018). Maturation refers to the structural and functional changes occurring during the body's progress towards maturity. Maturation is described as a process, whilst maturity is the end state (Malina et al., 2015). The timing and tempo of maturation varies significantly between individuals (Meylan et al., 2010). Timing refers to the occurrence of specific maturational events (e.g age at peak height velocity), whilst tempo refers to the rate at which maturation occurs (Malina et al., 2015; Meylan et al., 2010). The progression of these processes is measured to provide an indication of advancement towards maturity. Maturation status is typically assessed in terms of the level of maturation at the current chronological age (Malina et al., 2015). The physical changes associated with maturation are well documented, with previous research demonstrating that within a chronological age group, early developing males performed better in strength, power, speed, and repeated sprint tasks compared to late developers (Malina et al., 2004; Mujika et al., 2009b). Maturation can also work in a contrasting manner to the relative age effect. Meylan et al. (2010) explain that early developers born towards the end of the year can be more physically mature than late developers born early in the year. As a consequence, it is vital that an indicator of maturity status is provided in conjunction with talent identification structures.

Soccer competition is characterised by explosive activities performed intermittently, for example sprinting, jumping, tackling, and changing pace and direction (Meylan et al., 2010). As a result, the physical characteristics essential for soccer success are suggested to be body composition, aerobic and anaerobic capacity, speed, agility and power (Figueirdo et al., 2009). The physical characteristics associated with superior soccer performance are suggested to favour early developing males (Cumming et al., 2006; Spencer et al., 2011). Increases in muscle mass associated with maturation are demonstrated to contribute towards increased maximal strength, power output, and subsequent performance in field based tests (Meylan et al., 2010). Cumming et al. (2006) demonstrate this, concluding that maturity status had a positive influence on endurance, speed and power in adolescent male soccer players aged 13 - 15 years. Similarly, Figueirdo et al. (2010) demonstrated that advanced maturity contributed towards better power, speed and agility results in players aged 11 - 14 years. The effects of maturation create numerous physical advantages for early developers in soccer, whilst simultaneously creating disadvantages for late developers (Malina et al., 2004). Malina et al. (2004) suggest the differences in physical performance between males of contrasting maturity status are most pronounced between 13 - 16 years. In certain populations, the effects of maturation have resulted in correlations between playing positions. In Portuguese players aged 13 - 15 years, Malina et al. (2004) found forwards were more mature, taller, and heavier in comparison to other playing positions. This is likely the result of the emphasis placed upon scoring goals within soccer.

Although early developers tend to be heavier and taller, the use of height and weight measurements alone cannot provide an accurate representation of maturation status. Malina et al. (2012) explains that two individuals of the same age can be the same height, but one individual is closer to their final mature height than the other. Consequently, the individual closer to their mature height is more advanced in maturity. Commonly used indicators of maturation in males are skeletal age, and secondary sex characteristics (e.g pubic hair, genitals, testicular volume) (Malina et al., 2007b). However, given the logistical issues associated with x-rays, and the perceived invasiveness of identifying secondary sex characteristics, there is interest in anthropometric estimates of maturity status (Malina et al., 2015). Two alternative non-invasive indicators have been identified, resulting in less physical and psychological risk for individuals (Malina et al., 2012). Current age, height, seated height, and weight measurements can be used to estimate the time to or from peak height velocity, and consequently age at peak height velocity. This method provides an indication of timing. An alternative method is to calculate current height in relation to predicted mature adult height using age, height, weight, and mid-parent height (Meylan et al., 2010). This is termed the percentage of predicted adult height, and provides an estimate of maturity status. Malina et al. (2007a) identified the 90% percentile error band as 5.3 centimetres between actual and predicted mature height at 18 years of age. When using this method, it is important to adjust self reported parental height with gender specific equations, as individuals have a tendency to over estimate height (Meylan et al., 2010). Using mean and standard deviations from large sample sizes as references, maturity status can be expressed as Z-scores and used to classify maturity status (Meylan et al., 2010). Previous classifications have attributed Z-scores of below -1 as late developers, between -1 and +1 as on-time, and above +1 as early developers (Malina et al., 2007a; Meylan et al., 2010).

Large variations in maturity status within chronological age groups provide problems for youth sport. Specifically, there are risk factors associated with maturity mismatches and subsequent injuries for late developing players (Malina et al., 2007b). The associated problems are not limited solely to late developers however. The physical advantages initially experienced by early developers may be detrimental to their development in the long term (Cumming et al., 2018). Whilst progressing through age groups and impressing through the use of their physical strengths, the technical and tactical development of early developers is commonly neglected. Cumming et al. (2018) state that adolescence provides a period of increased neural refinement, whereby frequently used neural connections are strengthened, and sparsely used connections are removed. This may result in early developers failing to progress as expected once maturity associated differences are removed. For the future of the sport, in addition to the potential economic, psychological, and health related implications of late developers being released from the system prematurely, it is important to consider variations in maturity status between athletes of the same chronological age (Albuquerque et al., 2015; Delorme, 2014).

2.13 Bio-banding in Academy Soccer

Combat sports commonly group athletes using age and weight criteria in an attempt to create equal opportunity and reduce injury risk (Figueirdo et al., 2010). When relating to soccer, body size has a negligible impact upon performance, and grouping athletes using age and weight would have limited practical value (Cumming et al., 2018). An alternative solution involves bio-banding athletes into groups of similar levels of growth or biological maturation (Delorme, 2014; Spencer et al., 2011). Simmons and Paull (2001) provide evidence from the 1930s and 1940s demonstrating biological maturation is more beneficial for competitive grouping than chronological age groups. The aim of bio-banding is to reduce the variance in physical attributes, resulting in competitive equity and a reduced risk of injury (Cumming et al., 2018). By creating diverse challenges and learning environments, bio-banding can have a positive effect upon both early and late developing athletes. For early developers, competing against older and more physical athletes will result in a larger emphasis having to be placed upon technical and tactical attributes. For late developers, a physically balanced environment will result in the ability to develop both physical and technical attributes. Bio-banding could potentially enhance the talent identification process, providing coaches and scouts the ability to evaluate athletes with differences in physical maturity removed (Cumming et al., 2018). The main beneficiaries would be developmental programs where technically skilled, late developing players are frequently overlooked and released due to maturity related limitations in physical performance (Malina et al., 2007a). Bio-banding aims to reduce the release of later developing athletes, who would potentially reach the highest level, provided they receive quality coaching and opportunities for competition. An additional aim of bio-banding is to reduce the inclusion of early developing athletes approaching their final physical status, who may not reach the highest level once their physical attributes are matched (Simmons & Paull, 2001). There are implications of grouping older, late developing boys with a group of younger boys however (Figueirdo et al., 2010). This may have potential social and psychological repercussions, and therefore be acknowledged.

From a theoretical perspective, the positive effects of bio-banding can be understood using a constraints-based framework (Newell, 1986). The framework states a player's motor performance results from the interactions of three constraints; task, individual and environmental. Task constraints relate to the specific performance context and may be the rules specifying behaviour, the goal of the task, or task-related implements. Individual constraints refer to the individual's characteristics, all of which can influence performance at any moment in time. Examples of such include developmental and maturational factors. Environmental constraints refer to the general factors influencing motor performance, such as weather conditions, as well as socio-culture and economic factors. From the interaction of the constraints, emergent behaviour is seen. Certain types of motor behaviour may only emerge when particular constraints limiting performance are removed. There is an argument that soccer athletes playing in chronologically grouped competition may result in the motor performance of late developers being constrained by the presence of early developers. As a consequence, if there is a change in the task constraint of athlete maturation as seen in bio-banded matches, then a different motor performance will emerge. There is currently no experimental evidence for the hypothesis predicted by the constraints model, however qualitative accounts do exist (Cumming et al., 2018).

In a novel study, Cumming et al. (2018) analysed Premier League academy players' experiences of participating in bio-banded soccer matches. Results indicated that early developers felt bio-banded matches provided a superior physical challenge and learning stimulus relative to their age group matches. Early developers also felt there was an increased emphasis placed upon technique, tactics, and teamwork. Effectively, bio-banded games exposed the early developers to the challenges typically encountered by late developers. Conversely, late developers described bio-banded matches as less physically challenging relative to their age group matches. Late developers found bio-banded matches provided them with a greater opportunity to utilise their technical, physical, and psychological attributes, and exert their influence upon the match. This study was the first to provide feedback on the effect of bio-banded fixtures, focusing on the qualitative views of participants. Research is yet to investigate the effects of bio-banding upon physical and technical actions produced during matches however. In addition to the qualitative information previously presented, physical and technical data is vital to determine the holistic effects of bio-banding soccer matches.

Despite no research to date having investigated the effects of bio-banding upon physical outputs produced during competition, previous studies have identified the effects of maturation upon competitive physical outputs measured using GPS. In addition to performing better in strength and power tests, early developing boys were found to cover greater high-speed distances, achieved higher peak speeds, and produced more frequent high-intensity, and repeated high-intensity actions (Buchheit & Mendez-Villaneuva, 2014; Meylan et al., 2010). In a study examining the effects of age, maturity and body dimensions on match running performance in U15 soccer players, results demonstrated older, more mature players consistently outperformed their younger, less mature teammates during competition (Buchheit & Mendez-Villaneuva, 2014). This compliments previous research suggesting age and maturation positively impacted match-running performance (Buchheit et al., 2010). Subsequently, Buchheit and Mendez-Villaneuva (2014) identified investigation into technical and tactical outputs for players of differing maturation levels as an area for future research. With the differences in physical outputs between players of different maturation levels clear, there is rationale for subsequent investigation into the effects of bio-banding competition. Research investigating the physical and technical differences between bio-banded and chronologically aged competition would provide coaches with a holistic insight into the effects of bio-banding. Additionally, further analysis into the differences for early, on-time, and late developers would allow for the benefits of competition formats to be identified.

2.14 Determining Significance and Effect Size of Experimental Results

During experimental investigation, *p* values are used to determine the probability associated with the experimental hypothesis being false. Typically, $p < 0.05$ is utilised as a measure of statistical significance, indicating there is a 5% chance the observed difference is due to chance (Wasserstein & Lazar, 2016). However, with a sufficiently large sample, a statistical test may demonstrate a significant difference despite very small differences, often considered trivial when applying the findings in practice (Sullivan & Feinn, 2012). Conversely, measurements of effect size report the relative magnitude of differences (Thalheimer & Cook, 2002). Researchers are encouraged to report effect sizes for numerous reasons (Wilkinson, 1999). First, the magnitude of effect is presented in a standardised metric. This allows for the practical significance of results to be demonstrated. Second, effect sizes allow for meta-analytic conclusions to be made across studies. Finally, effect sizes from prior research can be used to plan future research, specifically the sample size required to observe statistical significance given a size of an effect observed (Lakens, 2013). Cohen's *d* is a commonly used method of determining effect size for t-tests (Cohen, 1988). This effect size is described as the difference between two means, divided by the standard deviation of the two conditions. The division by standard deviation enables comparison of effect sizes across experiments. An advantage of Cohen's *d* in comparison to other effect size measurements is that first, it's popularity enables comparison of results to a large volume of published studies. Second, Cohen's *d* allow effect sizes to be interpreted against known benchmarks; small (d = 0.2), medium, (d = 0.5), or large (d = 0.8) (Lakens, 2013; Thalheimer & Cook, 2002). Partial eta-squared (η_p^2) is an effect size calculation used for more than two sets of observations, typically within ANOVA analyses. Partial eta-squared measures the ratio of the variance accounted for by an effect, and that effect plus its associated error variance (Levine & Hullett, 2002). Partial eta-squared values range between 0 and 1, with $\eta_p^2 = .02$ considered small, $\eta_p^2 = .13$ considered medium, and $\eta^2 = .26$ considered a large effect size. An η_p^2 of .13 suggests that 13% of the total variance can be accounted for by the group (Lakens, 2013). In summary, it is suggested that only reporting the *p* value is inadequate for readers to fully understand the results. Instead, it is advised that both the statistical significance (*p* value), and the effect size are reported within experimental investigations (Lakens, 2013; Sullivan & Feinn, 2012; Wilkinson, 1999).

3.0 General Methods

3.1 Participant Recruitment

The participants recruited for studies within the current thesis were all contracted to Brighton and Hove Albion FC. For Study One, Study Two, Study Three and Study Four, participants were recruited from the club's U23 and U18 squads. For Study Five, participants were recruited from the club's U16 - U12 squads. Prior to being recruited, participants were briefed with a detailed explanation of the proposed study and the requirements. Participants were informed of potential risks, and all provided written consent. For participants under the age of 18, parental or guardian consent was provided. Participants were free to withdraw at any time, without any repercussions from the football club, or otherwise.

The participants recruited for Study One, Study Two, Study Three and Study Four were all well trained, and either professional soccer players (U23) or had a full time scholarship (U18) with Brighton and Hove Albion FC. All participants had trained four to five times, and played one to two competitive matches per week for a minimum of two years. Participants recruited for Study Five were part-time soccer players contracted to Brighton and Hove Albion FC. Study Five participants were aged 11 - 15 years, and between 85 - 90% of predicted adult stature. Participants had trained two to three times, and played competitive matches one to two times per week for a minimum of one year prior to the study.

All studies were conducted with protocols being fully approved by the ethical review board at the University of Brighton prior to commencing. The study conformed to the requirements stipulated by the Declaration of Helsinki, and all health and safety procedures were complied with during the study.

3.2 Participant Exclusion Criteria

Participants were not considered for the studies if they were currently taking medication, or had any previous history of renal, gastrointestinal or cardiovascular complications. Participants were not considered for the studies if they had suffered from a musculoskeletal injury within the past three months. Goalkeepers were excluded from all of the studies, as they did not participate in the same training programmes. Participants were excluded from Study Five if they were not between 85 - 90% of predicted adult stature.

3.3 Data Collection Procedures

During Study One, high-speed locomotion GPS data was collected for 19 full-time professional soccer players over a six-week pre-season period. The six-week data collection period consisted of 32 training sessions and two friendly matches. This programme was designed by the head coach, and strength and conditioning coach. The programme consisted of technical and tactical practices, small-sided games, replications of competition, and physical conditioning work.

For Study Two, GPS derived acceleration data was collected for 31 full-time professional soccer players over a four-week pre-season period. The data collection period was comprised of 23 training sessions and four friendly matches. With a similar structure to Study One, the pre-season programme was designed by head coach, and strength and conditioning coach, consisting of a mixture of technical, tactical and physical practices.

During Study Three, GPS data was collected for 37 full-time professional soccer players across 44 competitive matches. Data collection spanned two seasons, during which matches were played once per week. Prior to both competitive seasons, participants had undergone pre-season training and had appropriate conditioning levels. Fixtures used within the study were U23 Premier League Two fixtures. Fixtures were in a competitive league format, with emphasis placed upon results, ensuring motivation was high. Fixtures were consistently played on a Monday evening, on natural grass. A 4-3-3 playing formation was adopted throughout the data collection period.

During Study Four, GPS data from competition and training was collected for 46 full-time professional soccer players across a competitive season. Data collection was comprised of 22 competitive matches, and 39 training game sessions. Prior to the commencement of data collection, participants had undergone pre-season training, and had appropriate conditioning levels. Fixtures used within the study were competitive U23 Premier League Two fixtures, ensuring motivation was high. Fixtures were played on a Monday evening, on natural grass. A 4-3-3 playing formation was utilised throughout the data collection period. Competition and training game data was collected once per week. During training game sessions, one game format was utilised (e.g large, medium or small), resulting in data collection for each format every three weeks. The head technical coach allocated teams prior to each training session, ensuring abilities were normally distributed, and participants played in their designated playing positions. Training sessions occurred on a Thursday morning, with Tuesday and Wednesday being designated rest days for the participants, reducing the effects of fatigue. Large training games were characterised as 10v10, 9v9, 8v8, or 7v7 plus goalkeepers. Medium training games were characterised as 6v6, 5v5, or 4v4 plus goalkeepers. Small training games were characterised as 3v3, 2v2, or 1v1 plus goalkeepers (Verheijen, 2014). Training games were played for four quarters of four-minutes each, with three minutes rest between games (Hodgson et al., 2014). To maintain tactical validity, relative player area for all formats was 120m^2 per player, excluding goalkeepers (Hill-Haas et al., 2011; Hodgson et al., 2014).

During Study Five, physical and technical performance data was collected for 25 male soccer players across both bio-banded and chronological competition. Bio-banded competition was against athletes grouped by the same maturation band, whilst chronological competition was against athletes of the same chronological age. Both competition formats took place within the competitive season, with participants having undertaken pre-season training. To ensure comparability, competition formats were completed within two-weeks of each other. Bio-banded fixtures were played in 11v11 format, with four 20-minute quarters. Games were played on full-sized standard grass pitches (100 x 64m), with full-sized goals (8 x 2.4m). Three substitutions were permitted in accordance with Football Association rules for youth competition, and standard officiating was applied. Fixture format for the chronologically aged competition was identical to the bio-banded fixtures. Fixtures were played in 11v11 format, four 20-minute quarters, on a 100 x 64m pitch and with standard Football Association rules and officiating applied. The only exceptions were the U15 fixtures, which were divided into two 40-minute halves to comply with league rules for the age group. All participants had been members of the academy for at least one year prior to data collection, meaning they had experience of competitive academy soccer.

3.4 Participant Preparation and Warm Up Procedures

Prior to the commencement of data collection for Study Three, Study Four, and Study Five, participants completed a six-week pre-season consisting of physical and technical training sessions, and friendly matches. The aim of the pre-season programme was to ensure the participants had appropriate conditioning levels prior to the commencement of the competitive season. Competitive matches within Study Three and Study Four were comprised of official Premier League Two fixtures. Chronological matches during Study Five were respective age group's Premier League fixtures. Bio-banded matches during Study Five were informal fixtures organised by the football clubs, as no formal competitive programmes exists for bio-banded competition.

Prior to each fixture participants completed a 25-minute warm up consisting of physical drills, passing, possessions, and finishing. This ensured adequate preparation for competition, and was consistent throughout data collection periods for all studies within the thesis. Prior to the commencement of training games, participants completed a 25-minute warm up consisting of physical drills, passing, and possessions. All training games and matches were played on natural grass. Participants used the same footwear throughout the individual studies.

3.5 Physical and Technical Metrics Collected

Due to the varying analyses and aims of the studies within the current thesis, different physical and technical performance metrics were collected. The sub-sections below detail the metrics recorded and analysed, as well as their descriptions.

Study One

Within Study One, GPS derived high-speed locomotion data was collected. Two different analysis methods and thresholds were applied; global and individual. Table 3.1 and 3.2 detail the high-speed locomotion metrics and their descriptions.

Table 3.1 Global high-speed locomotion thresholds utilised within Study One.

Global GPS Metric	Description
High-speed running distance (m)	The distance travelled 4.2 - 5.5 $m.s^{-1}$ (Abt & Lovell, 2009; Hunter et al., 2015; Lovell & Abt, 2013).
Very high-speed running distance (m)	The distance travelled 5.5 – 7.0 $m.s^{-1}$ (Abt & Lovell, 2009; Hunter et al., 2015; Lovell & Abt, 2013).
Sprinting distance (m)	The distance travelled > 7.0 $m.s^{-1}$ (Abt & Lovell, 2009; Hunter et al., 2015; Lovell & Abt, 2013).

Table 3.2 Individual high-speed locomotion thresholds utilised within Study One.

Individual GPS Metric	Description
High-speed running distance (m)	The distance travelled 80 – 99% of individual's maximum aerobic speed (Hunter et al., 2015; Mendez-Villanueva et al., 2013).
Very high-speed running distance (m)	The distance travelled 100% maximum aerobic speed – 30% of individual's anaerobic speed reserve (Hunter et al., 2015; Mendez-Villanueva et al., 2013).
Sprinting distance (m)	The distance travelled >30% of individual's anaerobic speed reserve (Hunter et al., 2015; Mendez-Villanueva et al., 2013).

Study Two

Within Study Two, GPS derived acceleration data was collected. Two different analysis methods and thresholds were applied; global and individual. Table 3.3 and 3.4 detail the acceleration metrics and their descriptions.

Table 3.3 Global acceleration thresholds utilised within Study Two.

Global GPS Metric	Description
Low-intensity acceleration distance (m)	The distance travelled accelerating 1 - 2 $m \cdot s^{-2}$ (Akenhead et al., 2013).
Moderate-intensity acceleration distance (m)	The distance travelled accelerating 2 - 3 $m \cdot s^{-2}$ (Akenhead et al., 2013).
High-intensity acceleration distance (m)	The distance travelled accelerating > 3 $m \cdot s^{-2}$ (Akenhead et al., 2013).

Table 3.4 Individual acceleration thresholds utilised within Study Two.

Individual GPS Metric	Description
Low-intensity acceleration distance (m)	The distance travelled accelerating between 25 - 50% of an individual's maximum accelerative capacity (Sonderegger et al., 2016).
Moderate-intensity acceleration distance (m)	The distance travelled accelerating between 50 - 75% of an individual's maximum accelerative capacity (Sonderegger et al., 2016).
High-intensity acceleration distance (m)	The distance travelled accelerating > 75% of an individual's maximum accelerative capacity (Sonderegger et al., 2016).

Study Three

Within Study Three, GPS derived data including distance, speed, high-speed locomotion, and acceleration was collected. Table 3.5 details the GPS metrics and their descriptions.

Table 3.5 GPS and subjective metrics utilised within Study Three, Study Four and Study Five.

GPS Metric	Description
Total distance (m)	The total distance travelled.
Maximum speed (m.s^{-1})	The maximum speed travelled by an individual during competition.
Very high-speed running distance (m)	The distance travelled between 100% maximum aerobic speed and 30% anaerobic speed reserve. Calculated using modified Montreal track test (Leger & Boucher, 1980). Protocol previously utilised by Hunter et al. (2015) and Mendez-Villanueva et al. (2013).
Sprinting distance (m)	The distance travelled above 30% anaerobic speed reserve. Calculated using modified Montreal track test (Leger & Boucher, 1980). Protocol previously utilised by Hunter et al. (2015) and Mendez-Villanueva et al. (2013).
Moderate-intensity acceleration distance (m)	The distance travelled accelerating between 50 - 75% of an individual's maximum accelerative capacity (Sonderegger et al., 2016).
High-intensity acceleration distance (m)	The distance travelled accelerating > 75% of an individual's maximum accelerative capacity (Sonderegger et al., 2016).
Rating of perceived exertion	Subjective rating of exertion using the modified CR10 Borg scale (Borg, 1982).

Study Four

Within Study Four, GPS derived data including distance, high-speed locomotion, and acceleration was collected. Subjective measures of training load in the form of ratings of perceived exertion were also collected. Table 3.5 details the descriptions of the GPS and subjective metrics.

Study Five

Within Study Five, physical and technical performance data was collected. Physical performance data was in the form of GPS derived data and subjective measures of training load. Table 3.5 details the descriptions of the GPS and subjective metrics. Technical performance data was recorded and coded by trained academy analysts. Table 3.6 details the descriptions of technical performance metrics.

Table 3.6 Technical performance metrics utilised within Study Five.

Physical and Technical Performance Metrics	Description
Shot	A successful strike of the ball aimed at the opposing goal.
Short pass	A strike of the ball (< 20m in distance) directed at a teammate, and that was successfully controlled.
Long pass	A strike of the ball (> 20m in distance) directed at a teammate, and that was successfully controlled.
Cross	A successful long pass from the widest quarter of the pitch landing in the opposition penalty area.
Dribble	Successfully running past an opponent with the ball.
Tackle	A successful attempt to remove the ball from the opponent's possession through a physical challenge.

Ratings of Perceived Exertion

Individual's ratings of perceived exertion (RPE) were collected during Study Four and Study Five. The RPE scale used during both studies was the modified Borg CR10-scale. This scale has previously been utilised as a method to monitor psychological and physiological load within an elite soccer environment. RPE values were recorded 30-minutes following the cessation of competition or training. During Study Four, when collecting RPE for training games, participants were asked to provide an RPE value solely representative of the intensity of training games. Following competition in Study Four and Study Five, participants were asked to provide an RPE value solely representative of the intensity of competition. Individual RPE was collected separately from each individual to ensure each participant's decision-making was not influenced. Participants had been familiarised with the RPE scale prior to the data collection period.

3.6 Speed and Acceleration Thresholds

Global and individual speed thresholds were utilised within Study One, with differences in high-speed locomotion distances produced by the thresholds investigated. The global speed thresholds utilised within Study One were high-speed running as 4.2 – 5.5 $m.s^{-1}$, very high-speed running as 5.5 - 7.0 $m.s^{-1}$, and sprinting as > 7.0 $m.s^{-1}$. These thresholds were frequently cited within soccer literature (Abt & Lovell, 2009; Hunter et al., 2015; Lovell & Abt, 2013). The individual thresholds utilised were high-speed running as 80 - 99% maximum aerobic speed, very high-speed running as 100% maximum aerobic speed to 30% anaerobic speed reserve, and sprinting as > 30% of anaerobic speed reserve. These individual thresholds had previously been utilised by Hunter et al. (2015) and Mendez-Villanueva et al. (2013), to represent the functional limits of endurance and sprint locomotor capacities. As in previous research, individual thresholds were determined using athlete's maximum aerobic speed, and maximum sprint speed values, calculated using validated field tests. The methodology and processes used to calculate and apply individual speed thresholds in Study One were also utilised within Study Three and Study Four to individualise high-speed locomotion.

Within Study Two, global and individual acceleration thresholds were utilised to determine differences in low-, moderate-, and high-intensity acceleration distances produced. The global acceleration thresholds utilised were frequently cited thresholds within soccer literature (Akenhead et al., 2013). Global thresholds were low-intensity acceleration as 1 - 2 $m{\cdot}s^{-2}$, moderate-intensity acceleration as 2 - 3 $m{\cdot}s^{-2}$, and high-intensity acceleration as > 3 $m{\cdot}s^{-2}$. The individual acceleration thresholds had previously been utilised by Sonderegger et al. (2016). Individual thresholds were low-intensity acceleration as 25 - 50% of maximum accelerative capacity, moderate-intensity acceleration as 50 - 75%, and high-intensity acceleration as > 75%. Individual's maximum accelerative capacity was used to determine individual acceleration thresholds. This protocol was field based and had previously been used by Sonderegger et al. (2016) to individualise acceleration thresholds. The methodology and processes used to calculate and apply individual acceleration thresholds in Study Two were also utilised for Study Three, Study Four, and Study Five.

3.7 Physical Performance Testing Procedures

Field tests were used to determine athlete's maximum sprint speed, maximum aerobic speed, and maximum accelerative capacity. Maximum sprint speed and maximum aerobic speed were used to determine peak speed and estimate $v\dot{V}O_{2max}$ respectively. These values were used to calculate individual speed thresholds for Study One, Study Three, Study Four, and Study Five. In each study, maximum sprint speed and maximum aerobic speed protocols were completed the day prior to data collection starting. The maximum sprint speed protocol required each athlete to complete three maximal 40m linear sprints, with a minimum of three minutes rest between repetitions. Maximum sprint speed was defined as the average speed recorded over the quickest 10m sector, and measured using electronic light gates (Brower TC Timing System) to the nearest 0.01s. The intraclass correlation coefficient for the maximum sprint speed protocol has been cited as 0.94 - 0.99 (Mendez-Villanueva et al., 2013; Winchester et al., 2008). The maximum sprint speed protocol was completed on an indoor artificial grass surface with football boots.

The protocol used to identify maximum aerobic speed was a modified version of the University of Montreal Track Test (Leger & Boucher, 1980). This protocol had previously been used by Mendez-Villanueva et al. (2013) to estimate maximum aerobic speed. The correlation coefficient for this protocol has been cited as 0.97 (Leger & Boucher, 1980). The modified University of Montreal Track Test began with an initial running speed of 8 $km.h^{-1}$, with the speed increasing by 0.5 $km.h^{-1}$ each minute. Athletes ran around a 200m athletics track, marked with 20m intervals, in time with an audible cue, until either exhaustion or three consecutive cones were missed. Maximum aerobic speed was estimated using the speed of the final one-minute stage completed. The maximum aerobic speed protocol was completed on the same grass surface and using the same footwear as data collection during the study. Following the calculation of maximum sprint speed, and maximum aerobic speed scores, each athlete's theoretical anaerobic speed reserve was calculated. Anaerobic speed reserve was defined as the difference between the maximum sprint and maximum aerobic speed score. Both maximum sprint speed and maximum aerobic speed protocols had previously been utilised by Mendez-Villanueva et al. (2013) and Hunter et al. (2015) to determine soccer player's maximum sprint and maximum aerobic speeds, and individualise speed thresholds.

Maximum accelerative capacity was used to individualise acceleration thresholds for Study Two, Study Three, Study Four, and Study Five. Maximum accelerative capacity was determined using a maximum acceleration protocol. In each study, the maximum acceleration protocol was completed the day prior to data collection starting. The protocol required athletes to complete three maximal 40m linear sprints, with a minimum of three minutes rest between repetitions. The maximum rate of acceleration was calculated for each sprint utilising 10-Hz portable GPS devices (OptimEye S5B, Version 7.18; Catapult Innovations, Melbourne, Australia), with the highest acceleration values recorded for each athlete. The protocol was completed on an indoor artificial grass surface, with football boots. This protocol had previously been utilised to determine maximum sprint speed (Mendez-Villanueva et al., 2013), with a similar protocol utilised by Sonderegger et al. (2016) to determine maximum accelerative capacity and individualise acceleration thresholds.

3.8 Athlete Groups

Within Study One and Study Two, athletes were sub-divided dependent upon physical performance testing scores. The purpose was to add further depth to the studies, examining differences between global and individual analysis methods to be compared between athletes of differing physical capacities. In Study One, athletes were sub-divided into three groups based upon maximum aerobic speed testing scores. The athlete groups were characterised as low maximum aerobic speed (LO_{MAS}) (< 1 *SD* from mean), medium maximum aerobic speed (ME_{MAS}) (± 1 *SD* from mean), and high maximum aerobic speed (HI_{MAS}) (> 1 *SD* from mean). The athlete groups for Study Two were determined using maximum acceleration scores. Athlete groups were characterised as low accelerative capacity (LO_{ACC}) (< 1 *SD* from mean), medium accelerative capacity (ME_{ACC}) (± 1 *SD* from mean), and high accelerative capacity (HI_{ACC}) (> 1 *SD* from mean).

For Study Three and Study Four, participants were assigned an outfield playing position by the head technical coach. Each participant only featured in one playing position. Playing positions were central defender, wide defenders, central midfielders, wide attackers, and strikers.

For Study Five, participants were sub-divided dependent upon maturation status. The three sub-divisions of maturation status were early developers, on-time developers, and late developers, derived using Maturity Z-scores. Early developers had a maturity Z-score of > 1, on-time developers between 1 and -1, and late developers < -1. Maturity Z-scores were calculated using participant's percentage predicted adult height, and age and sex specific reference values as previously utilised by Cumming et al. (2018) (Bayer & Bailey, 1959; Malina et al., 2007a).

3.9 GPS Data Analysis

Following the recording of each set of data, GPS devices were downloaded to a computer and analysed using Catapult Sprint software (Catapult Sprint 5.1.5, Catapult Innovations, Melbourne, Australia). Using time and location data, distance, speed and acceleration could be calculated. Speed was calculated using measurements of the Doppler shift of signals received, distance was measured using positional differentiation (Malone et al., 2017). Acceleration was calculated as the increasing rate of change in instantaneous speed over time. Only the increasing rate of change in speed was measured, as a decreasing rate of change in speed is classified as a deceleration (Hodgson et al., 2014). When analysing high-speed locomotion tasks (e.g high-speed running, very high-speed running, sprinting, sprinting), the minimum effort duration for was one-second (Hunter et al., 2015). When analysing acceleration tasks (low-intensity, moderate-intensity, and high-intensity acceleration distances) a minimum effort duration of 0.4 seconds was used. This was similar to minimum effort durations cited in previous research (Dalen et al., 2016; Hodgson et al., 2014; Ingebrigtsen et al., 2015).

When investigating physical demands during competition (Study Three), specific data analysis processes were adhered to. To allow direct comparisons in data, only participants completing 90-minutes were included within the analysis process. Once downloaded, each data set was edited and split into two 45-minute halves. Extra time at the end of each half was excluded to ensure comparison between matches. The same process was applied when investigating training games within Study Four. Each training game data set was edited and split into four quarters of four-minutes. Considering Study Four investigated both competition and training game demands, GPS metrics were presented as per minute values to allow comparability between competition and training games of different durations. Within Study Four, peak and average values were calculated for GPS metrics. Peak values were calculated by dividing each 90-minute match, or 16-minute training game, into one-minute intervals, and recording the highest values achieved per minute for each GPS metric. Average values were calculated by dividing total values for the 90-minute match, or 16-minute training game, by the overall duration. For Study Five, competition data was edited and split into four quarters of 20-minutes. Only participants completing the entire match were included within the analysis process. As with previous research, extra time at the end of each quarter was excluded to enable comparison between matches.

3.10 GPS Data Quality and Accuracy

10-Hz GPS devices (OptimEye S5B, Version 7.18; Catapult Innovations, Melbourne, Australia) were used to record and collect data for all studies within the current thesis. It has been demonstrated that 10-Hz GPS devices have an acceptable level of accuracy and reliability when assessing the speed of movement within intermittent exercise (Aguiar et al., 2013; Barbero-Alvarez et al., 2010; Varley et al., 2012). Devices sampling at 10-Hz provide sufficient accuracy when quantifying acceleration, deceleration and constant speed locomotion in team sports (Varley et al., 2012). When assessing reliability, Aughey (2011) demonstrated coefficient of variations of 0.7 - 1.3% for 15m and 30m sprints, whilst Delaney et al. (2017) demonstrated coefficient of variations of 3.6 - 5.9% for quantifying instantaneous speed during acceleration.

In accordance with manufacturer's instructions all GPS devices were switched on 15-minutes prior to the beginning of each data collection session, and switched off immediately following. Each GPS unit was worn in a designated tight-fitting vest located between the scapulae to reduce unwanted movement. Athletes wore the same unit for each training session to avoid inter-unit error.

3.11 Data Exclusion Criteria

Data exclusion criteria were applied to ensure the accuracy and validity of data was maintained. For GPS data, the number of satellites, and horizontal dilution of position were monitored for data quality purposes. If values ranged < 12 for number of satellites, or > 1 for horizontal dilution of position, data was excluded.

During all of the studies, if participants did not complete the training session or match due to injury, their data was excluded from the study. During Study Three, Study Four, and Study Five, if the participants did not complete the entirety of the training game session (16-minutes), or competition (80- or 90-minutes), their data was excluded.

3.12 Technical Data Analysis

Technical data during both bio-banded and chronological competition formats was recorded using a camcorder (Sony HDR CX570). Fixtures were coded both live and retrospectively using SportsCode (Version 10.3.36, Sportscode Elite Software), by trained academy performance analysts. Video recordings and their respective coding were then downloaded to a computer and synced. Technical performance metrics were produced using custom reports on SportsCode software.

3.13 Statistical Analysis

Descriptive analyses were conducted on all data sets within the current thesis, with normality values assessed using Kolmogorov-Smirnov and Shapiro-Wilk tests. Significance values of $p < 0.05$ were used to analyse the distribution of data. Skewness and kurtosis values were assessed, with standard error between -2 and +2 indicating the data was normally distributed. Within Study One, analysis indicated data was non parametric. Consequently, Wilcoxon signed rank tests were used to determine the within group (global, individual) differences in high-speed running, very high-speed running, and sprinting values. This form of statistical testing was used as the data was non-parametric. A Bonferroni adjustment was used in conjunction with the Wilcoxon signed rank tests. Cohen's *d* tests were used to determine the effect sizes of the differences.

Within Study Two, descriptive analyses indicated data was parametric and normally distributed. To determine differences in low-, moderate-, and high-intensity acceleration distances produced by global and individual analysis methods, a two-way mixed design ANOVA was used, where analysis method (global, individual) was the within-subjects variable, and athlete group (LO_{ACC}, ME_{ACC}, HI_{ACC}) was the between subjects variable. Partial eta-squared values were calculated to estimate the effect size for the ANOVA. Bonferroni tests were used post-hoc to assess where differences occurred, with Cohen's *d* tests used to calculate effect sizes.

Within Study Three, descriptive analyses indicated that data was parametric, and normally distributed. To investigate differences and interactions between match outcome and playing position in the GPS metrics produced during competition, a two-way between subjects ANOVA was used. Partial eta-squared values were calculated to estimate the effect size for the ANOVA. Match outcome and playing position were the between-subjects variables. Bonferroni tests were used post-hoc to assess where differences occurred, with Cohen's *d* tests used to calculate effect sizes.

Data within Study Four was parametric, and normally distributed. To investigate the differences in eight GPS metrics and RPE produced by game formats for playing positions, two-way between subjects ANOVAs were used, with playing position and game format being the between-subjects variables. Partial eta-squared values were calculated to estimate the effect size for the ANOVA. Bonferroni tests were used post-hoc to assess where differences occurred, with Cohen's *d* tests used to calculate effect sizes.

Descriptive analysis indicated Study Five data was parametric, and normally distributed. To investigate differences in physical and technical performance between bio-banded and chronologically aged fixtures for early, on-time, and late developers, two-way mixed design ANOVAs were used where competition format (bio-banded, chronological) was the within-subjects variable, and maturation status (early, on-time, late) was the between subjects variable. Partial eta-squared values were calculated to estimate the effect size for the ANOVA. Bonferroni tests were used post-hoc to assess where differences occurred, with Cohen's *d* tests used to calculate effect sizes.

The level of statistical significance for all tests within the studies was set at $p < 0.05$. For all studies within the current thesis, Cohen's *d* tests were used to calculate effect sizes. A Cohen's *d* effect size of $d = 0.2$ was considered a small effect size, $d = 0.5$ a medium effect size, whilst $d = 0.8$ was considered a large effect size. For studies that used an ANOVA, partial eta-squared values were calculated to estimate the effect size for the ANOVA. A partial eta-squared effect size of $\eta_p^2 = .02$ was considered a small effect size, an effect size of $\eta_p^2 = .13$ was considered a medium effect size, whilst $\eta_p^2 = .26$ was considered a large effect size. All statistical analyses within the current thesis were performed using the software IBM SPSS statistics (version 22; SPSS, Inc., Chicago, IL, USA).

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4.0 Study One - An individual approach to monitoring locomotive training load in English Premier League academy soccer players

Publication arising from this chapter: Abbott, W., Brickley, G., & Smeeton, N.J. (2018). An individual approach to monitoring locomotive training load in English Premier League academy soccer players. *International Journal of Sports Science & Coaching, 13(3),* 421-428.

Abstract

To account for the individual intensity of locomotion tasks, individualised speed thresholds have been proposed as an alternative to global speed thresholds. Methodologies to determine individual speed thresholds have typically been laboratory based, time consuming, and expensive, rendering them inappropriate for applied practitioners working with large squads. The current study utilised easy to administer field tests to individualise speed thresholds. The aim was to investigate differences between high-speed locomotion measured using global and individual analysis methods. Nineteen, male, professional soccer players completed maximum sprint and maximum aerobic speed protocols, and were divided into groups dependent upon maximum aerobic speed performance (high – HI_{MAS}, medium - ME_{MAS}, and low - LO_{MAS}). Locomotion data was collected using portable GPS units, and analysed using global and individual analysis methods to determine distances travelled performing high-speed running (HSR), very high-speed running (VHSR), and sprinting (SPR). In LO_{MAS} athletes, the individual analysis method produced significantly higher HSR, VHSR and SPR distances compared to global (mean differences 390m, 310m, and 88m respectively, $p < 0.01$). In ME_{MAS} athletes, no significant differences were found between analysis methods for HSR and VHSR. In HI_{MAS} athletes, the individual analysis method produced significantly lower HSR and VHSR distances compared to global (mean differences 549m and 341m, $p < 0.01$). Results concluded that the global analysis method produced high-speed locomotion distances significantly higher, or lower than the individual analysis method for 47% of athletes. The current study recommends the use of field tests to individualise speed thresholds, allowing applied practitioners to accurately quantify individual athlete intensity.

4.1 Introduction

Determining associations between training load and injury occurrence in team sports is important for optimising performance. A fine balance exists between applying the optimum training stimulus to promote adaptation, and exceeding the optimum stimulus, which is associated with a higher incidence of injury (Bowen et al., 2017; Casamichana et al., 2012). Consequently, monitoring and understanding training load is vital to facilitate physical performance, and reduce injury risk (Bowen et al., 2017; Hill-Haas et al., 2008). Distance travelled performing high-speed locomotion tasks (e.g. high-speed running, very high-speed running, and sprinting) has received significant attention when investigating training load (Bradley et al., 2009; Di Salvo et al., 2010). Faude et al. (2012) highlighted the importance of high-speed locomotion by stating that straight-line sprinting is the most dominant action when scoring goals. Adding to the importance of sprinting, Barnes et al. (2014) demonstrated distances travelled sprinting in the English Premier League have increased by ~35% between 2006 and 2013. Considering sprinting tasks are associated with impaired muscle function, and increased perceived muscle soreness, the volume of sprinting completed has implications upon recovery time and injury risk (Howatson & Milak, 2009). It is therefore important that high-speed locomotion is quantified accurately (Carling, 2013).

High-speed locomotion tasks are typically banded using speed thresholds. Subjectively, these have been equated to descriptions of movement and designated a specific speed band (Carling, 2013; Akenhead et al., 2013). Despite growing interest in the area of global positioning systems (GPS), there are no consistent definitions for speed thresholds, making comparison between research difficult (Dwyer & Gabbett, 2012). Common speed thresholds cited within soccer research are, high-speed running as 4.2 - 5.5 $m.s^{-1}$ (Hunter et al., 2015; Lovell & Abt, 2013), very high-speed running as 5.5 - 7.0 $m.s^{-1}$ (Lovell & Abt, 2013; Abt & Lovell, 2009), and sprinting as > 7.0 $m.s^{-1}$ (Bradley et al., 2010; Hunter et al., 2009). In the past, speed thresholds have been applied arbitrarily to all athletes. Global speed thresholds allow for comparisons in absolute workload completed by athletes, but are suggested to mask important information regarding the relative intensity an individual is working (Hunter et al., 2015). Athlete's internal responses to the same external demands vary, and result in differing degrees of adaptation (Hunter et al., 2015). This is further emphasised when monitoring athletes of different ages and maturation levels (Gabbett, 2015). Despite allowing for comparisons between athletes, researchers have suggested the potential for large differences in quantifying an individual's high-intensity demands using global speed thresholds (Abt & Lovell., 2009; Cummins et al., 2013).

Having identified the disadvantages associated with global speed thresholds, researchers have attempted to individualise thresholds using physical performance markers (Abt & Lovell, 2009; Hunter et al., 2015; Mendez-Villanueva et al., 2013). The aim of individualising speed thresholds is to account for the individual nature of the exercise-intensity continuum, and accurately represent the relative intensity an athlete is working. In a recent case study, Abt and Lovell (2009) individualised speed thresholds utilising athlete's ventilatory thresholds. The second ventilatory threshold represented the transition from moderate to high-intensity exercise. Results found marked differences in high-intensity work performed between athletes of the same playing position using the individualised speed thresholds, whilst negligible results were demonstrated between the athletes using global thresholds. Limitations of ventilatory thresholds to individualise high-speed locomotion are that it is time consuming, expensive, and requires access to facilities and expertise to administer (Lovell & Abt, 2013). This provides barriers for practitioners working with large squads of athletes. An alternative method for increasing the specificity of speed thresholds, is using the athlete's functional limits of endurance and sprint locomotor capacities. Hunter et al. (2015) and Mendez-Villanueva et al. (2013) recently applied this to youth athletes, using field tests to assess athlete's maximum aerobic, and maximum sprint speeds. Maximum aerobic speed is strongly correlated with $v\dot{V}O_{2max}$, whilst maximum sprint speed allowed for the estimation of an individual's anaerobic speed reserve, and transition to sprinting (Hunter et al., 2015). Currently, no research has utilised field tests to individualise speed thresholds in an elite adult soccer population. Additionally, previous research has focused upon competition, excluding training sessions from the analyses. Considering training scenarios may differ significantly from competition, and a high volume of locomotive training load is accumulated whilst training, further analysis is warranted.

To increase the accuracy of assessing athlete locomotion and improve the training monitoring process, the aim of the current study was to determine the discrepancies between global and individual methods for monitoring high-speed locomotion. Previous research has used youth athletes, presented results in a case study format, and focused solely upon soccer competition (Abt & Lovell, 2009; Hunter et al., 2015; Mendez-Villanueva et al., 2013). The current study focused upon a squad of professional academy soccer athletes, with data collected over a six-week pre season period consisting of training sessions and matches. Cost effective, easy to administer, field tests were used to determine individual speed thresholds, and increased the utility of the method for applied practitioners. Differences in high-speed locomotion, determined using global and individual analysis methods, were assessed. The global method used frequently cited speed thresholds for soccer (Bradley et al., 2010; Lovell & Abt, 2013) whilst the individual method used thresholds derived from athlete's physical testing results (Hunter et al., 2015; Mendez-Villanueva et al., 2013). It was predicted that there would be significant differences between the high-speed locomotion distances produced by global and individual analysis methods. It was also predicted that the differences in high-speed locomotion distances produced between analysis methods would vary dependent upon an athlete's physical capacity.

H_1 – There will be a significant difference in high-speed locomotion distances produced by global and individual analysis methods.

H_{01} - There will be no significant differences in high-speed locomotion distances produced by global and individual analysis methods.

H_2 – Differences in high-speed locomotion distances produced by global and individual analysis methods will vary dependent upon an athlete's physical capacity.

H_{02} - Differences in high-speed locomotion distances produced by global and individual analysis methods will not vary dependent upon an athlete's physical capacity.

4.2 Methodology

Design

Data collection for the study spanned a six-week pre-season period. Participants took part in 32 training sessions, and two friendly matches, resulting in a total of 645 data points. High-speed locomotion was recorded and quantified for each athlete, using 10-Hz portable GPS devices (OptimEye S5B, Firmware Version 7.18; Catapult Innovations, Melbourne, Australia). GPS data for each athlete was analysed using two analysis methods, a global analysis method, and an individual analysis method. Distances travelled performing high-speed running (HSR), very high-speed running (VHSR), and sprinting (SPR) tasks were recorded for each athlete's training session. Values produced by global and individual analysis methods were compared for each locomotion activity. The two analysis methods, global and individual, were the independent variables within the study. The dependent variables within the study were HSR, VHSR, and SPR distances.

Participants

Nineteen, male, full-time professional soccer athletes from an U23 Premier League academy in the UK (18.2 ± 1.1 years, height 180.3 ± 7.1 cm, weight 75.6 ± 9 kg) participated in the study. The participant's mean involvement in soccer was 8.5 (± 1.5) years. Participants had trained four to five times, and played one to two competitive matches per week for a minimum of two years. Goalkeepers were excluded from the study, as they did not participate in the same training sessions. All participants were briefed with a detailed explanation of the proposed study and the requirements. They were informed of potential risks to them, and provided written consent. For participants under the age of 18, parental or guardian consent was provided. Participants were free to withdraw at any time, without any repercussions. The study was conducted with the protocol being fully approved by the ethical review board at the institution prior to commencing. The study conformed to the requirements stipulated by the Declaration of Helsinki, and all health and safety procedures were complied with during the study.

Procedures

The day prior to the start of pre-season training, each athlete completed maximum sprint speed (MSS), and maximum aerobic speed (MAS) protocols to determine peak speed and estimate $v\dot{V}O_{2max}$ respectively. The MSS protocol required the athlete to complete three maximal 40m linear sprints, with a minimum of three minutes rest between repetitions. MSS was defined as the average speed recorded over the quickest 10m sector, and measured using electronic light gates (Brower TC Timing System) to the nearest 0.01s. Intraclass correlation coefficient for the MSS protocol has been cited as 0.94 - 0.99 (Mendez-Villanueva et al., 2013). The MAS protocol was a modified version of the University of Montreal Track Test (Leger & Boucher, 1980), previously used by Mendez-Villanueva et al. (2013). Correlation coefficient for the MAS protocol has been demonstrated as 0.97 (Leger & Boucher, 1980). The test began with an initial running speed of 8 $km.h^{-1}$, with the speed increasing by 0.5 $km.h^{-1}$ each minute. Athletes continued running around a 200m athletics track, marked with

20m intervals, in time with an audible cue, until either exhaustion or three consecutive cones were missed. MAS was estimated as the speed of final one-minute stage completed by the athlete. The MSS protocol was completed on an indoor artificial grass surface with football boots. The MAS protocol was completed on the same grass surface and footwear used throughout the study. Using MSS and MAS scores, each athlete's theoretical anaerobic speed reserve (ASR) was calculated. ASR was defined as the difference between the MSS and MAS score, and reported in $m.s^{-1}$. The MSS and MAS protocols were previously utilised by Mendez-Villanueva et al. (2013) and Hunter et al. (2015) to determine soccer player's maximum sprint and maximum aerobic speeds.

During the six-week study, athletes followed the pre-season training plan constructed by the head technical coach and the strength and conditioning coach. Training sessions (mean duration 72 ± 9 minutes) were a mixture of technical practices, tactical practices, small-sided games, replication of competition, and physical conditioning work. GPS units were switched on 15-minutes prior to the beginning of each training session, in accordance with manufacturer's instructions, and switched off immediately following the session. Each GPS unit was worn in a designated tight-fitting vest located between the scapulae to reduce unwanted movement. Athletes wore the same unit for each training session to avoid inter-unit error.

Data Analysis

10-Hz GPS devices were used to record data for each athlete's training session. It has been shown that 10-Hz GPS devices have an acceptable level of accuracy and reliability when assessing the speed of movement within intermittent exercise (Aguiar et al., 2013; Barbero-Alvarez et al., 2010; Varley et al., 2012). Specifically, Varley et al. (2012) state devices sampling at 10-Hz provide sufficient accuracy when quantifying acceleration, deceleration and constant speed locomotion in team sports. When assessing reliability, Aughey (2011) demonstrated coefficient of variation of 0.7 - 1.3% for 15m and 30m sprints, whilst Delaney et al. (2017) demonstrated coefficient of variation of 3.6 - 5.9% for quantifying instantaneous speed during acceleration using 10-Hz GPS devices. The mean number of satellites during data collection was 15 ± 1, and the mean horizontal dilution of position was 0.7 ± 0.1. Following the recording of each training session, the individual GPS units were downloaded to a computer and analysed using Catapult Sprint software (Catapult Sprint 5.1.5, Catapult

Innovations, Melbourne, Australia). Speed was calculated using measurements of the Doppler shift of signals received, distance was measured using positional differentiation. Distances travelled performing HSR, VHSR, and SPR tasks were recorded. The minimum effort duration for high-speed locomotion tasks was one-second (Hunter et al., 2015). HSR, VHSR and SPR variables were selected considering their use in previous literature investigating individualised training load in soccer (Abt & Lovell, 2009; Hunter et al., 2015; Lovell & Abt, 2013). This analysis process was repeated twice, once applying global speed thresholds, and once applying individual speed thresholds. Data was presented as mean ± standard deviation of distances travelled performing each locomotion task within the session.

Classification of Speed Thresholds

Distances travelled performing HSR, VHSR, and SPR tasks were calculated using global and individual analysis methods. Forms of locomotion was designated a specific speed threshold, which differed for global and individual analysis methods. Speed thresholds used for the global analysis method were locomotion thresholds typically cited within soccer literature. Global speed thresholds for HSR, VHSR, and SPR were 4.2 – 5.5 $m.s^{-1}$, 5.5 - 7.0 $m.s^{-1}$, and > 7.0 $m.s^{-1}$ respectively (Abt & Lovell, 2009; Hunter et al., 2015; Lovell & Abt, 2013). The speed thresholds utilised by the individual analysis method were athlete specific, and determined by MSS and MAS performance. The individual analysis method was previously utilised by Hunter et al. (2015) and Mendez-Villanueva et al. (2013), to represent the functional limits of endurance and sprint locomotor capacities. Individual speed thresholds for HSR, VHSR, and SPR were 80 - 99% MAS, 100% MAS - 30% ASR, and > 30% ASR respectively.

Athlete Groups

Athletes were sub-divided into three groups based upon MAS testing scores. The purpose was to add further depth to the study, allowing for differences in analysis methods to be compared between athletes of differing physical capacities. The groups were characterised as low MAS (LO_{MAS}) (< 1 *SD* from mean), medium MAS (ME_{MAS}) (± 1 *SD* from mean), and high MAS (HI_{MAS}) (> 1 *SD* from mean). Mean testing data for each athlete group, and mean speed thresholds utilised for global and individual analysis methods, are shown in Table 4.1.

Table 4.1 Speed thresholds for LO_{MAS}, ME_{MAS}, and HI_{MAS} athlete groups using global and individual analysis methods.

		Mean Running Speeds			Global Analysis Method			Individual Analysis Method		
Athlete Group	**Data Points**	**Mean MAS ($m.s^{-1}$)**	**Mean MSS ($m.s^{-1}$)**	**Mean ASR ($m.s^{-1}$)**	**HSR Threshold ($m.s^{-1}$)**	**VHSR Threshold ($m.s^{-1}$)**	**SPR Threshold ($m.s^{-1}$)**	**HSR Threshold ($m.s^{-1}$)**	**VHSR Threshold ($m.s^{-1}$)**	**SPR Threshold ($m.s^{-1}$)**
LO_{MAS}	n = 166	4.7 ± 0.2	9.2 ± 0.4	4.6 ± 0.4	4.2 - 5.5	5.5 – 7.0	> 7.0	3.7 – 4.7	4.7 – 6.0	> 6.0
ME_{MAS}	n = 347	5.4 ± 0.2	9.2 ± 0.3	3.9 ± 0.4	4.2 - 5.5	5.5 – 7.0	> 7.0	4.3 – 5.4	5.4 – 6.6	> 6.6
HI_{MAS}	n = 132	6.0 ± 0.2	9.1 ± 0.2	3.1 ± 0.3	4.2 - 5.5	5.5 – 7.0	> 7.0	4.8 – 6.0	6.0 - 6.9	> 6.9

Statistical Analysis

Descriptive analyses were conducted on the data set, with normality values assessed using Kolmogorov-Smirnov and Shapiro-Wilk tests. Significance values of $p < 0.05$ indicate uneven distribution of the data. Skewness and kurtosis values were assessed, with standard error below -2 and above +2 indicating the data was not normally distributed. To determine the within group differences in HSR, VHSR, and SPR values, Wilcoxon signed rank tests were used. This form of statistical testing was used as the data was non-parametric. Wilcoxon signed rank tests were used to determine the differences between HSR, VHSR, and SPR values produced by global and individual analysis methods. A Bonferroni adjustment was used in conjunction with the Wilcoxon signed rank tests. Cohen's *d* tests were used to calculate effect sizes of the differences. A Cohen's *d* effect size of $d = 0.2$ was considered a small effect size, $d = 0.5$ a medium effect size, whilst $d = 0.8$ was considered a large effect size. The level of statistical significance was set at $p < 0.05$. All statistical analyses were performed using the software IBM SPSS statistics (version 22; SPSS, Inc., Chicago, IL, USA).

4.3 Results

Figure 4.1 shows the mean distances travelled performing HSR, VHSR, and SPR in LO_{MAS} athletes, calculated using global and individual analysis methods. Distance travelled performing HSR, VHSR, and SPR were all significantly higher when calculated using the individual analysis method compared to global (HSR Global Mdn = 1220m, Individual Mdn = 1586m, $Z = 11.175$, $p < 0.01$, $d = 0.94$; VHSR Global Mdn = 418m, Individual Mdn =

618m, $Z = 11.165$, $p < 0.01$, $d = 0.54$; SPR Global Mdn = 0m, Individual Mdn = 80m, $Z = 11.040$, $p < 0.01$, $d = 0.77$). Large effect sizes were demonstrated for HSR, with medium effect sizes demonstrated for VHSR and SPR. Mean differences were 390m (95% CI ± 21m), 310m (95% CI ± 32m), and 88m (95% CI ± 14m) higher using the individual analysis method for HSR, VHSR, and SPR respectively.

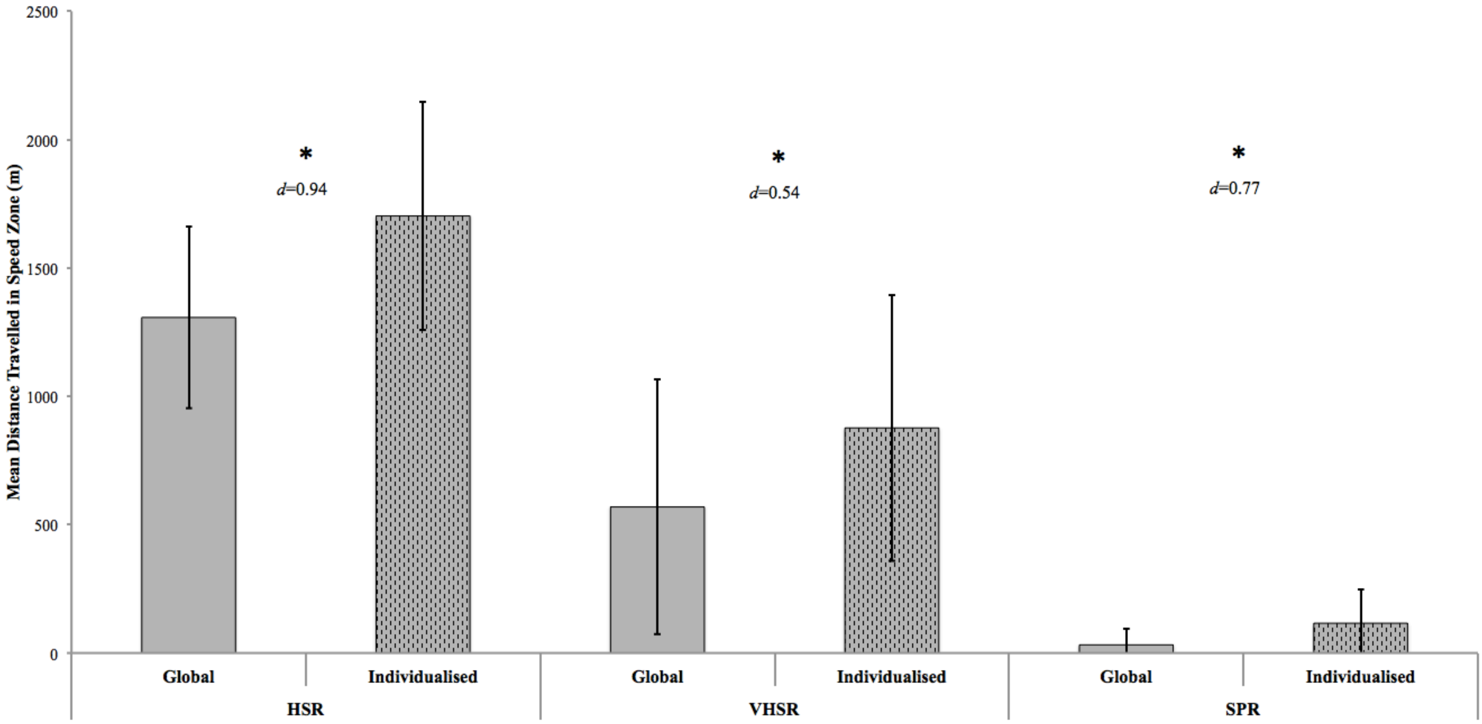

Figure 4.1 Mean (± SD) Distance travelled HSR, VHSR, and SPR when utilising global or individual analysis methods, in LO_{MAS} athletes. N.B. asterisk represents significant difference of $p < 0.01$, d represents effect size.

Figure 4.2 shows mean distances travelled performing HSR, VHSR, and SPR in ME_{MAS} athletes, calculated using global and individual analysis methods. For HSR, and VHSR no significant differences in distances produced by individual and global analysis methods were identified. For SPR, the individual analysis method produced significantly higher distances when compared to the global analysis method (Global Mdn = 79m, Individual Mdn = 151m, $Z = 15.395$, $p < 0.01$, $d = 0.39$), demonstrating a small effect size. Mean SPR differences were 76m (95% CI ± 12m), higher using the individual analysis method compared to the global.

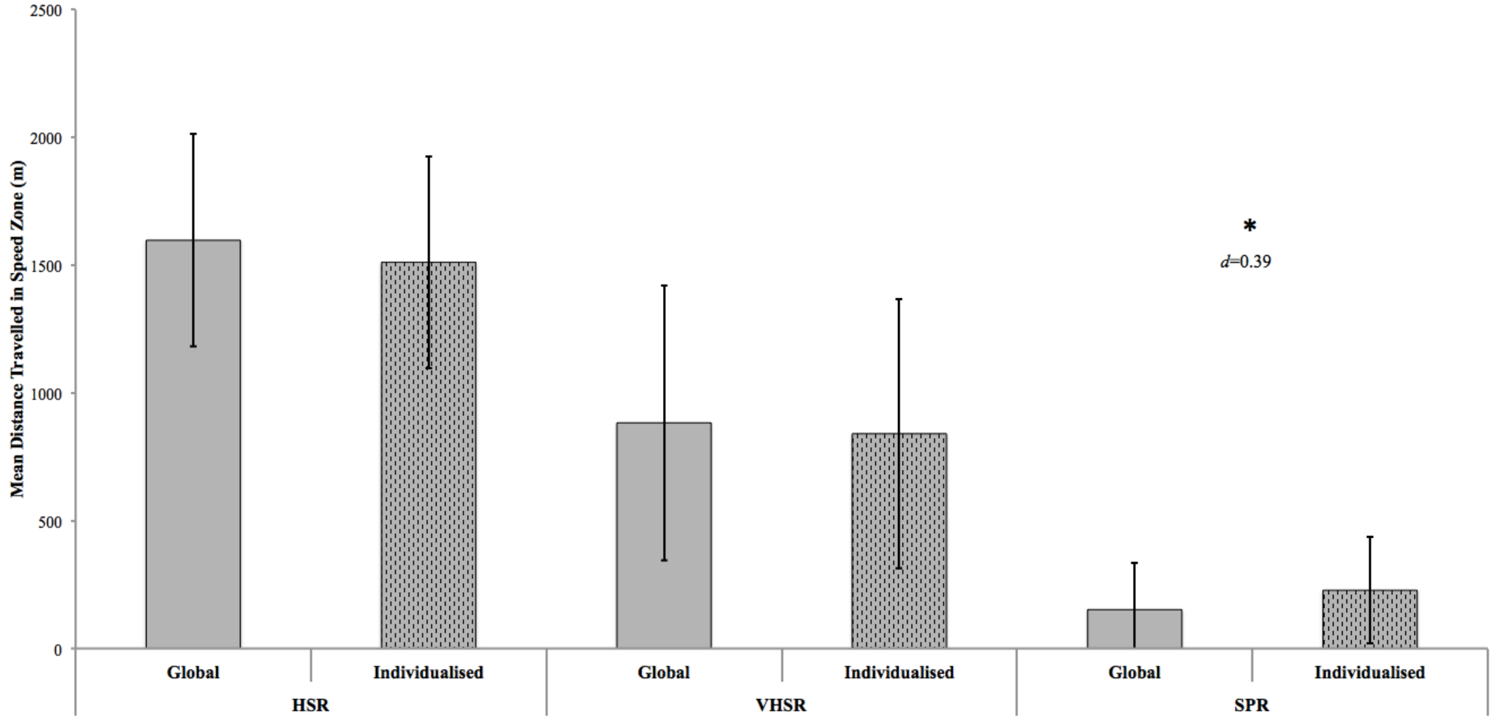

Figure 4.2 Mean (± SD) Distance travelled HSR, VHSR, and SPR when utilising global or individual analysis methods, in ME_{MAS} athletes. N.B. asterisk represents significance difference of $p < 0.01$, d represents effect size.

Figure 4.3 shows mean distances travelled performing HSR, VHSR, and SPR in HI_{MAS} athletes, calculated using global and individual analysis methods. Results for the HI_{MAS} athlete group show the opposite trend to the LO_{MAS} athlete group. The individual analysis method produced significantly lower distances, when compared to the global analysis method for both HSR (Global Mdn = 1893m, Individual Mdn = 1374m, $Z = 3.956$, $p < 0.01$, $d = 1.73$), and VHSR (Global Mdn = 1153m, Individual Mdn = 829m, $Z = 3.274$, $p < 0.01$, $d = 0.72$). A large effect size was demonstrated for HSR, with a medium effect size for VHSR. Mean differences were 549m (95% CI ± 24m) and 341m (95% CI ± 30m) lower for HSR and VHSR, when utilising the individual method compared to global. No differences were seen in SPR distances between the two analysis methods.

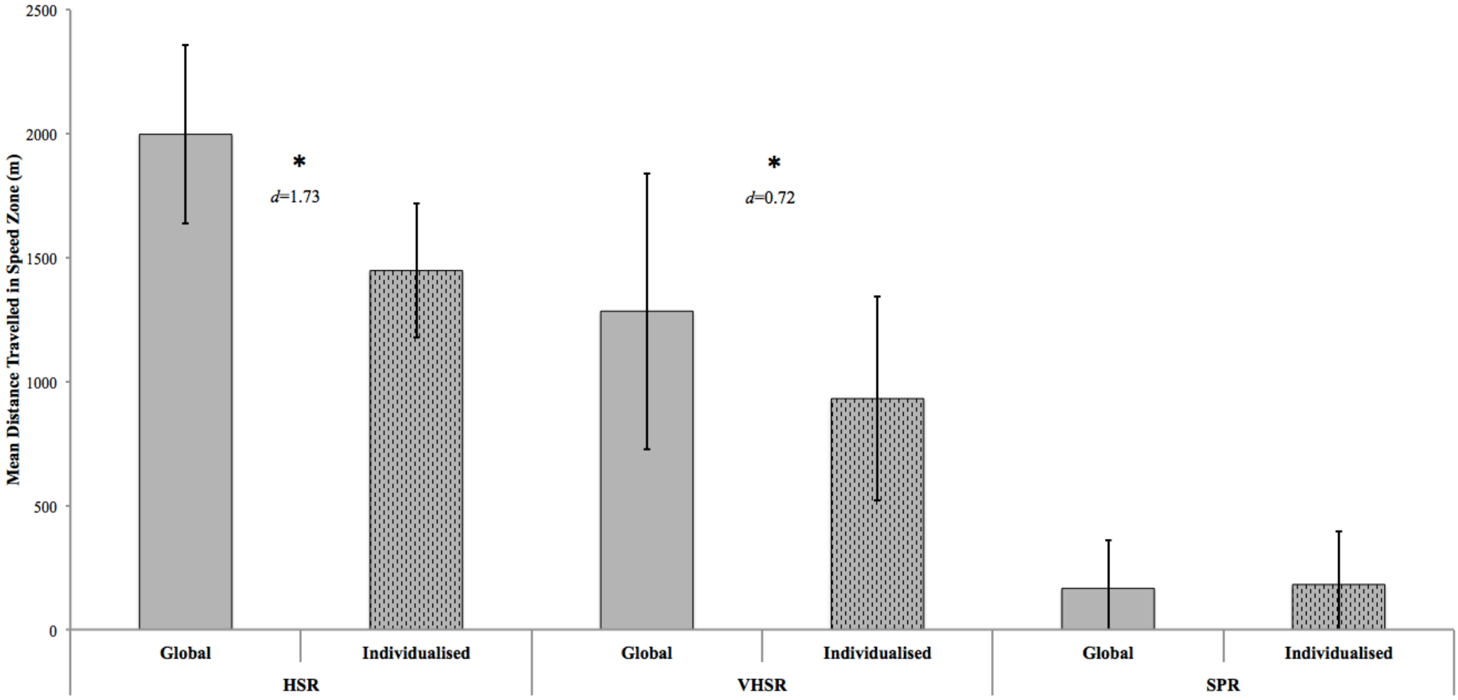

Figure 4.3 Mean (± SD) Distance travelled HSR, VHSR, and SPR when utilising global or individual analysis methods, in HI_{MAS} athletes. N.B. asterisk represents significance difference of $p < 0.01$, d represents effect size.

4.4 Discussion

The aim of the study was to analyse differences between global and individual methods for monitoring high-speed locomotion. Individual speed thresholds for athletes were determined using field based assessments of MSS and MAS, with athletes sub-divided into three groups dependent upon MAS performance. This study was the first to individualise speed thresholds using two field based performance tests, and to sub-divide athletes dependent upon physical capacity.

The significant differences in HSR, VHSR, and SPR distances produced by global and individual analysis methods were the result of the speed thresholds employed (Table 4.1). Results for LO_{MAS} athletes demonstrated mean HSR, VHSR, and SPR distances were significantly higher using the individual analysis method compared to the global. This resulted from lower speed thresholds used for the individual analysis method (≥ 3.7 ± 0.1 m.s^{-1}, ≥ 4.7 ± 0.2 m.s^{-1}, and ≥ 6.0 ± 0.2 m.s^{-1}) in comparison to the global (≥ 4.2 m.s^{-1}, ≥ 5.5

m.s^{-1}, and ≥ 7.0 m.s^{-1}). For ME_{MAS} athletes, the only significant difference between analysis methods were between mean SPR distances, with individual producing significantly higher distances than global. This was the result of a lower SPR threshold for individual (≥ 6.6 ± 0.2 m.s^{-1}) compared to the global analysis method (≥ 7.0 m.s^{-1}). Similar speed thresholds were employed for HSR and VHSR, resulting in no significant differences between analysis methods. For HI_{MAS} athletes, the individual analysis method produced significantly lower mean HSR and VHSR distances compared to global. This was the result of higher speed thresholds for individual (≥ 4.8 ± 0.1 m.s^{-1} and ≥ 6.0 ± 0.2 m.s^{-1}) in comparison to global (≥ 4.2 m.s^{-1} and ≥ 5.5 m.s^{-1}). For SPR, thresholds employed were similar, resulting in no significant differences. When considering current study predictions, the significant differences in HSR, VHSR and SPR distances produced between analysis methods meant H_1 was accepted, and H_{01} rejected. Considering the significant differences between HSR, VHSR, and SPR distances varied between athlete groups, H_2 was accepted, and H_{02} was rejected.

Current results demonstrated the individual analysis method produced significantly higher HSR, VHSR, and SPR distances in LO_{MAS} athletes, and significantly lower HSR and VHSR distances in HI athletes, compared to the global analysis method. The findings compliment research by Gabbett (2015) and Lovell and Abt (2013), despite differences in methodologies. Gabbett (2015) recently compared global and individual analysis thresholds in youth Rugby players, individualising speed thresholds using only maximum sprint speed. Gabbett (2015) concluded that individualising speed thresholds increased the high-speed running attributed to relatively slower athletes, and decreased the high-speed running attributed to faster athletes. Lovell and Abt (2013) investigated the differences between high-intensity distances produced by global and individual speed thresholds in elite soccer players. In contrast to the current study, where speed thresholds were individualised using field based performance tests, Lovell and Abt (2013) calculated ‘high-intensity’ as distance travelled above the second ventilatory threshold. Results were similar to those demonstrated in LO_{MAS} athletes within the current study, with high-intensity distance significantly lower when using global thresholds. Although results produced by Gabbett (2015) and Lovell and Abt (2013) are similar for HI_{MAS} and LO_{MAS} athletes, the present study showed no significant differences in HSR and VHSR distances produced between analysis methods for ME_{MAS} athletes. Differences in findings are likely the result of further analysis conducted within the current study. Current results highlight the importance of sub-dividing athlete groups, providing insight as to how differences between analysis methods vary within a squad of athletes. Additionally, the current study utilised multiple performance markers to determine individual thresholds. When individualising speed thresholds, Hunter et al. (2015) recommend multiple performance markers to characterise the functional limits of endurance and sprint capacities. Multiple performance measures allow for more representation of the relative locomotive training load elicited upon athletes when compared to global speed thresholds. Considering previous research used a single performance marker to individualise speed thresholds, this may provide explanation for differing results within the current study.

Current findings have significant implications for applied practitioners aiming to accurately monitor locomotive training load, and reduce injury risk. Recent research has focused upon the association between training load and injury occurrence. Gabbett (2016) utilised the acute:chronic workload ratio as a tool to identify injury risk, citing a ‘sweet spot’ of optimal training load associated with a reduced probability of injury occurrence. When utilising workload ratios to calculate injury risk, it is vital training load data included is a valid representation of load elicited upon the athlete. Previous research suggests individual speed thresholds produce more accurate representations of actual training load elicited, due to individual’s physical performance capacities being accounted for (Hunter et al., 2015). Integrating individual’s physical capacity within calculation of speed thresholds results in increased validity of training load data. Without acknowledging an athlete’s physical capacities, global speed thresholds may result in inaccurate representations of locomotive training load. Inaccurate representation of training load increases the difficulty associated with prescribing optimal training loads, increasing the probability of inappropriate training load prescription and injury risk. Global speed thresholds allow practitioners to compare performance between athletes, and assess an individual’s ability to tolerate locomotive training load. However, if the aim is to accurately quantify the intensity of high-speed locomotion, individual analysis methods distinguish between athletes of differing capacities and maturation. The current study demonstrated individual speed thresholds could be calculated using field based MAS and MSS tests. This provides practitioners operating with large squads in applied settings an efficient and cost-effective method to individualise the monitoring of high-speed locomotion.

4.5 Conclusion

Significant differences were demonstrated between high-speed locomotion distances calculated using global and individual analysis methods. High-speed locomotion was similar between analysis methods for ME_{MAS} athletes, but global distances were significantly lower for LO_{MAS} athletes, and significantly higher for HI_{MAS} athletes compared to individual distances. With a large emphasis in modern day soccer placed upon physical development, the need to accurately prescribe and monitor training load is paramount. Previous research suggested individual analysis methods account for the relative intensity of locomotion tasks by incorporating each athlete's physical capacities, with global analysis methods unable to. Comparatively, global speed thresholds allow practitioners to compare physical performance, and determine an individual's ability to tolerate a locomotive training load. If the objective is to accurately quantify the intensity of high-speed locomotion for athletes of differing capacities and maturation, it is recommended an individual analysis method be utilised. This provides practitioners with the necessary tools to accurately monitor locomotive training load, and ultimately optimise performance and reduce injury risk. The current study utilised field tests to determine individual speed thresholds, a method that can be replicated effectively for large squads. Although the study was conducted in soccer, similarities in movement demands and intermittent speed profiles mean that findings are applicable to the majority of team sports.

5.0 Study Two - Individualising acceleration in English Premier League academy soccer players

Publication arising from this chapter: Abbott, W., Brickley, G., Smeeton, N.J., & Mills, S. (2018). Individualizing acceleration in English Premier League academy soccer players. *The Journal of Strength and Conditioning Research, 32(12),* 3503-3510.

Abstract

Global thresholds are typically utilised to band acceleration dependent upon intensity. However, global thresholds do not account for variation in individual capacities, failing to quantify true intensity of acceleration. Previous research has investigated discrepancies in high-speed distances produced utilising global and individual speed thresholds, not yet investigated for acceleration. The current aim was to investigate discrepancies between global and individual thresholds when quantifying acceleration tasks. Acceleration data was recorded for 31 professional soccer players, utilising 10-Hz GPS devices. Distances travelled performing low-, moderate-, and high-intensity acceleration were calculated for athletes utilising global and individual thresholds. Global acceleration thresholds for low-, moderate-, and high-intensity acceleration were classified as 1 - 2 $m \cdot s^{-2}$, 2 - 3 $m \cdot s^{-2}$, and > 3 $m \cdot s^{-2}$ respectively, with individual thresholds classified as 25 - 50%, 50 - 75%, and > 75% of maximum acceleration respectively. Athletes were grouped low (LO_{ACC}), medium (ME_{ACC}), or high (HI_{ACC}) maximum accelerative capacity, determined utilising three maximal 40m linear sprints. Two-way mixed design ANOVAs were used to analyse differences in acceleration distances produced between analysis methods and athlete groups. No significant differences were identified between analysis methods for LO_{ACC}. For ME_{ACC}, no significant differences were demonstrated for low-intensity. Moderate- and high-intensity acceleration distances were significantly higher for global compared to individual analysis method ($p < 0.01$). For HI_{ACC}, significantly higher acceleration distances were produced for all acceleration intensities utilising global thresholds ($p < 0.01$). Significant differences identified between analysis methods suggest practitioners must apply caution when utilising global thresholds. Global thresholds do not account for individual capacities, and may provide an inaccurate representation of relative intensity of acceleration tasks.

5.1 Introduction

Introduction of global positioning systems (GPS) to soccer has allowed an increased focus on high-speed activities (Varley & Aughey, 2013). It is vital high-speed activities are quantified accurately, considering their high-energy cost (Howatson & Milak, 2009), and link to goal scoring opportunities (Faude et al., 2012; Little & Williams, 2005). Previously, global speed thresholds have been utilised to quantify an individual's high-speed activities (Bradley et al., 2009). A limitation of global thresholds is the inability to acknowledge the relative intensity of activity. The exercise intensity continuum is individual-dependent, resulting in reduced accuracy when applying global thresholds to determine relative intensity for individuals (Abt & Lovell, 2009). To increase the accuracy of quantifying individual training stimulus, individual thresholds have been developed. Individual speed thresholds have previously been calculated utilising maximum sprint speed (Gabbett, 2015; Reardon et al., 2015), maximum aerobic speed (Mendez-Villanueva et al., 2013), gas ventilatory thresholds (Abt & Lovell, 2009; Clarke et al., 2015), or a combination of the aforementioned markers (Hunter et al., 2015). Individual thresholds aim to quantify the relative intensity of high-speed locomotion, providing accurate information on an individual's training stimulus. Lovell and Abt (2013) compared distances produced by global speed thresholds, and individual speed thresholds determined utilising the second ventilatory threshold. Results demonstrated significant differences in high-intensity work performed between athletes of the same positional role utilising individual speed thresholds, whilst non-significant results were demonstrated between the same athletes when utilising global thresholds. Recently, several researchers have found discrepancies between values produced utilising global and individual speed thresholds (Clarke et al., 2015; Gabbett, 2015; Reardon et al., 2015). These discrepancies highlight the precision required to accurately monitor individual athlete training load.

Despite having an important role, soccer training load should not focus solely upon monitoring high-speed activities. Focusing upon speed thresholds neglects metabolically demanding tasks occurring at low speed, such as acceleration (Akenhead et al., 2013; Osgnach et al., 2010). Research has reported a three- to eight-fold greater number of accelerations than sprints when comparing their frequency during competition (Dalen et al., 2016; Varley & Aughey, 2013). Lockie et al. (2011) state the mean duration of a sprint in soccer is approximately two-seconds. Consequently, an athlete's ability to accelerate and reach high speed quickly is vital for on-field performance. Greig and Siegler (2009) suggest sprinting and acceleration tasks are important underlying factors for muscular fatigue, given the high neuromuscular demand associated. Considering the link between fatigue and the occurrence of muscular strain injuries, as demonstrated by epidemiological injury data from the latter stages of competition, quantifying acceleration within the training load monitoring process would have large consequences for recovery.

As with high-speed activities, when quantifying acceleration tasks it is vital individual capacities are acknowledged. Previous research demonstrated acceleration demands vary significantly between playing positions during competition (Dalen et al., 2016; Ingebrigtsen et al., 2015). Dalen et al. (2016) concluded wide defenders and wide attackers accelerated with higher frequency than central midfielders and central defenders. Ingebrigtsen et al. (2015) identified similar trends, with wide players producing significantly more acceleration manoeuvres than central players. Authors explained central players typically operate in congested areas of the pitch, limiting space to accelerate maximally and achieve high speeds. A limitation of previous research investigating acceleration occurrence in soccer, is global thresholds were utilised to band acceleration tasks. Currently, no consistent global acceleration thresholds exist within the literature. Aughey (2010) utilised a single threshold of 2.78 $m \cdot s^{-2}$ to quantify acceleration occurrence. Akenhead et al. (2013) further divided thresholds of 1 - 2 $m \cdot s^{-2}$ for low-intensity acceleration, 2 - 3 $m \cdot s^{-2}$ for moderate-intensity, and > 3 $m \cdot s^{-2}$ for high-intensity, whilst Bradley et al. (2010) defined moderate-intensity as 2.5 - 4 $m \cdot s^{-2}$ and high-intensity as > 4 $m \cdot s^{-2}$. Although global acceleration thresholds allow for comparisons in external workload completed by athletes, they fail to acknowledge individual's maximum accelerative capacities, and relative intensity of the stimulus placed upon individual athletes. The dose-response relationship is highly individual, with athletes' internal responses to the same external stimulus varying, and resulting in differing degrees of adaptation (Impellizzeri et al., 2005). Consequently, it is impossible to determine individual's acceleration intensity without an individualised approach to monitoring.

Considering the limitations of global acceleration thresholds, individual thresholds provide an alternative method for monitoring acceleration intensity. Sonderegger et al. (2016) were the first to attempt to individualise acceleration thresholds, incorporating individual's maximum accelerative capacity. This methodology was utilised to investigate acceleration values produced at various initial running speeds. Results highlighted the variance in maximum accelerative capacities in highly trained junior soccer players, with values ranging from 4.5 -

7.1 $m \cdot s^{-2}$. Despite a non-elite cohort, large variations in individual accelerative capacity provide further rationale for an individualised approach to quantifying acceleration tasks. Akenhead and Nassis (2016) recently investigated current training load practices and perceptions amongst applied practitioners. Despite compelling physiological rationale, results demonstrated infrequent use of individual thresholds within applied sport. This is likely due to the time-cost associated with testing large squads, and the availability of expensive testing equipment. These barriers could be overcome by utilising a field-based assessment with the capability of testing squads of athletes simultaneously.

Considering the advantages of an individual approach to monitoring acceleration, and the vast literature currently utilising global acceleration thresholds, rationale exists for study into the discrepancies between global and individual acceleration thresholds. The current study aimed to determine the discrepancies between global and individual thresholds when quantifying acceleration tasks. Athletes were categorised dependent upon maximum accelerative capacities to provide further insight into individualising thresholds for athletes of varying physical capacities. Considering the high proportion of applied practitioners utilising global acceleration thresholds for athletes, results will have significant implications for future quantification of acceleration. It was predicted that significant differences would be evident between acceleration distances produced by global and individual analysis methods. Additionally, it was predicted the magnitude of differences between analysis methods would vary dependent upon individual's maximum accelerative capacities.

H_3 – There will be significant differences in acceleration distances produced by global and individual analysis methods.

H_{03} – There will be no significant differences in acceleration distances produced by global and individual analysis methods.

H_4 – Differences in acceleration distances produced by global and individual analysis methods will vary dependent upon an athlete's maximum accelerative capacity.

H_{04} – Differences in acceleration distances produced by global and individual analysis methods will not vary dependent upon an athlete's maximum accelerative capacity.

5.2 Methodology

Design

Participants were sub-divided into three groups utilising individual maximum acceleration values (LO_{ACC} – low accelerative capacity, ME_{ACC} – medium accelerative capacity, HI_{ACC} – high accelerative capacity). Participants took part in 23 training sessions, and four friendly matches. Data collection spanned a four-week pre-season period. Acceleration data was recorded and quantified for each athlete, utilising 10-Hz portable GPS devices (OptimEye S5B, Version 7.18; Catapult Innovations, Melbourne, Australia). GPS-derived acceleration data was analysed for individual athletes utilising two analysis methods; a global analysis method, and individual analysis method. Distances travelled performing low-intensity, moderate-intensity, and high-intensity acceleration was recorded for individual athlete's training sessions. Distances produced utilising global and individual analysis methods were compared for low-, moderate-, and high-intensity acceleration.

Participants

Thirty-one, male, full-time professional soccer athletes from a Premier League academy in the UK (19.4 ± 1.7 years, height 180.4 ± 9.2 cm, weight 76.9 ± 7.2 kg) participated in the study. Participants took part in 23 training sessions, and four friendly matches during the study (median 26 (IQR 26 – 27) data collections per participant). Participant's mean involvement in soccer was 7.1 (± 1.6) years. Participants had trained four to five times per week, and played one to two competitive matches per week for a minimum of two years. Goalkeepers were excluded from the study as they participated in separate training. Participants were briefed with a detailed explanation of the proposed study and requirements. Participants were informed of potential risks, and provided written consent. For participants under the age of 18, parental or guardian consent was provided. Participants were free to withdraw at any time, without any repercussions. The study was conducted with the protocol fully approved by the ethical review board at the institution prior to commencing. The study conformed to the requirements stipulated by the Declaration of Helsinki, and all health and safety procedures were complied with.

Procedures

The day prior to commencement of pre-season training, athletes completed a maximum acceleration protocol. The protocol required athletes to complete three maximal 40m linear sprints, with at least three minutes rest between repetitions. The protocol was completed on artificial grass, with football boots. This protocol has previously been utilised to determine maximum sprint speed (Mendez-Villanueva et al., 2013), with a similar protocol utilised to determine maximum accelerative capacity in previous research (Sonderegger et al., 2016). The maximum rate of acceleration was calculated for each sprint utilising 10-Hz portable GPS devices (OptimEye S5B, Version 7.18; Catapult Innovations, Melbourne, Australia), with the highest acceleration values recorded for each athlete.

During the study, athletes followed the pre-season training plan constructed by the head technical coach and strength and conditioning coach. Training sessions (mean duration 81 ± 10 minutes) were a mixture of technical practices, tactical practices, small-sided games, replication of competition, and physical conditioning work. GPS units were switched on 15-minutes prior to each training session, in accordance with manufacturer's instructions, and switched off immediately following the session. Each GPS unit was worn in a designated tight-fitting vest located between the scapulae to reduce unwanted movement. Athletes wore the same unit for each training session to avoid inter-unit error.

Data Analysis

10-Hz GPS devices were utilised to record data for individual athlete's training sessions. Akenhead et al. (2014) state 10-Hz GPS units can accurately assess acceleration in team-sports, having been validated against 2000-Hz laser devices. The coefficient of variation for quantifying instantaneous speed during acceleration tasks ranged from 3.6 - 5.9%, confirming an acceptable level of validity (Akenhead et al., 2014; Delaney et al., 2017). The mean number of satellites during data collection was 15 ± 1, and mean horizontal dilution of position was 0.8 ± 0.1. Malone et al. (2017) suggest > 6 satellites for adequate data quality, however following conversations with the manufacturer, data was excluded if number of satellites decreased < 12. If horizontal dilution of position was > 1, data was excluded (Malone et al., 2017). Following training sessions, individual GPS units were downloaded to a computer and analysed utilising Catapult Sprint software (Catapult Sprint 5.1.5, Catapult Innovations, Melbourne, Australia). Using time and location data, speed and acceleration were calculated. Speed was calculated using measurements of the Doppler shift of signals received, distance was measured using positional differentiation (Malone et al., 2017). Acceleration was calculated as the increasing rate of change in instantaneous speed over time. Only the increasing rate of change in speed was measured, as a decreasing rate of change in speed is classified as a deceleration (Hodgson et al., 2014). Distances travelled performing low-, moderate-, and high-intensity acceleration tasks were recorded. The minimum effort duration for acceleration tasks was 0.4 seconds, similar to minimum effort durations cited in previous research (Dalen et al., 2016; Hodgson et al., 2014; Ingebrigtsen et al., 2015). The analysis process was repeated twice, first applying global acceleration thresholds, and again applying individual acceleration thresholds.

Classification of Acceleration Thresholds

Acceleration thresholds utilised for the global analysis method were frequently cited thresholds within soccer literature. Global acceleration thresholds for low-, moderate-, and high-intensity acceleration was classified as 1 - 2 $m·s^{-2}$, 2 - 3 $m·s^{-2}$, and > 3 $m·s^{-2}$ respectively (Akenhead et al., 2013; Hodgson et al., 2014). The acceleration thresholds utilised by the individual analysis method were athlete specific, and determined by maximum acceleration values recorded during the testing protocol. The individual analysis method had previously been utilised by Sonderegger et al. (2016) to quantify intensity of acceleration activities. Sonderegger et al. (2016) banded low-, moderate-, and high-intensity acceleration as 25 - 50%, 50 - 75%, and > 75% of maximal acceleration respectively.

Athlete Groups

Athletes were sub-divided into three groups utilising maximum acceleration testing scores. The purpose was to compare discrepancies between analysis methods for athletes of varying accelerative capacities. Groups were characterised as low accelerative capacity (LO_{ACC}) (< 1 *SD* from mean), medium accelerative capacity (ME_{ACC}) (± 1 *SD* from mean), and high accelerative capacity (HI_{ACC}) (> 1 *SD* from mean). Mean testing data for athlete groups, and mean acceleration thresholds utilised for global and individual analysis methods are presented in Table 5.1.

Table 5.1. Acceleration thresholds for LO, ME, and HI athlete groups utilising global and individual analysis methods.

Athlete Group	Number of Athletes (n)	Data Points	Maximum Acceleration ($m \cdot s^{-2}$)	Low-Intensity Acceleration Threshold ($m \cdot s^{-2}$)	Moderate-Intensity Acceleration Threshold ($m \cdot s^{-2}$)	High-Intensity Acceleration Threshold ($m \cdot s^{-2}$)
Global Analysis Method						
LO_{ACC}	9	N = 238	5.7 ± 0.1	1.0 – 2.0	2.0 - 3.0	> 3.0
ME_{ACC}	14	N = 366	6.5 ± 0.2	1.0 – 2.0	2.0 - 3.0	> 3.0
HI_{ACC}	8	N = 211	7.2 ± 0.2	1.0 – 2.0	2.0 - 3.0	> 3.0
Individual Analysis Method						
LO_{ACC}	9	N = 238	5.7 ± 0.1	1.4 – 2.8	2.8 – 4.3	> 4.3
ME_{ACC}	14	N = 366	6.5 ± 0.2	1.6 – 3.3	3.3 – 4.9	> 4.9
HI_{ACC}	8	N = 211	7.2 ± 0.2	1.8 – 3.6	3.6 – 5.4	> 5.4

LO_{ACC} = low accelerative capacity, ME_{ACC} = medium accelerative capacity, HI_{ACC} = high accelerative capacity.

Statistical Analysis

Descriptive analyses were conducted on the data set, with normality values assessed using Kolmogorov-Smirnov and Shapiro-Wilk tests. Significance values $p > 0.05$ indicated data was normally distributed. Skewness and kurtosis values were assessed, with standard error between -2 and +2 indicating the data was normally distributed. To investigate differences low-, moderate-, and high-intensity acceleration distances produced by global and individual thresholds for LO_{ACC}, ME_{ACC}, and HI_{ACC} athlete groups, two-way mixed design ANOVAs were used where Analysis Method (Global, Individual) was the within-subjects variable, and Athlete Group (LO_{ACC}, ME_{ACC}, HI_{ACC}) was the between subjects variable. Partial eta-squared values were calculated to estimate the effect size for the ANOVA. A partial eta-squared effect size of $\eta_p^2 = .02$ was considered a small effect size, an effect size of $\eta_p^2 = .13$ was considered a medium effect size, whilst $\eta_p^2 = .26$ was considered a large effect size. Bonferroni tests were used post-hoc to assess where differences occurred, with Cohen's *d* tests used to calculate effect sizes. An effect size of $d = 0.2$ was considered a small effect size, an effect size of $d = 0.5$ was considered a medium effect size, whilst $d = 0.8$ was considered a large effect size. All statistical analyses were performed using the software IBM

SPSS statistics (version 22; SPSS, Inc., Chicago, IL, USA). The level of statistical significance was set at $p < 0.05$.

5.3 Results

For low-intensity acceleration distance, significant differences and large effects were identified for analysis method ($F_{(1,812)} = 2356.036$; $p < 0.01$, $\eta_p^2 = .81$), with a weak interaction between analysis method and athlete group ($F_{(2,812)} = 27.766$; $p < 0.01$, $\eta_p^2 = .09$). No significant differences were identified between athlete group ($F_{(2,812)} = 0.921$; $p = 0.40$, $\eta_p^2 = .01$). Moderate-intensity acceleration distance also highlighted significant differences between analysis method ($F_{(1,812)} = 2424.522$; $p < 0.01$, $\eta_p^2 = .81$), and interaction ($F_{(2,812)} = 48.897$; $p < 0.01$, $\eta_p^2 = .15$), demonstrating large and moderate effect sizes respectively. No significant differences were identified for athlete group ($F_{(2,812)} = 0.257$; $p = 0.774$, $\eta_p^2 = .01$). High-intensity followed a similar trend to moderate-intensity and low-intensity acceleration distance, with significant differences identified for analysis method ($F_{(1,812)} = 3072.155$; $p < 0.01$, $\eta_p^2 = .85$), and interaction ($F_{(2,812)} = 23.312$; $p < 0.01$, $\eta_p^2 = .08$), but no significant differences identified for athlete group ($F_{(2,812)} = 3.206$; $p = 0.41$, $\eta_p^2 = .01$). A large effect size was demonstrated for analysis method, whilst a small effect was demonstrated for the interaction. When examining the direction of differences between analysis methods for low-, moderate-, and high-intensity acceleration distances, the global analysis method produced significantly higher distances than individual for all intensities ($p < 0.05$).

Figure 5.1 presents mean distance travelled performing low-intensity, moderate-intensity, and high-intensity acceleration by LO_{ACC} athletes utilising global and individual thresholds. Analysis demonstrated no significant differences in acceleration distances produced between analysis methods for any acceleration intensity.

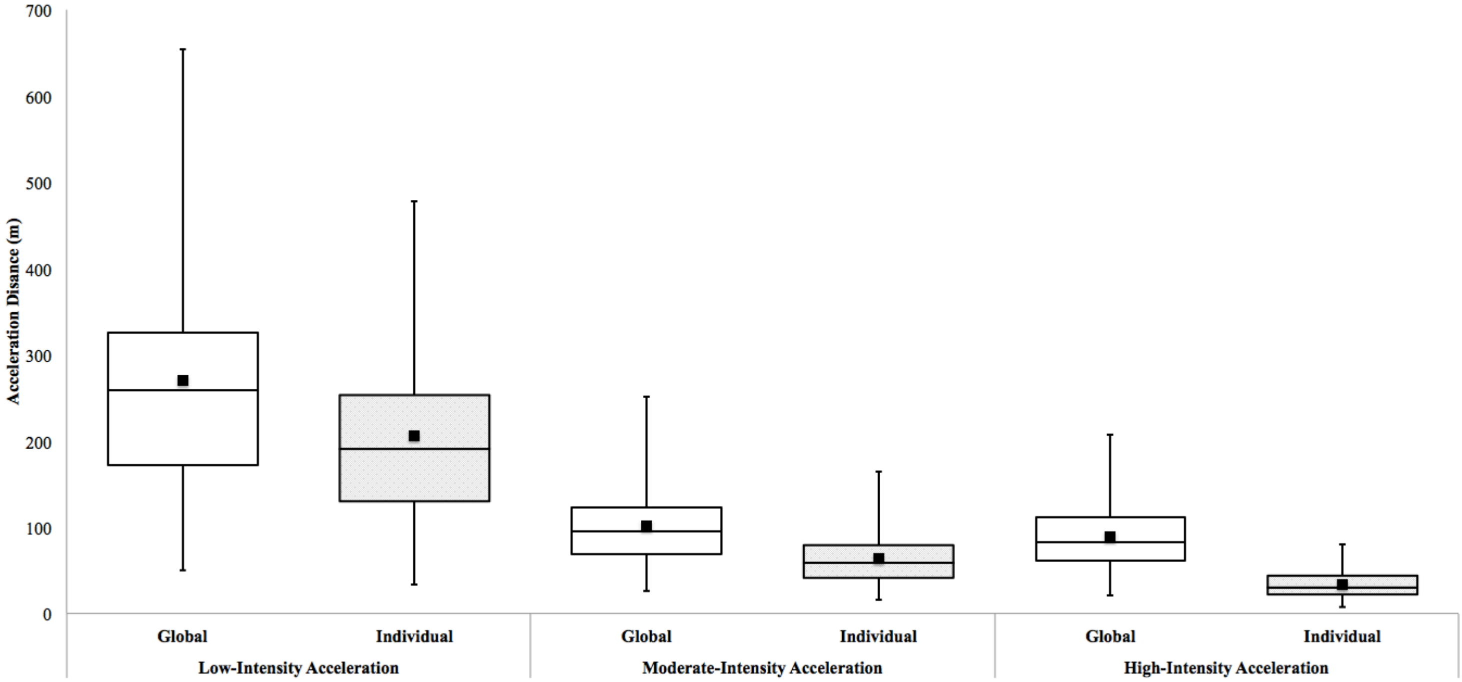

Figure 5.1. Distribution and mean distance travelled performing low-, moderate-, and high-intensity acceleration when utilising global or individual thresholds, in LO_{ACC} athletes. N.B. asterisk represents significant difference, *d* represents effect size.

Figure 5.2 presents mean distance travelled performing low-intensity, moderate-intensity, and high-intensity acceleration by ME_{ACC} athletes utilising global and individual thresholds. Post-hoc analysis demonstrated no significant difference in low-intensity acceleration distances produced utilising global and individual analysis methods, however significant differences were identified in moderate-intensity ($t_{(365)} = 34.060$, $p < 0.01$, $d = 1.06$) and high-intensity acceleration distances ($t_{(365)} = 39.140$, $p < 0.01$, $d = 2.24$) between analysis methods. For both moderate- and high-intensity, significant higher acceleration distances were produced utilising the global analysis method. Mean moderate-intensity acceleration distances utilising global thresholds were 43m (95% CI ± 2.5m) higher than individual thresholds, whilst mean high-intensity acceleration distances were 62m (95% CI ± 3.1m) higher. These distances equated to 74% (95% CI ± 4%) higher moderate-intensity, and 248% (95% CI ± 12%) higher high-intensity acceleration distances when utilising the global analysis method.

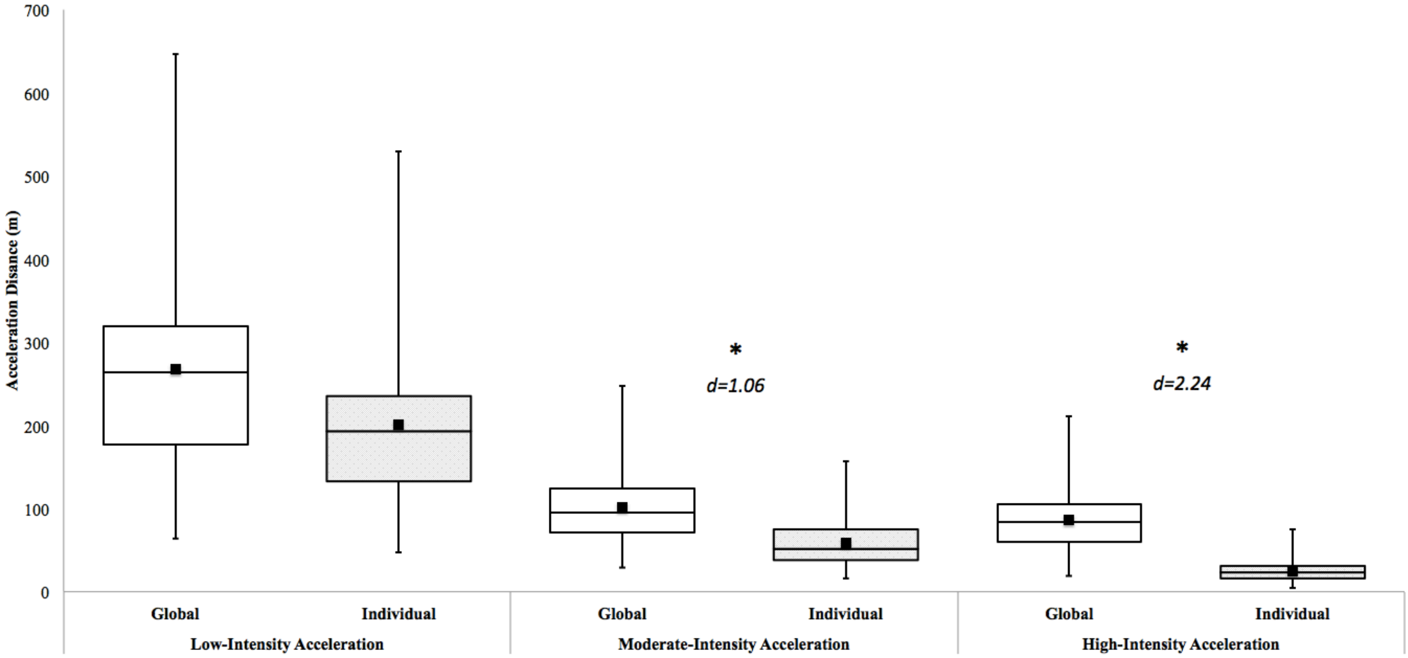

Figure 5.2. Distribution and mean distance travelled performing low-, moderate-, and high-intensity acceleration when utilising global or individual thresholds, in ME_{ACC} athletes. N.B. asterisk represents significant difference, *d* represents effect size.

Figure 5.3 presents mean distance travelled performing low-intensity, moderate-intensity, and high-intensity acceleration by HI_{ACC} athletes utilising global and individual thresholds. Post-hoc analysis demonstrated significant differences between analysis methods for low-intensity ($t_{(210)} = 26.397$, $p < 0.01$, $d = 0.70$), moderate-intensity ($t_{(210)} = 25.512$, $p < 0.01$, $d = 1.38$), and high-intensity acceleration distances ($t_{(210)} = 28.173$, $p < 0.01$, $d = 2.59$). For all acceleration intensities, the global analysis method produced significantly higher distances than the individual. When utilising the global analysis method, mean distances were 92m (95% CI ± 6.9m), 61m (95% CI ± 4.7m), and 75m (95% CI ± 5.2m) higher for low-, moderate-, and high-intensity acceleration respectively. Distances equated to 45% (95% CI ± 3%), 122% (95% CI ± 9%), and 441% (95% CI ± 30%) higher low-, moderate-, and high-intensity acceleration distances respectively when utilising the global analysis method.

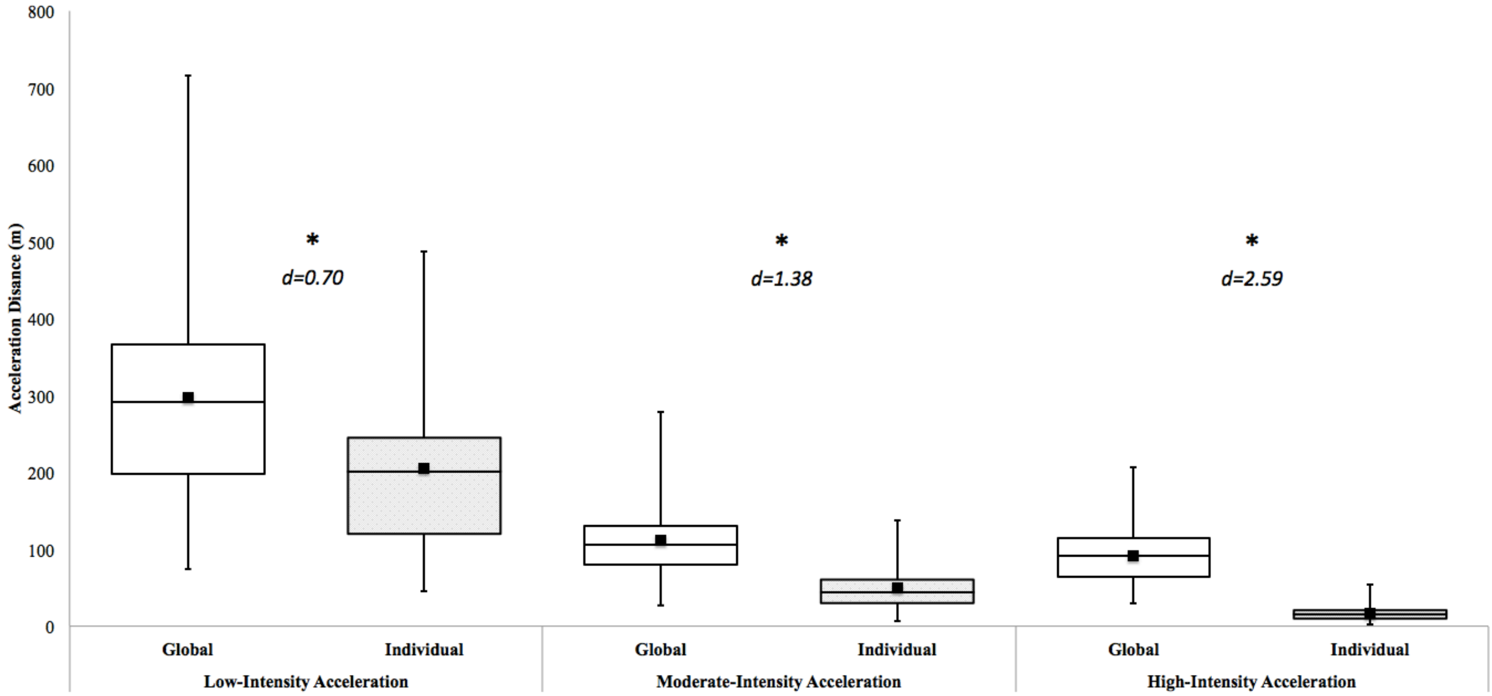

Figure 5.3. Distribution and mean distance travelled performing low-, moderate-, and high-intensity acceleration when utilising arbitrary or individual thresholds, in HI_{ACC} athletes. N.B. asterisk represents significant difference, *d* represents effect size.

5.4 Discussion

The current study examined discrepancies in low-, moderate-, and high-intensity acceleration distances produced utilising global and individual methods of analysis. Athletes were categorised dependent upon maximum accelerative capabilities, providing detailed insight into the effects of individualising thresholds for athletes of varying physical capacities. Past research investigated discrepancies between global and individual analysis methods for quantifying high-speed activities, with the current study the first to examine discrepancies for acceleration.

Acceleration distances produced utilising global and individual analysis methods varied significantly between athlete groups. The LO_{ACC} athlete group demonstrated no significant differences in low-, moderate-, or high-intensity acceleration distances produced utilising global or individual analysis methods. In ME_{ACC} athletes, there were no significant differences between low-intensity acceleration distances, but moderate- and high-intensity acceleration distances were significantly higher utilising the global analysis method compared to individual. For HI_{ACC} athletes, significantly higher distances were produced utilising the global analysis method, for low-, moderate-, and high-intensity acceleration. For all acceleration intensities, the global analysis method produced higher acceleration distances when compared to the individual analysis method. Individual acceleration thresholds were calculated utilising individual athlete's maximum accelerative capacities. Individuals with higher maximum accelerative capacities experienced larger variance between individual acceleration thresholds and global acceleration thresholds. For example, average individual thresholds for HI_{ACC} athletes were ≥ 1.8 ± 0.1 $m{\cdot}s^{-2}$, ≥ 3.6 ± 0.1 $m{\cdot}s^{-2}$, and ≥ 5.4 ± 0.2 $m{\cdot}s^{-2}$ for low-, moderate-, and high-intensity acceleration respectively. Global acceleration thresholds were ≥ 1 $m{\cdot}s^{-2}$, ≥ 2 $m{\cdot}s^{-2}$, and ≥ 3 $m{\cdot}s^{-2}$ respectively for all athlete groups. Average individual thresholds for LO_{ACC} athletes were ≥ 1.4 ± 0.0 $m{\cdot}s^{-2}$, ≥ 2.8 ± 0.1 $m{\cdot}s^{-2}$, and ≥ 4.3 ± 0.1 $m{\cdot}s^{-2}$ for low-, moderate-, and high-intensity acceleration respectively. With less variance between global and individual acceleration thresholds in LO_{ACC} athletes, fewer significant differences were demonstrated between acceleration distances when compared to HI_{ACC} athletes. Considering the current study predictions, the significant differences in low-, moderate-, and high-intensity acceleration distances produced between analysis methods meant H_3 was accepted, and H_{03} rejected. As significant differences between low-, moderate-, and high-intensity acceleration distances varied between athlete groups, H_4 was accepted, and H_{04} was rejected.

The current study was the first to examine discrepancies between global and individual thresholds for acceleration. Previous research conducted by Lovell and Abt (2013), Clarke et al. (2015), Gabbett (2015), and Reardon et al. (2015), investigated discrepancies between global and individual speed thresholds. Lovell and Abt (2013) recruited elite soccer players, and determined individual thresholds utilising the second ventilatory threshold. Similar to current results, Lovell and Abt (2013) identified significant discrepancies between analysis methods. Specifically, significantly lower high-intensity distances were produced when utilising global speed thresholds compared to individual. Clarke et al. (2015) utilised the second ventilatory threshold to individualise speed thresholds, for Women's Rugby Sevens players. Results concluded global thresholds underestimated high-intensity running distances by up to 30% when compared to individual thresholds. Similar to current results, both research groups identified significant discrepancies between global and individual analysis methods. Direction of discrepancies varied in comparison, with the global analysis method overestimating acceleration distances produced by ME_{ACC} and HI_{ACC} athletes within the current study. In contrast to current and previous research, Lovell and Abt (2013) and Clarke et al. (2015) did not allow for discrepancies to be examined between athlete groups.

Gabbett (2015) calculated individual speed thresholds utilising maximum sprint speed in youth Rugby League athletes. Results demonstrated that individual speed thresholds increased high-speed running attributed to relatively slower athletes, and decreased high-speed running attributed to relatively faster athletes. Reardon et al. (2015) identified similar trends utilising maximum sprint speed to individualise thresholds in professional Rugby Union. Results demonstrated a high-speed running underestimation of 22% for forwards, and an overestimation of 18% for backs when utilising global speed thresholds. Results from Gabbett (2015) and Reardon et al. (2015) compliment current results, with significant differences identified between analysis methods, and varying differences identified between athlete groups. Current results identified significant differences in low-, moderate-, and high-intensity acceleration distances produced between analysis methods for HI_{ACC} athletes, but no significant differences were identified for any acceleration intensity in LO_{ACC} athletes. In addition, current results suggest discrepancies between analysis methods were more pronounced at higher acceleration intensities. For low-intensity accelerations, differences of 45% were identified between analysis methods in HI_{ACC} athletes. Whilst for moderate-intensity accelerations, differences of 74% and 122% were identified, and for high-intensity accelerations, differences of 248% and 441% were identified for ME_{ACC} and HI_{ACC} athletes respectively. Findings highlight the variance in physical capacity between athletes, providing further rationale for an individual approach to monitoring acceleration.

Current findings have significant implications for quantifying the relative demands of acceleration tasks. Previously, global acceleration thresholds have been utilised regardless of individual physical capacity. Although global acceleration thresholds allow for comparisons in external workloads between athletes, they do not represent the intensity an athlete is operating (Hunter et al., 2015). This is vital when monitoring training loads of athletes with different ages and physical capacities (Gabbett, 2015). Accounting for athletes maximum capacity within acceleration thresholds provide practitioners a greater understanding of the relative intensity of activity. The mean maximum acceleration within the current study was 6.4 ± 0.6 m·s^{-2} with the mean 50-percentile equating to 3.2 m·s^{-2}. Application of the individual analysis method resulted in the activity being classified as the beginning of moderate-intensity acceleration. However, when applying frequently cited global acceleration thresholds, the same activity would be classified as a high-intensity acceleration. For the majority of athletes within the current study, global acceleration thresholds provide an inaccurate representation of intensity when compared to individual acceleration thresholds.

Significant research currently focuses upon quantifying injury risk in team sports (Gabbett, 2016). Whilst utilising such models, it is vital the training load input is a valid representation. An invalid representation of training load would render information obtained from the model inaccurate, increasing risk of over- or under-training athletes. Current findings identified a mean overestimation of two-fold when utilising global acceleration thresholds, potentially affecting the validity of injury risk models. Previous research suggests individual thresholds provide more accurate representations of athlete training load, considering the relative intensity of activity is acknowledged (Hunter et al., 2015). Identifying an individual's relative demands for training or competition could potentially improve the prescription of training and recovery interventions. Researchers have highlighted the importance of acceleration within team sport performance, and the neuromuscular demand associated with acceleration tasks (Greig & Siegler, 2009; Lockie et al., 2011). Considering the aforementioned, and the discrepancies demonstrated between analysis methods, it is suggested an individual approach to monitoring should be applied to accurately quantify the relative demand of acceleration tasks.

It is important to note the limitations of the current study. Despite recent improvements in GPS hardware and software, associated error still exists within the devices. Delaney et al. (2017) state 10-Hz GPS devices demonstrate coefficient of variations of 1.2 - 6.5% when assessing acceleration, requiring practitioners to adopt caution when applying results. An issue associated with determining individual thresholds using physical capacities, is that physical performance has been demonstrated to fluctuate throughout a season (Meckel et al., 2018). Performance can increase as a result of training adaptation, or decrease due to deconditioning or injury, requiring frequent re-testing of physical capacities. Currently, there are no recommendations for the frequency of re-testing when utilising individual thresholds, requiring further investigation. Finally, the current study was conducted over a four-week period, with a limited sample size of 31 U23 professional soccer players at a Premier League academy. Consequently, findings are a representative of the athletes recruited, for the time period of the study, and not directly applicable to all populations.

5.5 Conclusion

Current findings have significant implications for applied practitioners aiming to quantify the relative demands of acceleration tasks for squads of athletes. Significant discrepancies were demonstrated between acceleration distances calculated utilising global and individual acceleration thresholds. Additionally, the discrepancies in distances produced by global and individual acceleration thresholds varied dependent upon an athletes' maximum accelerative capacities. Considering the high neuromuscular demand of accelerating, and the frequent use of modeling to predict injury risk, it is vital training load is accurately represented. Advantages of global acceleration thresholds are the ability to compare physical performance between athletes, and determine an individual's ability to tolerate a given workload. Conversely, individual acceleration thresholds allow the relative intensity of acceleration tasks to be quantified, acknowledging athletes of different ages and physical capacities. If the aim of monitoring training load is to accurately quantify the relative intensity an athlete is operating, individual acceleration thresholds are recommended. Identification of the relative demands placed upon an individual by training and competition can improve consequent prescription training and recovery. The current protocol to determine maximum accelerative capacity can be replicated with large squads, and minimal equipment. Although the current study recruited soccer players, similarities in movement patterns mean findings are applicable to the majority of team sports.

6.0 Study Three - Physical demands of playing position within English Premier League academy soccer

Publication arising from this chapter: Abbott, W., Brickley, G., & Smeeton, N.J. (2018). Physical demands of playing position within English Premier League academy soccer. *Journal of Human Sport & Exercise, 13(2),* 1-11.

Abstract

Physical demands of soccer competition vary between playing positions. Previous research investigated total, and high-speed distances, with limited research into acceleration demands of competition. Research investigating speed and acceleration demands have utilised global thresholds, overlooking the individual nature of athlete locomotion. The current study was the first utilising individual speed and acceleration thresholds, investigating the relative intensity of activities. Relationship between match outcome and physical outputs were also investigated. GPS data from 44 professional matches was collected using 10-Hz GPS and 100-Hz accelerometer devices. 343 observations were divided by playing position, and match result, with differences in GPS metrics analysed. Central midfielders produced the highest total distances, and moderate-intensity acceleration distances ($p < 0.01$). Wide defenders and attackers produced the highest very high-speed running, sprinting, and high-intensity acceleration distances ($p < 0.01$). Central defenders produced the lowest values for all metrics ($p < 0.01$). No significant differences were found between GPS metrics for differing match outcomes ($p > 0.05$). In addition to differing tactical and technical roles, soccer playing positions have specific physical demands associated. Current results allow coaches to overload individual training intensities relative to competition. No relationships were evident between GPS metrics and match outcome, suggesting soccer success is the result of superior technical and tactical strategies.

6.1 Introduction

Extensive research has focused upon quantifying the physical demands of soccer competition (Bangsbo et al., 2006; Molinos, 2013). Despite constituting only 12% of distance travelled, high-speed locomotion has received significant attention when analysing competitive performance (Bradley et al., 2009; Di Salvo et al., 2010). Rationale is that high-speed actions occur during the most significant moments of competition (Barnes et al., 2014; Di Salvo et al., 2009). Adding to the importance of high-speed actions, Faude et al. (2012) state straight-line sprinting is the most dominant action during goal scoring. Despite the importance, previous research investigating high-speed demands of soccer has utilised global speed thresholds (Di Salvo et al., 2010). Considering the highly individual nature of athlete locomotion, there is potential for training load error when using global speed thresholds for athletes (Abt & Lovell, 2009). To improve accuracy when identifying the high-speed demands of soccer, Lovell and Abt (2013) have recommended individualised speed thresholds.

The physical demands of soccer cannot be characterised solely by high-speed global positioning systems (GPS) metrics. Osgnach et al. (2010) suggest accelerations are of greater energy cost than constant speed movements. In addition, an athlete's ability to accelerate is suggested to contribute to on-field performance (Delaney et al., 2017). Focusing specifically upon high-speed metrics would result in accelerations occurring at low absolute speeds not being quantified (Akenhead et al., 2013; Guadino et al., 2010). The majority of research investigating physical demands of soccer competition have analysed total distance, and high-speed distances, but not considered acceleration activities (Bradley et al., 2009; Dellal et al., 2011c; Di Salvo et al., 2010). Accelerations are highly fatiguing in nature, and with muscular fatigue responsible for a large proportion of injuries within soccer, consideration of accelerations are vital when assessing training load (Dalen et al., 2016; Ingebrigtsen et al., 2015). Of the limited research including acceleration analysis, global thresholds were utilised to determine acceleration intensity (Dalen et al., 2016; Ingebrigtsen et al., 2015). Similar to global speed thresholds, global acceleration thresholds fail to account for individual factors such as maturation status, or maximal capacities. Consequently, the intensity at which individual athletes are operating cannot be calculated, an important aspect of monitoring training load (Hunter et al., 2015). To obtain vital information upon individual high-speed and acceleration demands during soccer competition, further investigation is necessary.

The physical demand elicited upon athletes during soccer competition differs significantly dependent upon playing position (Molinos, 2013). For total distance, previous research concluded central defenders and strikers produced the lowest distances, whilst central midfield players produced the highest (Dellal et al., 2012; Guadino et al., 2010). For high-speed activities, wide players (both attacking and defending) produced the highest distances for sprinting and high-intensity running, whilst players operating in central areas produced the lowest (Carling, 2013). Number of accelerations produced by playing positions followed a similar pattern, with wide players accelerating significantly more than central players (Dalen et al., 2016; Ingebrigtsen et al., 2015). Research is yet to combine these GPS metrics into a collaborative study, determining the exact physical demands elicited upon soccer playing positions in an elite population. Alongside the physical demands of soccer playing positions, another area of interest to practitioners is the relationship between physical outputs and match outcome. Previous research investigating this relationship has proved equivocal. Mohr et al. (2003) found top class soccer players produce higher physical outputs when compared to moderate professional players. More recently, researchers have concluded that successful teams demonstrate lower physical outputs in comparison to unsuccessful teams (Carling, 2013). Others cite no significant differences between teams of differing levels of success (Castellano et al., 2014).

To increase the probability of success, a large emphasis of soccer training is focused upon developing the physical attributes of athletes (Bowen et al., 2017). Training sessions are guided by competition, and aim to replicate or exceed the physiological demands encountered during matches. A high occurrence of specific activities may overload muscle groups, and have implications for conditioning athletes (Bloomfield et al., 2007). Consequently, it is vital for the training prescription process that competitive demands are accurately identified. The aim of the study was to identify the physical demands placed upon soccer playing positions using an individualised approach to monitoring. Previous research investigating the positional demands of competition utilised global speed and acceleration thresholds, overlooking the relative intensity of activities. The current study was the first to incorporate individual speed and acceleration thresholds, providing an accurate representation of intensity for playing positions. It was predicted that significant differences would be evident in the physical outputs produced by soccer playing positions. The study also examined the effect of physical outputs upon match outcome. It was predicted there would be significant differences in physical outputs produced during matches of differing outcome.

H_5 – There will be significant differences in the physical outputs produced by soccer playing positions.

H_{05} - There will be no significant differences in the physical outputs produced by soccer playing positions.

H_6 – There will be significant differences in the physical outputs produced during matches of differing match outcome.

H_{06} - There will be no significant differences in the physical outputs produced during matches of differing match outcome.

6.2 Methodology

Design

Thirty-seven professional soccer players participated in 44 competitive matches spanning two seasons. Physical data was recorded using 10-Hz GPS devices (OptimEye S5B, Version 7.18; Catapult Innovations, Melbourne, Australia), resulting in 343 collections of data. GPS metrics consisting of total distance, very-high speed running distance, sprinting distance, maximal speed achieved, moderate-intensity acceleration distance, and high-intensity acceleration distance were calculated. Data was divided by playing position, and match result, with differences in GPS metrics analysed.

Participants

Thirty-seven, male, full-time professional soccer players from an U23 Premier League academy (19.9 ± 1.4 years, height 180.3 ± 8.0 cm, weight 78.9 ± 8.4 kg) participated in the study. Participants were assigned an outfield playing position by the head technical coach. Playing positions were central defenders (n = 7) wide defenders (n = 7), central midfielders (n = 8), wide attackers (n = 8), and strikers (n = 7). Each participant only featured in one playing position. All participants were briefed with a detailed explanation of the aims and requirements of the study, as well as potential risks. All participants provided written consent for their involvement. For participants under the age of 18, parental or guardian consent was provided. Participants were free to withdraw at any time, without any repercussions. The study was conducted with full approval from the ethical review board at the institution prior to commencing. The study conformed to the requirements stipulated by the Declaration of Helsinki, and all health and safety procedures were complied with.

Procedures

GPS match data was collected for 44 competitive matches using 10-Hz GPS and 100-Hz accelerometer devices (OptimEye S5B, Version 7.18; Catapult Innovations, Melbourne, Australia). Data collection spanned two seasons, during which matches were played once per week. Prior to the commencement of both competitive seasons, participants completed a six-week pre-season consisting of physical and technical training sessions, and friendly matches. Competitive matches within the study were comprised of Premier League Two fixtures. Prior to competition, participants completed a standardised warm up, ensuring adequate preparation for competition. For each match, participants wore a portable GPS device in a designated tight-fitting vest located between the scapulae. GPS devices were switched on 15-minutes prior to the warm up, in accordance with manufacturer's instructions, and switched off immediately following competition. Participants wore the same GPS device for each match, avoiding inter-device error.

Prior to the data collection periods, participants completed maximum sprint speed (MSS), and maximum aerobic speed (MAS) protocols previously utilised by Mendez-Villanueva et al. (2013) and Hunter et al. (2015) to determine anaerobic and aerobic locomotor capacities respectively. The MSS protocol required participants to complete three maximal 40m linear sprints, with a minimum of three minutes rest between repetitions. MSS was defined as the fastest speed recorded over any 10m sector, and measured using electronic light gates (Brower TC Timing System) to the nearest 0.01s. The MAS protocol was a modified version of the University of Montreal Track Test (Leger & Boucher, 1980), previously used by Mendez-Villanueva et al. (2013). The test began with an initial running speed of 8 $km.h^{-1}$, with the speed increasing by 0.5 $km.h\text{-}^{1}$ each minute. MAS was estimated as the speed of the final stage completed by the participant. Using MSS and MAS values, each participant's anaerobic speed reserve (ASR) was calculated. ASR was defined as the difference between the MSS and MAS score, and reported in $m.s^{-1}$. MSS, MAS and ASR values were used to determine each participant's speed thresholds, and consequent values for very high-speed running and sprinting GPS metrics. During the MSS protocol, the maximum rate of acceleration was calculated for each sprint using 10-Hz portable GPS devices (OptimEye S5B, Version 7.18; Catapult Innovations, Melbourne, Australia). The highest acceleration value was recorded for each participant. Each participant's maximal accelerative capacity value was used to determine their individual acceleration thresholds. This method had previously been utilised by Sonderegger et al. (2016) to assess maximal accelerative capacity of athletes, and individualise acceleration thresholds.

Data Analysis

10-Hz GPS devices have demonstrated an acceptable level of accuracy and reliability when assessing the speed of movement within intermittent exercise (Varley et al., 2012). Mean number of satellites during data collection was 14.7 ± 1.8, and the mean horizontal dilution of position was 0.8 ± 0.1. Following each match recording, GPS devices were downloaded to a computer and analysed using Catapult Sprint software (Catapult Sprint 5.1.5, Catapult Innovations, Melbourne, Australia). Speed was calculated using measurements of the Doppler shift of signals received, distance was measured using positional differentiation. To allow direct comparisons in data, only participants completing 90-minutes were included within the analysis process. Once downloaded, each data set was edited and split into two 45-minute halves. Extra time at the end of each half was excluded to ensure comparison between matches. A total of 343 observations were collected from 44 matches, the mean number of observations per participant was 8.7 ± 1.9 matches. Speed-related GPS metrics recorded were maximal speed achieved, very high-speed running distance, and sprinting distance. Very-high speed running, and sprinting distances were characterised as the distances travelled between 100% MAS – 30% ASR, and > 30% ASR respectively (Hunter et al., 2015; Mendez-Villanueva et al., 2013). Acceleration-related GPS metrics recorded were moderate-intensity acceleration, and high-intensity acceleration distances. These were characterised as distances travelled accelerating between 50 - 75% and > 75% of an individual's maximal accelerative capacity respectively (Sonderegger et al., 2016). The total distance travelled during competition was also recorded (Molinos, 2013; Guadino et al., 2010). Mean values for GPS metrics were calculated for each playing position, and match outcome. Match outcome was sub-divided into matches won (n = 14), drawn (n = 11), or lost (n = 19).

Statistical Analysis

Descriptive analyses were conducted on the data set, with normality values in the form of Kolmogorov-Smirnov and Shapiro-Wilk tests. Significance values $p < 0.05$ indicated data was normally distributed. Skewness and kurtosis values were assessed, with standard error between -2 and +2 indicating the data was normally distributed. To investigate differences and interactions between match outcome and playing position, in the GPS metrics produced during competition, a two-way between subjects ANOVA was used. Partial eta-squared values were calculated to estimate the effect size for the ANOVA. A partial eta-squared effect size of $\eta_p^2 = .02$ was considered a small effect size, an effect size of $\eta_p^2 = .13$ was considered a medium effect size, whilst $\eta_p^2 = .26$ was considered a large effect size. Bonferroni tests were used post-hoc to assess where differences occurred, with Cohen's *d* tests used to calculate effect sizes. The level of statistical significance was set at $p < 0.05$. All statistical analyses were performed using the software IBM SPSS statistics (version 22; SPSS, Inc., Chicago, IL, USA).

6.3 Results

Two-way ANOVA results showed no significant differences in GPS metrics between different match outcomes ($p < 0.05$). For the purpose of clarity, these results have not been presented below. Two-way ANOVA results showed significant differences between playing positions for all GPS metrics ($p < 0.05$). The following sections discuss the follow up analysis, and detail between which playing positions differences in GPS metrics occurred.

Results for total distance demonstrated significant differences between playing position ($F_{(4,338)} = 187.898$; $p < 0.01$, $\eta_p^2 = .77$), with mean total distances shown in Table 6.1. Central midfielders produced significantly higher total distances when compared to all playing positions ($p < 0.01$). Wide defenders and wide attackers produced similar total distances for competition, significantly higher than distances produced by strikers and central defenders ($p < 0.01$). Strikers produced significantly higher total distances when compared to central defenders, but significantly lower than all other playing positions ($p < 0.01$). Central defenders produced the lowest total distance, significantly lower than all other playing positions ($p < 0.01$). Table 6.1 demonstrates the significant differences in maximum speed achieved by playing positions during competition ($F_{(4,338)} = 173.999$; $p < 0.01$, $\eta_p^2 = .63$). Wide defenders and wide attackers achieved similar maximum speeds during competition, significantly higher than central defenders, central midfielders, and strikers ($p < 0.01$). There were no significant differences in maximum speed when comparing wide defenders and wide attackers, or comparing central defenders, central midfielders, and strikers.

	Playing Position				
	CD	**WD**	**CM**	**WA**	**ST**
Total distance (m)	9,830 ± 428	10,747 ± 420	11,570 ± 469	10,918 ± 353	10,320 ± 420
Significant differences present ($p < 0.05$)	Sig. less than: WD (*d* = 2.1) CM (*d* = 3.9) WA (*d* = 2.8) ST (*d* = 1.1)	Sig. more than: CD (*d* = 2.1) ST (*d* = 1.0) Sig less than: CM (*d* = 1.8)	Sig. more than CD (*d* = 3.9) WD (*d* = 1.8) WA (*d* = 1.6) ST (*d* = 2.8)	Sig more than CD (*d* = 2.8) ST (*d* = 1.5) Sig less than: CM (*d* = 1.6)	Sig more than: CD (*d* = 1.1) Sig less than: WD (*d* = 1.0) CM (*d* = 2.8) WA (*d* = 1.5)
Maximum speed ($m.s^{-1}$)	7.4 ± 0.3	8.4 ± 0.4	7.5 ± 0.3	8.6 ± 0.4	7.6 ± 0.5
Significant differences present ($p < 0.05$)	Sig less than: WD (*d* = 2.8) WA (*d* = 3.4)	Sig more than: CD (*d* = 2.8) CM (*d* = 2.5) ST (*d* = 1.8)	Sig less than: WD (*d* = 2.5) WA (*d* = 3.1)	Sig more than: CD (*d* = 3.4) CM (*d* = 3.1) ST (*d* = 2.2)	Sig less than: WD (*d* = 1.8) WA (*d* = 2.2)

CD = Central Defenders, WD = Wide Defenders, CM = Central Midfielders, WA = Wide Attackers, ST = Strikers.

Table 6.1 Differences in total distance, and maximum speeds achieved by soccer playing positions during competition. N.B. level of statistical significance $p < 0.05$, d represents effect size.

Figure 6.1 demonstrates the very high-speed running and sprinting distances produced by soccer playing positions during competition. Significant differences were identified between playing positions for both very-high speed running ($F_{(4,338)} = 684.486$; $p < 0.01$, $\eta_p^2 = .89$), and sprinting distances ($F_{(4,338)} = 200.446$; $p < 0.01$, $\eta_p^2 = .60$). When focusing upon very high-speed running distances, wide defenders and wide attackers produced the highest distances, with central defenders, central midfielders, and strikers producing significantly lower distances in comparison ($p < 0.01$). Strikers produced significantly higher very-high speed running distances when compared to central defenders and central midfielders ($p < 0.01$). Central defenders produced significantly lower very-high speed running distances when compared to all other playing positions ($p < 0.01$). The same significant differences were seen between playing positions for sprinting distances, with one exception. There was no significant difference in sprinting distances produced by central midfielders and strikers.

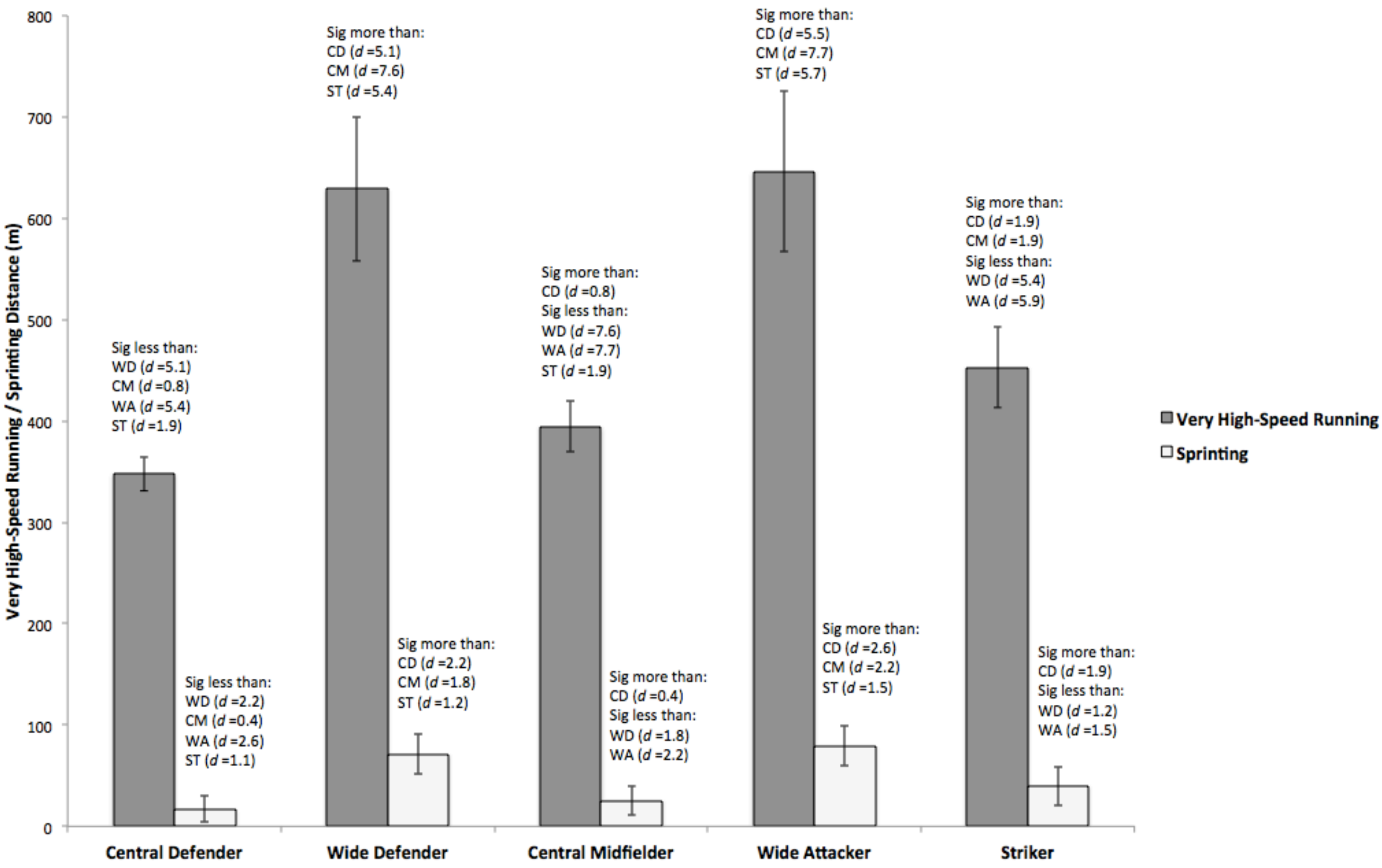

Figure 6.1 Differences in very high-speed running and sprinting distances produced by soccer playing positions. N.B. level of statistical significance $p < 0.05$, d represents effect size.

Figure 6.2 shows the moderate-intensity, and high-intensity acceleration distances produced by soccer playing positions during competition. Significant differences in moderate-intensity ($F_{(4,338)} = 91.475$; $p < 0.01$, $\eta_p^2 = .56$), and high-intensity acceleration distances ($F_{(4,338)} = 147.436$; $p < 0.01$, $\eta_p^2 = .64$) were demonstrated between playing positions. When focusing on moderate-intensity acceleration distances, central midfielders produced significantly higher distances than all other playing positions ($p < 0.01$). Wide defenders, wide attackers, and strikers produced similar moderate-intensity acceleration distances, with no significant differences between playing positions. Central defenders produced significantly lower moderate-intensity acceleration distances compared to all other playing positions ($p < 0.01$). Results for high-intensity acceleration distances differed to moderate-intensity acceleration distances. Wide defenders and wide attackers produced significantly higher high-intensity acceleration distances compared to central defenders, central midfielders, and strikers ($p <$

0.01). Central defenders, central midfielders, and strikers produced similar high-intensity acceleration distances, with no significant differences in distances produced.

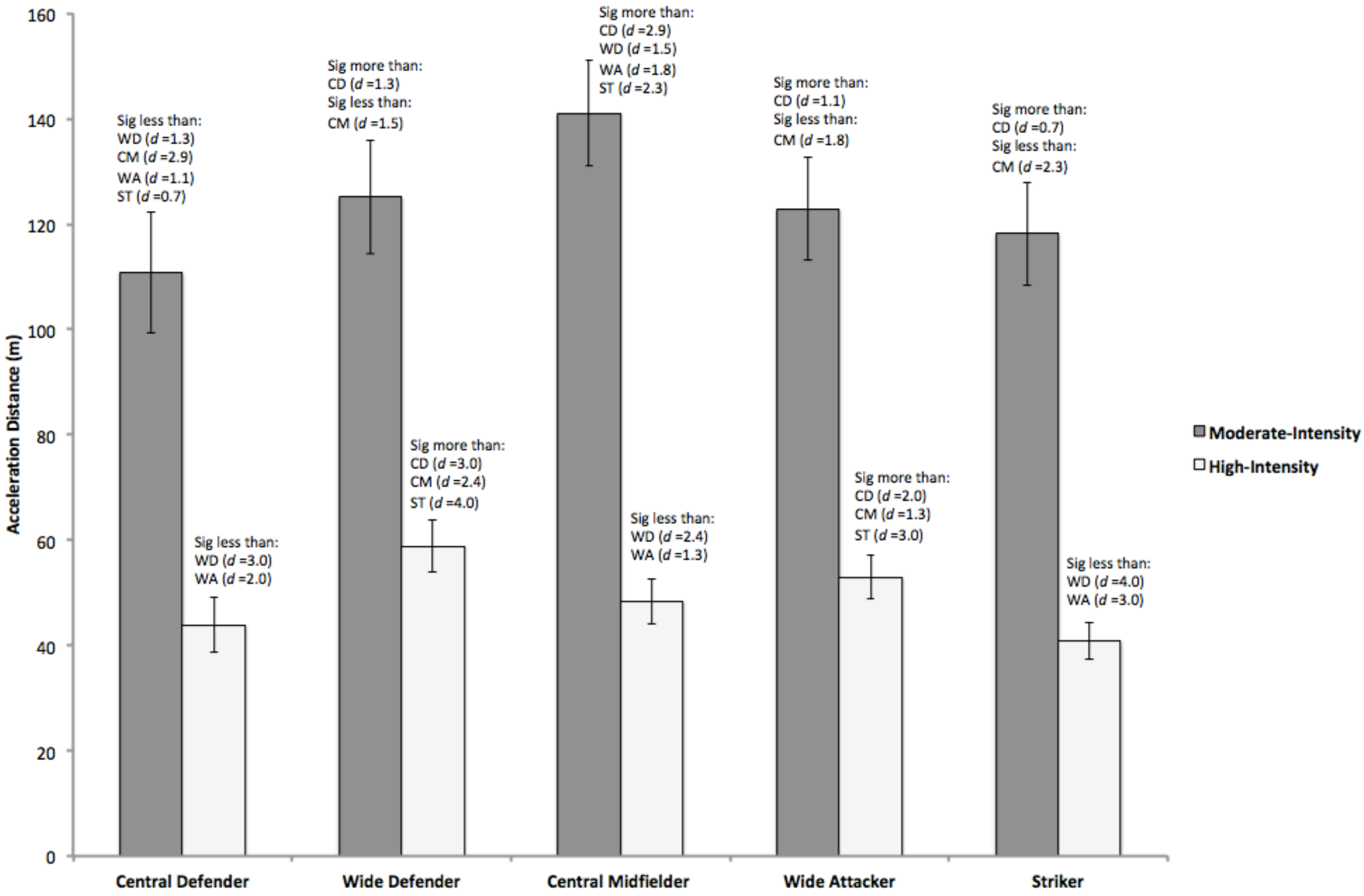

Figure 6.2 Differences in moderate-intensity and high-intensity acceleration distances produced by soccer playing positions. N.B. level of statistical significance $p < 0.05$, d represents effect size.

6.4 Discussion

The aim of the study was to identify differences in physical outputs produced by soccer playing positions, and between match outcomes. Total distance, maximum speed, high-speed distances, and moderate- and high-intensity acceleration metrics were recorded to identify the holistic physical demands placed upon playing positions. The study was the first to individualise speed and acceleration thresholds to quantify the individual intensity of activities.

Current results demonstrated central defenders produced the lowest total, very high-speed running, and sprinting distances, as previously reported by Dellal et al. (2011c) and Guadino et al. (2010). Despite being the least physically demanding position, central defenders are highlighted as an important position tactically, operating as the last line of defence (Bangsbo et al., 2006). Central midfielders produced the highest total distances, complimenting research by Bradley et al. (2009) and O'Donoghue et al. (2005). High total distances produced by central midfielders are related to the positional role of linking defence and attack, often requiring involvement in both phases of play. These results were in contrast to research conducted by Carling (2013), finding that wide attackers produced the highest total distances. Differences in results could be attributed to the varying tactical roles of wide attackers between research studies.

When investigating positional differences in very high-speed running and sprinting distances, current results emulated previous research, finding wide attackers produced the highest distances for very high-speed running, and sprinting (Bradley et al., 2010; Ingebrigtsen et al., 2015). Similar results were identified for maximum speeds achieved during competition, as previously demonstrated by Bradley et al. (2009). High-speed running and sprinting distances produced by wide defenders were similar to wide attackers, the result of operating on the flanks of the pitch. Wide areas are less congested when compared to central areas, resulting in increased opportunities to achieve high speeds unopposed. Significantly lower very high-speed running, and sprinting distances produced by central defenders and central midfielders owe to operating in congested, central areas of the pitch (Di Salvo et al., 2007).

When investigating positional differences in acceleration, Ingebrigtsen et al. (2015) reported a higher frequency of accelerations in wide players compared to central. Current results illustrate this for high-intensity acceleration distances, with wide attackers and wide defenders producing the highest distances. Rationale is the frequent requirement of wide positions to reach high-speeds, with rapid acceleration necessary to achieve this. For moderate-intensity accelerations, the current study found central midfielders produced the highest distances. This complimented research by Bloomfield et al. (2007), stating central midfielders are involved in high volumes of moderate-intensity activity. Differences in high-intensity and moderate-intensity acceleration distances produced by playing positions emphasise the importance of sub-dividing these manoeuvres dependent upon intensity.

Strikers produced significantly lower total distances in comparison to wide defenders, wide attackers and central midfielders, the result of limited involvement defensively, within the current formation. Operating in central areas, strikers are required to produce stretched runs behind opposition defenders, explaining moderate very high-speed running, sprinting, and high-intensity acceleration distances. Considering significant differences between playing positions were identified for all GPS metrics, H_5 was accepted, and H_{05} was rejected. When investigating the effects of physical outputs upon match outcome, no significant differences were identified for any GPS metric. This was contrary to previous research (Carling, 2013; Mohr et al., 2003), but complimented the suggestion by Castellano et al. (2014) that soccer success is the result of superior technical and tactical strategies. Considering current study predictions, the lack of significant differences between match outcomes meant H_6 was rejected, and H_{06} was accepted.

Considering the significant differences in physical demands placed upon playing positions, uniform training methods would be impractical. Specific playing positions require emphasis on distinct physical components relating to their competitive requirements (Dalen et al., 2016). Central defenders have the least physical demand associated, allowing for a larger volume of tactical and technical training, cited as important for the position (Bangsbo et al., 2006). To overload competitive intensities, recommendations for total distance are > 109 $m.min^{-1}$, with high-intensity acceleration distances > 0.5 $m.min^{-1}$.

Wide defenders and wide attackers are characterised by large volumes of very high-speed running, sprinting, and high-intensity accelerations. Specific training should incorporate linear speed production, rapid acceleration to maximal speeds, and the ability to repeat these actions. Overload intensities for very high-speed running, and sprinting are > 7.2 $m.min^{-1}$, and > 4.1 $m.min^{-1}$ respectively for wide attackers, and > 7.0 $m.min^{-1}$, and > 3.9 $m.min^{-1}$ respectively for wide defenders. To overload competitive high-intensity acceleration distances, intensities should exceed > 0.7 $m.min^{-1}$ for wide attackers, and > 0.6 $m.min^{-1}$ for wide defenders.

Considering the physical demands elicited upon central midfielders during competition, the training emphasis should differ from wide defenders and wide attackers. Specific training should involve high total distances, with frequent moderate-intensity accelerations. To overload competitive intensities for total distance, training intensity of > 129 $m.min^{-1}$ is required, with moderate-intensity acceleration intensity > 1.6 $m.min^{-1}$. For strikers, demands were multifaceted, with no dominant physical activity. To overload competitive intensities, very-high speed running and sprinting intensities of > 5.0 $m.min^{-1}$, and > 2.8 $m.min^{-1}$ are required. Training intensities of > 0.5 $m.min^{-1}$ are required to overload high-intensity accelerations. The current study's training intensity recommendations are derived from mean positional intensities for competition. Gabbett et al. (2016) warn that if the average demands of competition are focused upon, athletes may be underprepared for the most demanding passages of play. Consequently, further research is required to quantify the aforementioned most demanding passages.

6.5 Conclusion

The current study demonstrates the significant differences in physical demands elicited upon soccer playing positions during competition. In addition to differing tactical and technical roles, each playing position has a specific physical demand associated. Findings provide coaches with the information to accurately prescribe training intensities above those encountered during competition. Further individualisation can be achieved by prescribing training intensities to specific playing positions. Consequently, soccer training can be made specific to the individual, and physical activities overloaded improve competitive performance.

7.0 Study Four - Positional differences in GPS outputs and perceived exertion during soccer training games and competition

Publication arising from this chapter: Abbott, W., Brickley, G., & Smeeton, N.J. (2017). Positional differences in GPS outputs and perceived exertion during soccer training games and competition. *The Journal of Strength and Conditioning Research, 32(11), 3222-3231.*

Abstract

Soccer training games are popular training modalities, allowing technical, tactical, and physical aspects to be trained simultaneously. Small (SSGs), medium (MSGs) and large training games (LSGs) elicit differing physical demands. To date, no research has investigated physical and perceived demands of training games upon soccer playing positions relative to competitive demands. Additionally, previous research has referenced average competitive intensities, ignoring peak demands of competition. The current aim was to investigate the effect of training game formats upon average and peak physical outputs produced by soccer playing positions. Physical and perceptual data from 22 competitive matches and 39 training game sessions was collected for 46 U23 professional players using 10-Hz GPS and 100-Hz accelerometer devices (MinimaxX version 4.0; Catapult Innovations, Melbourne, Australia). Data analysed included GPS derived distance, speed, acceleration, and RPE. Two-way between subjects ANOVAs were used to compare average and peak GPS metrics, and RPE, between training games and competition for playing positions. Despite eliciting significantly higher average total distances compared to competition ($p < 0.01$), LSGs produced significantly lower peak total distance relative to competition ($p < 0.01$). For very high-speed running and sprinting, LSGs elicited similar average intensities to competition, however peak intensities were significantly lower than competition ($p < 0.01$). MSGs and LSGs produced significantly higher average and peak moderate-intensity acceleration distances than competition ($p < 0.01$). Results indicate the importance of analysing relative to peak competitive demands, instead of focusing solely upon average demands. The study demonstrates specific game formats can overload the competitive demands of playing positions, and provide an individualised training stimulus.

7.1 Introduction

The aim of soccer conditioning training is to replicate, or overload, competitive demands to develop performance during competition (Dellal et al., 2012). To prescribe an appropriate overload stimulus, competitive demands need to be accurately identified and recorded. Global Positioning Systems (GPS) has been integral in determining the frequency, intensity, and duration of physical activity (Bloomfield et al., 2007). GPS technology provides an indicator of external training load (e.g total distance, high-speed distances, and rates of change in speed), however it is important to consider the internal load elicited upon athletes (Owen et al., 2016). Rating of perceived exertion (RPE) is a valid indicator of internal training load, correlating with $\dot{V}O_2$, heart rate, and blood lactate, and quantifying stress from tasks unable to be recorded using GPS (e.g jumping, heading, tackling and grappling with opponents) (Coutts et al., 2009; Hill-Haas et al., 2011). Integration of GPS and RPE allows for physical and psychological demands of soccer competition to be comprehensively recorded, and overloaded during training. Past research has focused on a solitary marker of training load, failing to combine internal and external markers, and consequently overlooking the holistic training response (Kelly & Drust, 2009; Owen et al., 2011).

The competitive demands of soccer differ between playing positions. Central defenders produce the lowest total and high-speed distances during competition, whilst central midfielders produce the highest total distances when compared to other positions (Bradley et al., 2009; O'Donoghue et al., 2005). Wide attacking and wide defending positions are characterised by high-speed activities, producing the highest sprint distance, and number of high-intensity accelerations (Bradley et al., 2010, Ingebrigtsen et al., 2015). Considering the variation in competitive demands elicited upon playing positions, a one-size-fits-all approach to training must be avoided, instead focusing upon the specific requirements of athletes to maximise training efficiency (Domene, 2013; Owen et al., 2016). When analysing competitive demands, it is vital to consider the peak demands. Preparing for the average demands of competition could leave athletes underprepared, and at a higher risk of injury, during the most demanding periods of play (Gabbett et al., 2016).

Training games are a popular training modality in soccer, allowing for technical, tactical, and physical aspects to be trained simultaneously (Abrantes et al., 2012; Owen et al., 2011). Training games can elicit intensities higher than competition, with Dellal et al. (2011a) demonstrating sprint activities ranging from 1.8 - 2.6% of total distance during competition, compared to 13.6 – 16.3% of total distance during training games. Recent reviews suggest training game intensity can be manipulated to control the stimuli applied to athletes (Aguiar et al., 2012; Halouani et al., 2014). Increasing player number whilst maintaining a constant pitch size decreases intensity (Halouani et al., 2014). However, increasing the pitch size using a constant player number, increases intensity (Da Silva et al., 2011). Authors suggest investigating the effects of player number and pitch size in isolation limits the ecological validity of results. To maintain soccer specificity, and achieve tactical outcomes, it is important the relative playing area is consistent with competition, or those prescribed by technical coaches (Rampinini et al., 2007). Rationale exists for investigation of the effects of training game format (e.g small, medium, and large) upon physical outputs produced with a constant relative playing area. This would provide coaches the ability to manipulate physical outcomes of training games, whilst maintaining tactical validity for competition.

When maintaining relative playing area, research has shown small training games (SSGs – 3v3) elicit higher ratings of perceived exertion (RPE) and heart rate responses, and lower work:rest ratios in comparison to medium games (MSGs – 5v5), and large games (LSGs – 7v7) (Castellano et al., 2013). The same has been demonstrated for agility demands, and changes in speed (Davies et al., 2013; Guadino et al., 2014). SSGs are unable to replicate the sprint demands of competition however (Casamichana et al., 2012; Owen et al., 2014). LSGs demonstrate higher total distances, high-speed running, and number of accelerations when compared to their smaller equivalents (Brandes et al., 2012; Castellano et al., 2013). To date, no research has used GPS and RPE analyses to investigate how different training game formats overload playing positions relative to demands experienced during competition. Past research has referenced average competitive intensities, ignoring the peak demands of competition.

The aim of the current study was to investigate how training game format affects average and peak physical outputs produced by soccer playing positions. Results aim to provide coaches with vital information regarding the game formats most specific in stimulating competitive demands of playing positions. It was predicted that there would be significant differences in the average physical outputs produced by small, medium and large training games relative to competition. It was also predicted that there would be significant differences in peak physical outputs produced by different training game formats when compared to competition.

H_7 – There will be significant differences in the average physical outputs produced by small, medium and large training games relative to competition.

H_{07} - There will be no significant differences in the average physical outputs produced by small, medium and large training games relative to competition.

H_8 – There will be significant differences in the peak physical outputs produced by small, medium and large training games relative to competition.

H_{08} - There will be no significant differences in the peak physical outputs produced by small, medium and large training games relative to competition.

7.2 Methodology

Design

Competition and training data was collected for 46 U23 professional players during the 2016/17 soccer season. Players were divided into five playing positions (central defenders, wide defenders, central midfielders, wide attackers, and strikers), with positional physical data from 22 competitive matches, and 39 training game sessions (mean 12.3 ± 3.5 matches, 33.1 ± 2.2 training sessions) recorded using 10-Hz GPS and 100-Hz accelerometer devices (MinimaxX version 4.0; Catapult Innovations, Melbourne, Australia). GPS metrics analysed were distance, speed, and acceleration. Individual RPE data was collected following each match and training game session. Average and peak GPS metrics, and RPE were compared between training games and competition for each playing position.

Participants

Forty-six, male, full-time professional soccer players from an U23 Premier League academy participated in the study (age 19.1 ± 1.2 years, range 17-21 years, height 180.1 ± 7.9 cm, mass 79.8 ± 7.6 kg). Participants had been involved in soccer for a mean of 7.8 (± 1.6) years, training four to five times a week for the past two years. Participants were assigned one playing position by the head coach. Playing positions were; central defenders (n = 8) wide defenders (n = 9), central midfielders (n = 12), wide attackers (n = 9), and strikers (n = 8).

Participants were briefed with the aims, requirements, and potential risks of the study. Participants provided written consent for their involvement, parental or guardian consent was provided for participants under the age of eighteen. Participants were free to withdraw at any time, without any repercussions. Full approval was received from the ethical review board at the institution the research was conducted. The study conformed to the requirements stipulated by the Declaration of Helsinki, and all health and safety procedures were complied with.

Procedures

Data collection spanned from August 2016 – May 2017, with competition and training games occurring once per week. Prior to commencement of the competitive season, participants had undergone pre-season training and had appropriate conditioning levels. Fixtures used within the study were U23 Premier League Two fixtures. Fixtures were in a competitive league format, with emphasis placed upon results, ensuring high motivation. Fixtures were played on a Monday evening, on natural grass. Prior to competition, participants completed a 25-minute warm up consisting of physical drills, passing, possessions, and finishing. This ensured adequate preparation for competition, and was consistent throughout the data collection period. A 4-3-3 playing formation was utilised throughout the data collection period. During training game sessions, one game format was utilised (e.g large, medium or small), resulting in data collection for each format every three weeks. The head technical coach allocated teams prior to each training session, ensuring abilities were evenly distributed, and participants played in their designated playing positions. Training sessions occurred on a Thursday morning, with Tuesday and Wednesday being designated rest days for the participants, reducing the effects of fatigue. LSGs were characterised as 10v10, 9v9, 8v8, or 7v7 plus goalkeepers. MSGs were characterised as 6v6, 5v5, or 4v4 plus goalkeepers. SSGs were characterised as 3v3, 2v2, or 1v1 plus goalkeepers (Verheijen, 2014). Training games were played for four quarters of four minutes each, with three minutes rest between games (Hodgson et al., 2014). To maintain tactical validity, relative player area for all formats was $120m^2$ per player, excluding goalkeepers (Hill-Haas et al., 2011; Hodgson et al., 2014). Prior to the commencement of training games, participants completed a 25-minute warm up consisting of physical drills, passing, and possessions. As with competition, all training games were played on natural grass. Participants used the same footwear throughout the study.

For training games and competition, participants wore portable GPS devices (MinimaxX version 4.0; Catapult Innovations, Melbourne, Australia). Participants wore the same GPS devices throughout the data collection period to avoid inter-device error. Individual RPE was recorded using the modified Borg CR10-scale. RPE values were recorded 30-minutes following the cessation of competition or training. Following training, participants were asked to provide an RPE value solely representative of the intensity of training games. Participants had previously been familiarised with the RPE scale prior to the data collection period.

Data Analysis

Following the collection of data, GPS devices were downloaded to a computer and analysed using Catapult Sprint software (Catapult Sprint 5.1.5, Catapult Innovations, Melbourne, Australia). Once downloaded, competition data was edited and split into two 45-minute halves. Only participants completing the entire match or training session were included within the analysis process. Training data was edited to include only the active duration of training games. The mean number of satellites, and the horizontal dilution of position were recorded during data collection. If values ranged < 12 for number of satellites, or > 1 for horizontal dilution of position, data was excluded. A total of 156 data sets were collected from 22 fixtures. Totals of 156 data sets for SSGs (1v1, n = 48, 2v2, n = 48, 3v3, n = 60), 199 for MSGs (4v4, n = 64, 5v5, n = 74, 6v6, n = 61), and 224 for LSGs (7v7, n = 42, 8v8, n = 48, 9v9, n = 54, 10v10, n = 80) were collected during the study. GPS metrics were derived for each data set. To allow comparability between competition and training games of different durations, GPS metrics were presented as per minute values. Descriptions of GPS metrics are shown in Table 7.1.

Table 7.1 Descriptions of GPS metrics utilised.

GPS Metric	Description
Total distance (m.min^{-1})	The total distance travelled.
Very high-speed running distance (m.min^{-1})	The distance travelled between 100% maximum aerobic speed and 30% anaerobic speed reserve. Calculated using modified Montreal track test (Leger & Boucher, 1980). Protocol previously utilised by Hunter et al. (2015) and Mendez-Villanueva et al. (2013).
Sprinting distance (m.min^{-1})	The distance travelled above 30% anaerobic speed reserve. Calculated using modified Montreal track test (Leger & Boucher, 1980). Protocol previously utilised by Hunter et al. (2015) and Mendez-Villanueva et al. (2013).
Very high-speed running and sprinting distance (m.min^{-1})	Very high-speed running and sprinting distance added together.
Moderate-intensity acceleration distance (m)	The distance travelled accelerating between 50 - 75% of an individual's maximum accelerative capacity (Sonderegger et al., 2016).
High-intensity acceleration distance (m)	The distance travelled accelerating > 75% of an individual's maximum accelerative capacity (Sonderegger et al., 2016).
Rating of perceived exertion	Subjective rating of exertion using the modified CR10 Borg scale (Borg, 1982).

For competition and training game data, peak and average values were calculated for GPS metrics. Peak values were calculated by dividing each 90-minute match, or 16-minute training game, into one-minute intervals, and recording the highest values achieved per minute for each GPS metric. Average values were calculated by dividing total values for the 90-minute match, or 16-minute training game, by the overall duration. For data presentation purposes, very high-speed running and sprinting distances were added and analysed as a single value. These calculations are detailed in Table 7.1.

Statistical Analysis

Within the current study design, playing position and game format were independent variables, and GPS metrics produced were dependent variables. Descriptive analyses were conducted on all data sets. Normality values were assessed using Kolmogorov-Smirnov and Shapiro-Wilk tests. Significance values of $p > 0.05$ indicated even distribution of the data.

Skewness and kurtosis values were assessed, with standard error within -2 and +2 indicating normally distributed data.

To investigate the differences in eight GPS metrics and RPE produced by game formats for playing positions, two-way between subjects ANOVAs were used, with playing position (central defenders, wide defenders, central midfielders, wide attackers and strikers) and game format (SSGs, MSGs, LSGs, competition) being the between-subjects variables. Partial eta-squared values were calculated to estimate the effect size for the ANOVA. A partial eta-squared effect size of $\eta_p^2 = .02$ was considered a small effect size, an effect size of $\eta_p^2 = .13$ was considered a medium effect size, whilst $\eta_p^2 = .26$ was considered a large effect size. Bonferroni tests were used post-hoc to assess where differences occurred, with Cohen's *d* tests used to calculate effect sizes. A Cohen's *d* effect size of $d = 0.2$ was considered a small effect size, $d = 0.5$ a medium effect size, whilst $d = 0.8$ was considered a large effect size. All statistical analyses were performed using the software IBM SPSS statistics (version 22; SPSS, Inc., Chicago, IL, USA). The level of statistical significance was set at $p < 0.05$.

7.3 Results

Figure 7.1 presents average and peak total distance ($m.min^{-1}$) produced by game format and playing position. For average total distance, significant differences were identified between game formats ($F_{(3,715)} = 355.261$, $p < 0.01$, $\eta_p^2 = .60$). Follow up analysis showed competition produced lowest average total distance, followed by SSGs, MSGs, and LSGs (see Figure 7.1, $p < 0.01$). Significant differences were also identified for playing position ($F_{(4,715)} = 85.877$, $p < 0.01$, $\eta_p^2 = .33$). Central defenders produced significantly lower total distance than other playing positions, with central midfielders producing significantly higher ($p < 0.01$). There was a weak but significant interaction of playing position and game format ($F_{(12,715)} = 5.507$, $p < 0.01$, $\eta_p^2 = .09$). Generally, the higher average total distances produced by central midfielders compared to other positions were not evident in LSGs. For peak total distance, significant differences were identified between game formats ($F_{(3,715)} = 260.261$, $p < 0.01$, $\eta_p^2 = .52$). Follow up analysis demonstrated SSGs produced the lowest peak total distance, followed by MSGs, LSGs, and competition (see Figure 7.1, $p < 0.01$). Differences were also identified for playing position ($F_{(4,715)} = 66.992$, $p < 0.01$, $\eta_p^2 = .27$). Whilst central midfielders produced highest peak total distance, this did not differ significantly from wide attackers, with central defenders producing the lowest peak distance. Wide defenders did not differ significantly from wide attackers or strikers ($p < 0.01$). There was a weak but significant interaction of playing position and game format ($F_{(12,715)} = 4.278$, $p < 0.01$, $\eta_p^2 = .07$). Whilst all peak total distance increased with game format, differences between central defenders, wide defenders and strikers were not evident until LSGs and competition, with significant differences between central defenders and wide defenders only evident during competition.

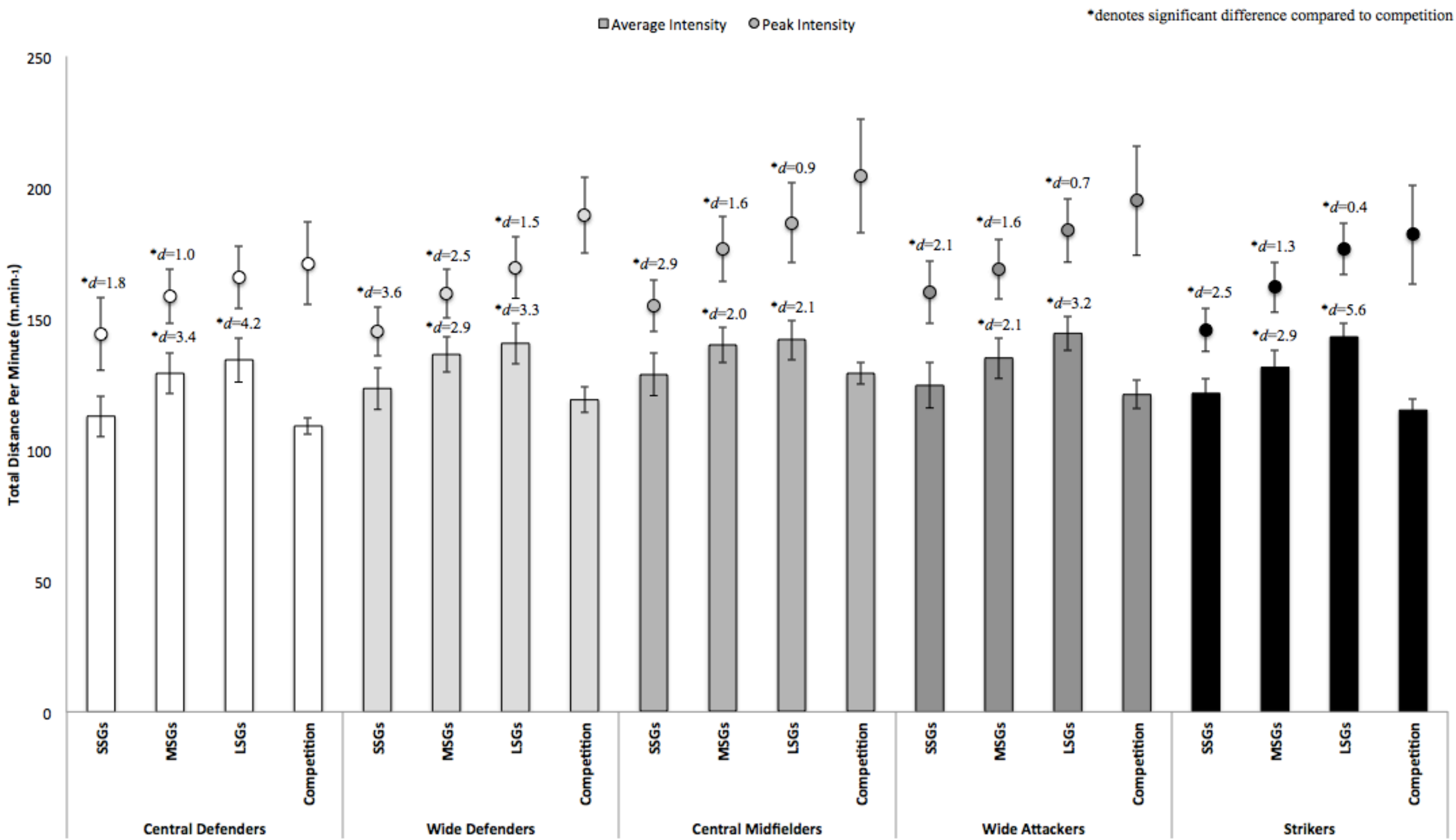

Figure 7.1 Average and peak total distance intensities produced by playing position during training games and competition. N.B. asterisk represents significant difference of $p < 0.05$ compared to competition, *d* represents effect size.

Figure 7.2 presents average and peak very high-speed running and sprinting distance ($m.min^{-1}$) produced by game format and playing position. For average very high-speed running and sprinting distance, significant differences were identified between game formats ($F_{(3,715)} = 1642.181$, $p < 0.01$, $\eta_p^2 = .87$). Follow up analysis demonstrated SSGs produced the lowest very high-speed running and sprinting distance, followed by MSGs, competition, and LSGs (see Figure 7.2, $p < 0.01$). Differences were also identified for playing position ($F_{(4,715)} =$

224.717, $p < 0.01$, $\eta_p^2 = .56$). There were significant differences between all playing positions for this measure ($p < 0.05$). There was a medium effect and significant interaction of playing position and game format ($F_{(12,715)} = 61.863$, $p < 0.01$, $\eta_p^2 = .51$). For all positions excluding wide defenders and wide attackers, typical differences between positions during competition were not evident until game format increased to LSGs. Significant differences between wide defenders and wide attackers were only evident in competition. For peak very high-speed running and sprinting distance, significant differences were identified between game formats ($F_{(3,715)} = 1125.315$, $p < 0.01$, $\eta_p^2 = .83$). Follow up analysis demonstrated SSGs produced the lowest peak very high-speed running and sprinting distance, followed by MSGs, LSGs, and competition ($p < 0.01$). Significant differences were also identified for playing position ($F_{(4,715)} = 1551.192$, $p < 0.01$, $\eta_p^2 = .35$). Highest peak very high-speed running and sprinting distance were observed in wide defenders and wide attackers, significantly different from all positions excluding each other, followed by strikers, central midfielders, and central defenders. There was a small effect and significant interaction of playing position and game format ($F_{(12,715)} = 16.415$, $p < 0.01$, $\eta_p^2 = .22$). Peak very high-speed running and sprinting distance increased with game format, however no significant differences were identified between playing positions in SSGs, and typical differences seen between positions in competition only emerged in LSGs.

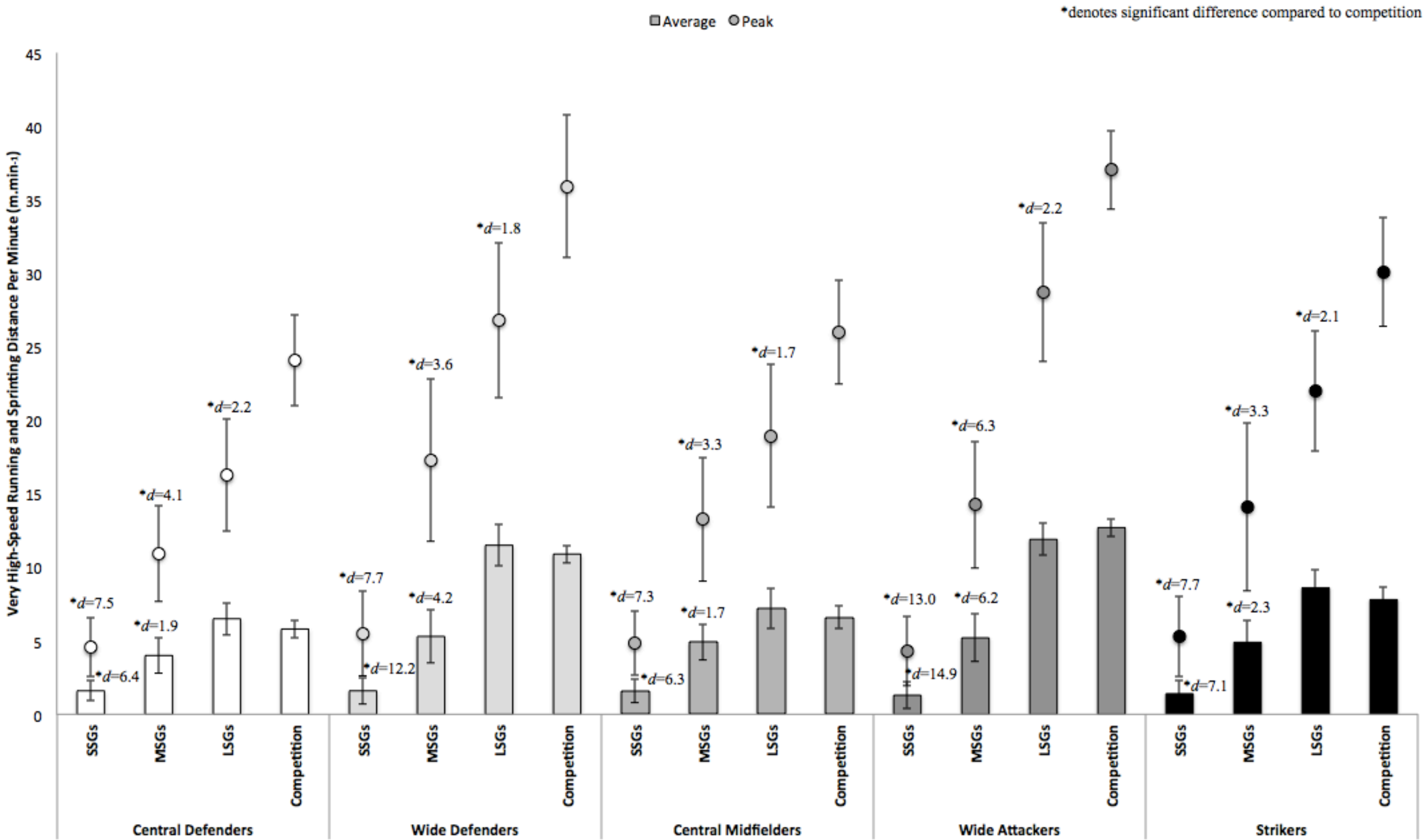

Figure 7.2 Average and peak very high-speed running and sprinting intensities produced by playing position during training games and competition. N.B. asterisk represents significant difference of $p < 0.05$ compared to competition, d represents effect size.

Figure 7.3 presents average and peak moderate-intensity acceleration distance (m.min^{-1}) produced by game format and playing position. For average moderate-intensity acceleration distance, significant differences were identified between game formats ($F_{(3,715)} = 464.523$, $p < 0.01$, $\eta_p^2 = .76$). Follow up analysis demonstrated SSGs produced highest average moderate-intensity acceleration distance, followed by MSGs, LSGs and competition (see Figure 7.3, $p < 0.05$). Differences were also identified for playing position ($F_{(4,715)} = 38.029$, $p < 0.01$, $\eta_p^2 = .21$). Central defenders produced significantly lower moderate-intensity acceleration distances than all other positions, with central midfielders producing significantly higher moderate-intensity acceleration distance than all positions ($p < 0.05$). No significant differences were identified between wide defenders, wide attackers and strikers. There was a small effect and significant interaction of playing position and game format ($F_{(12,715)} = 4.563$, $p < 0.01$, $\eta_p^2 = .06$). Differences in average moderate-intensity acceleration distance increased with game format. For peak moderate-intensity acceleration distance, significant differences were identified between game formats ($F_{(3,715)} = 195.359$, $p < 0.01$, $\eta_p^2 = .38$). Follow up analysis demonstrated SSGs produced the highest peak moderate-intensity acceleration distance, followed by MSGs. There were no significant differences between LSGs and competition. Differences were also identified for playing position ($F_{(4,715)} = 43.329$, $p < 0.01$, $\eta_p^2 = .21$). Central midfielders produced highest peak moderate-intensity acceleration distance, with central defenders producing the lowest. No significant differences were identified between wide defenders, wide attackers, and strikers. There was a small effect and significant interaction of playing position and game format ($F_{(12,715)} = 2.465$, $p < 0.01$, $\eta_p^2 = .04$). Whilst SSGs reflected the relative differences evident in competition, sizes of the differences were smaller in SSGs.

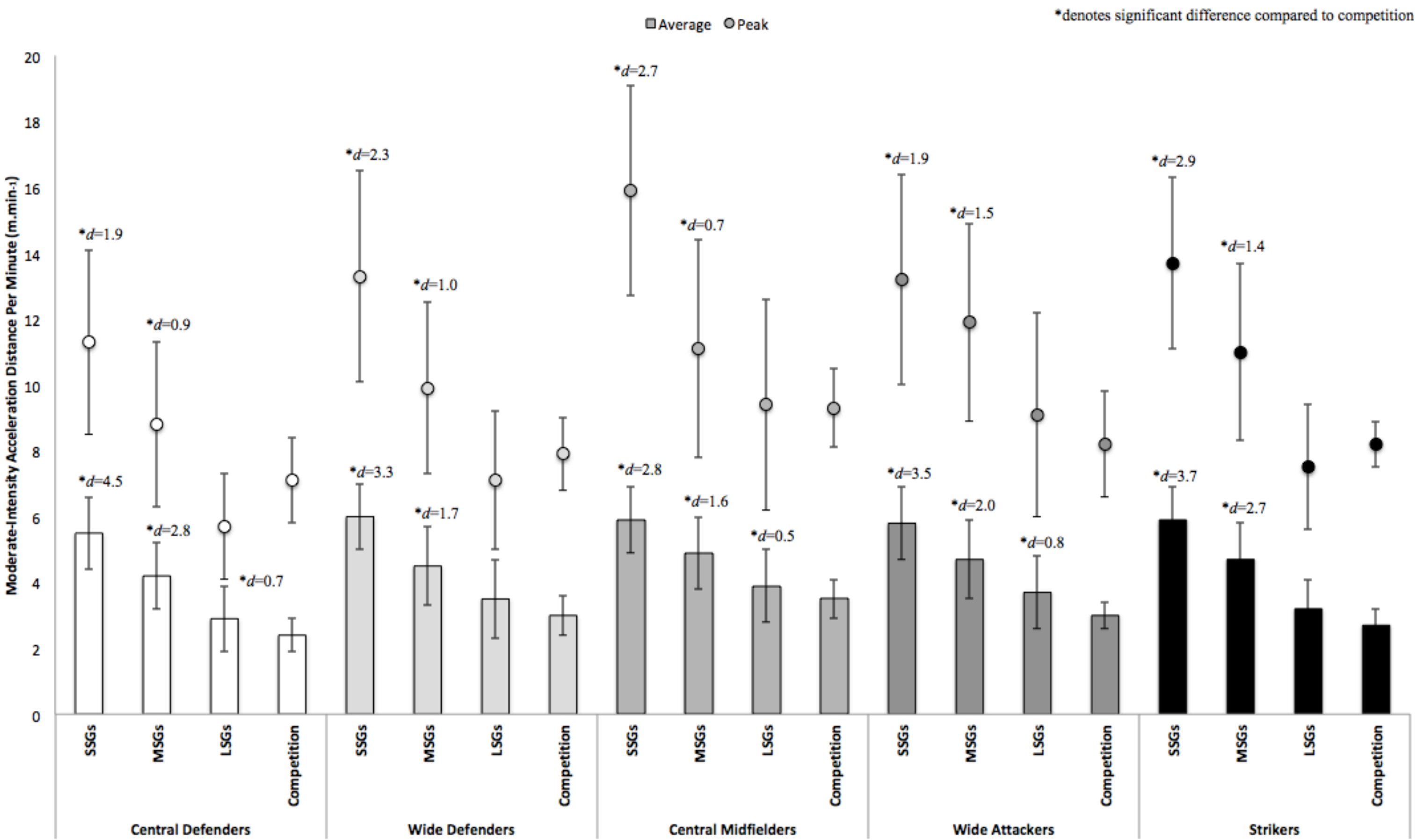

Figure 7.3 Average and peak moderate-intensity acceleration distance intensities produced by playing position during training games and competition. N.B. asterisk represents significant difference of p<0.05 compared to competition, d represents effect size.

Figure 7.4 presents average and peak high-intensity acceleration distance ($m.min^{-1}$) produced by game format and playing position. For average high-intensity acceleration distance, significant differences were identified between game formats ($F_{(3,715)} = 318.284$, $p < 0.01$, $\eta_p^2 = .53$). Follow up analysis demonstrated SSGs produced the lowest average high-intensity acceleration distance, differing significantly from all other formats ($p < 0.01$). LSGs produced the highest high-intensity acceleration distance, significantly different from all formats. There were no significant differences between MSGs and competition (see Figure 7.4, $p < 0.05$). Significant differences were also identified for playing position ($F_{(4,715)} = 101.932$, $p < 0.01$, $\eta_p^2 = .32$). Central defenders and central midfielders produced the lowest high-intensity acceleration distances, significantly different from all positions excluding each other. Wide defenders and wide attackers produced the highest distances, significantly different from all positions excluding each other ($p < 0.05$). There was a small effect and significant interaction of playing position and game format ($F_{(12,715)} = 7.313$, $p < 0.01$, $\eta_p^2 = .12$). MSGs most accurately reflected average competitive distance in wide defenders, wide attackers and strikers, whereas relative differences between central defenders and central midfielders during competition were only evident in LSGs, albeit at higher absolute distances. For peak high-intensity acceleration distance, significant differences were identified between game formats ($F_{(3,715)} = 269.531$, $p < 0.01$, $\eta_p^2 = .44$). Follow up analysis demonstrated significant differences between all formats. SSGs produced lowest peak high-intensity acceleration distance, followed by MSGs, competition, and LSGs. Significant differences were also identified for playing position ($F_{(4,715)} = 26.352$, $p < 0.01$, $\eta_p^2 = .17$). Wide defenders and wide attackers produced highest peak high-intensity acceleration distances, significantly different to all positions, excluding each other. Central defenders and central midfielders produced lowest peak high-intensity acceleration distances, with no significant differences between each other, or between central midfielders and strikers ($p < 0.05$). There was a small effect and significant interaction of playing position and game format ($F_{(12,715)} = 1.806$, $p < 0.05$, $\eta_p^2 = .03$). Generally, the relative differences between playing positions identified during competition were evident in game formats. However, strikers peak high-intensity acceleration distance was similar to central defenders and central midfielders during SSGs and MSGs, but similar to wide defenders and wide attackers during LSGs and competition.

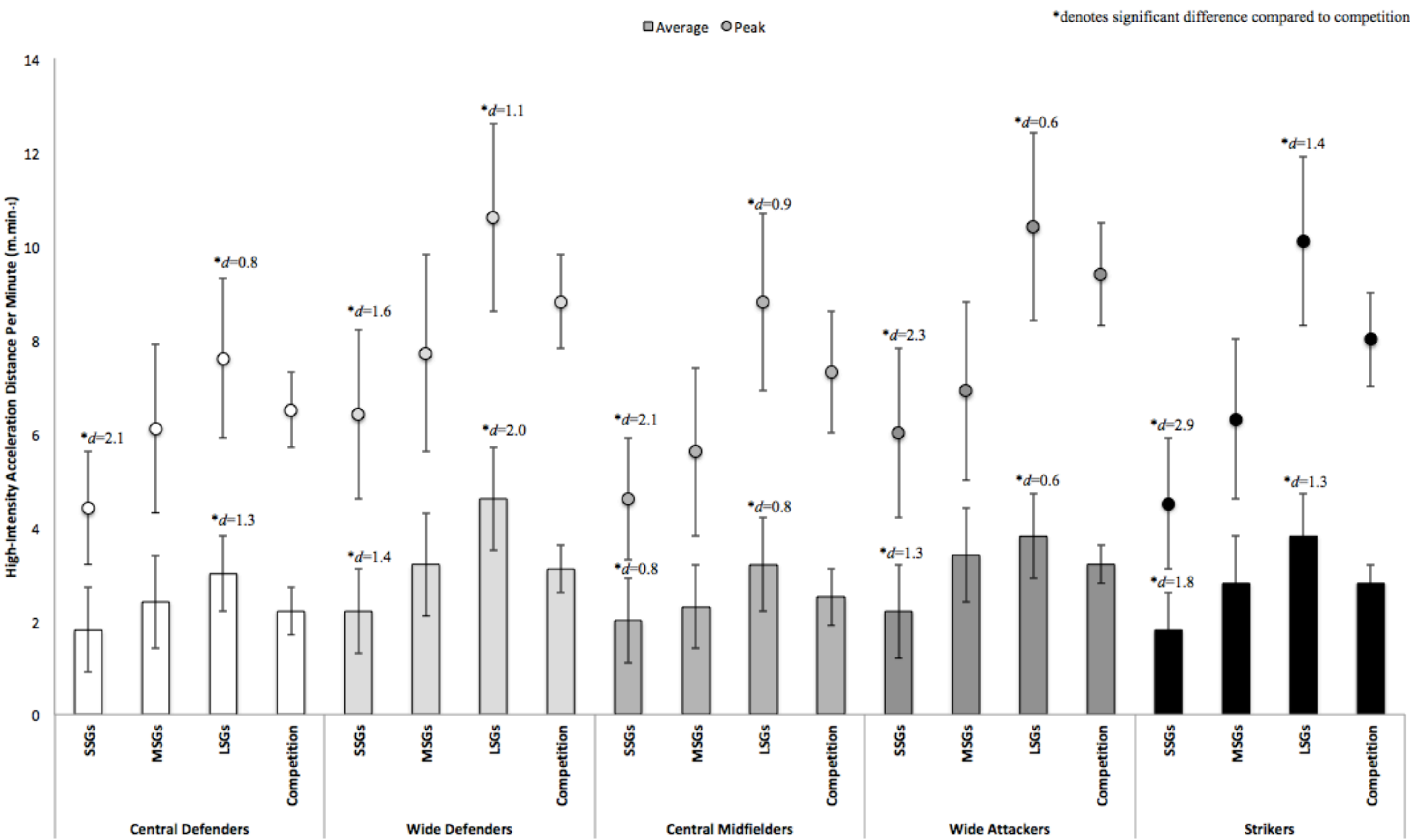

Figure 7.4 Average and peak high-intensity acceleration distance intensities produced by playing position during training games and competition. N.B. asterisk represents significant difference of $p < 0.05$ compared to competition, *d* represents effect size.

Figure 7.5 presents RPE (Borg CR10-scale) produced by game format and playing position. For average RPE, significant differences were identified between game formats ($F_{(3,750)}$ = 81.261, $p < 0.01$, $\eta_p^2 = .25$). Follow up analysis demonstrated SSGs elicited the highest RPE followed by MSGs, competition, and LSGs (see Figure 7.5, $p < 0.01$). No significant differences were identified for playing position ($F_{(4,750)} = .855$, $p > 0.05$, $\eta_p^2 = .01$). There was a small effect and a non-significant interaction of playing position and game format ($F_{(12,715)}$ = 1.402, $p > 0.05$, $\eta_p^2 = .02$).

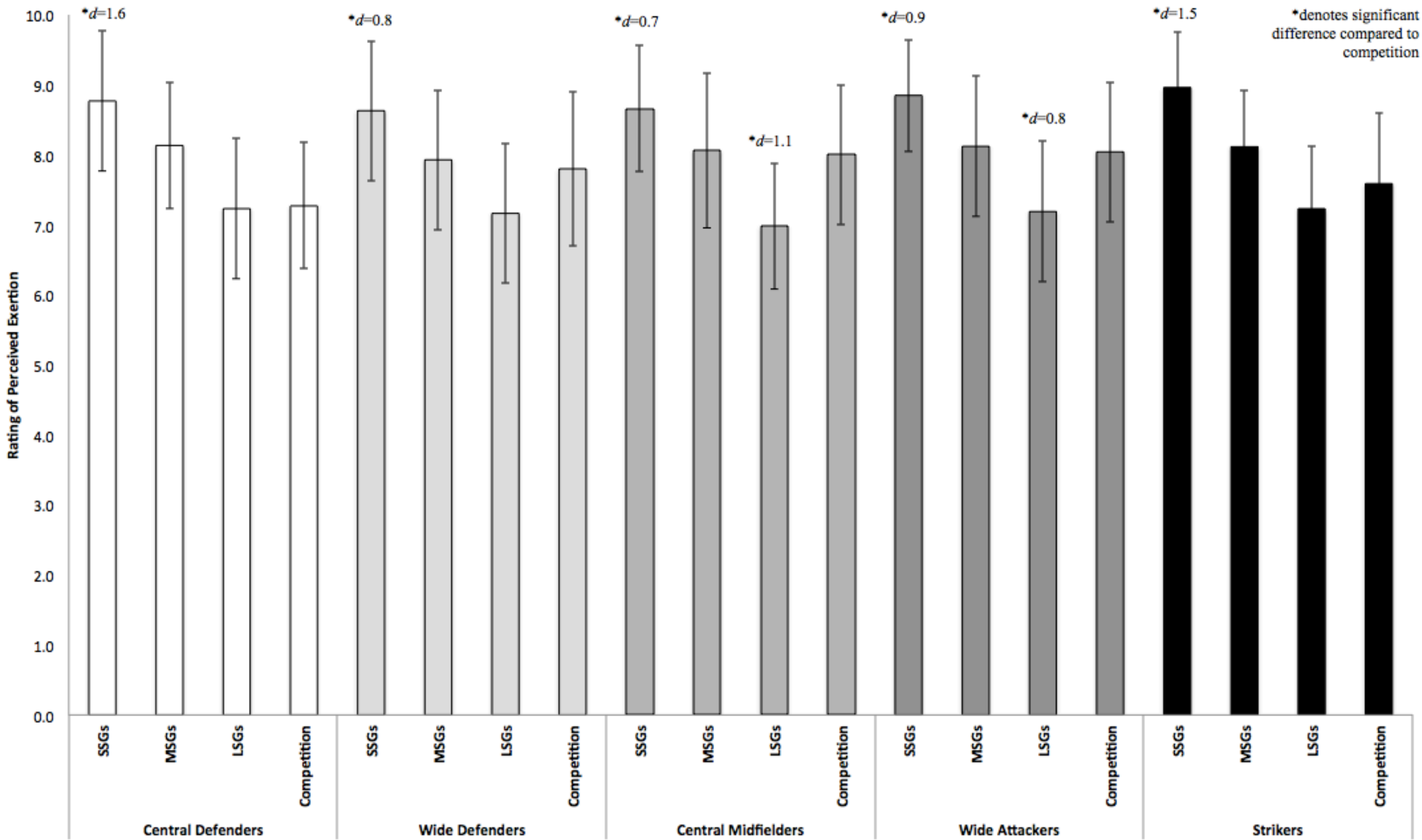

Figure 7.5 Ratings of perceived exertion produced by playing position during training games and competition. N.B. asterisk represents significant difference of $p < 0.05$ compared to competition, *d* represents effect size.

7.4 Discussion

The current study examined the effect of training game format upon physical outputs and perceived exertion within soccer playing positions. It was the first to combine GPS and RPE measures to identify positional demands elicited by game formats, relative to competition. Previous research had focused upon average demands, whilst the current study identified both average and peak positional demands for training games and competition. Current findings suggest no training game format develops overall soccer fitness, with each format eliciting a unique physical load. It is possible to attribute specific training game formats to playing positions, dependent upon the predominant activities performed during competition.

However, care must be taken to analyse training game outputs relative to the peak demands of competition, as these differ to the average demands of competition.

Results demonstrated average total distance intensities were highest in LSGs, and lowest in SSGs. Previous results investigating the effects of game format upon total distance have been mixed. Aguiar et al. (2013) and Hill-Haas et al. (2009) suggested game format had no effect upon distances travelled, whilst Castellano et al. (2013) and Guadino et al. (2014) found distances travelled increased with game format. The current study found the latter, with a larger absolute playing area, and increased 'off the ball' running associated with LSGs providing rationale for findings. Alternative results produced by Aguiar et al. (2013) and Hill-Haas et al. (2009) may result from only investigating SSGs and MSGs within their analysis. Despite MSGs and LSGs producing significantly higher average intensities than competition, peak total distance intensities results differed. For all positions excluding central defenders, competition produced significantly higher peak total distances than training game formats.

Very high-speed running and sprinting distances increased with game format, with LSGs producing the highest intensities. Similar findings have been cited in previous research (Castellano et al., 2013; Guadino et al., 2014). LSGs are characterised by larger absolute playing areas, and allow athletes to reach high-speeds unopposed (Hill-Haas et al., 2009). Comparing average very high-speed running and sprinting intensities to competition, only LSGs were able to replicate competitive demands, with SSGs and MSGs significantly below competitive values for all positions. For peak very high-speed running and sprinting distances, all training game formats were significantly below competitive demands. This suggests training games are an insufficient tool for replicating the peak demands of competition.

Average moderate-intensity acceleration distances were highest in SSGs, and decreased as game format increased. Current results contrast those reported by Castellano et al. (2013), stating larger formats are associated with a higher frequency of accelerations. Castellano et al. (2013) did not differentiate between moderate and high-intensity forms of acceleration, making comparison in results difficult. Research by Davies et al. (2013) state the number of agility manoeuvres produced during smaller formats were higher compared to larger formats, agreeing with the current study. Guadino et al. (2014) also produced comparable results, stating moderate acceleration increase as game format decreases. Smaller formats are associated with increased ball involvement, and elicit more frequent changes of direction and speed to evade opposition (Hill-Haas et al., 2009). When comparing average moderate-intensity acceleration distances between game formats and competition, all game formats were significantly higher, excluding LSGs for wide defender and striker positions. Peak demands followed a similar trend, with SSGs and MSGs demonstrating significantly higher peak moderate-intensity acceleration distances compared to competition. No significant differences were identified between LSGs and competition for peak demands.

High-intensity acceleration distances were highest in LSGs, and decreased with game format. Results compliment Guadino et al. (2014) and Owen et al. (2016), finding larger formats produce more high-intensity accelerations compared to smaller formats. Rationale mirrors very high-speed running and sprinting distances, with lower absolute playing areas resulting in fewer opportunities to maximally accelerate unopposed. In smaller formats, distance between players is less, reducing the distance covered to pressurise opponents (Owen et al., 2016). When comparing average high-intensity acceleration distances to competition, LSGs produced significantly higher intensities. MSGs produced average high-intensity acceleration distances similar to competition, whilst SSGs produced significantly lower intensities. Differences were replicated for peak high-intensity acceleration distances.

RPE was highest in SSGs, with lower ratings reported for MSGs, and the lowest for LSGs. Aguiar et al. (2013) reported similar, with higher RPE for 2v2 and 3v3 formats in comparison to 4v4 and 5v5. Abrantes et al. (2012) and Hill-Haas et al. (2009) also reported findings complimenting the current study. Rationale for higher RPE produced during smaller formats is an increased involvement with the football and opposition, and shorter recovery periods between physical actions (Davies et al., 2013; Dellal et al., 2013). When comparing RPE between game formats and competition, SSGs demonstrated significantly higher RPE, whilst MSGs were similar to competition, for all positions. LSGs produced significantly lower RPE values for central midfielders and wide attackers compared to competition. Considering current study predictions, the significant differences in average and peak physical outputs produced by SSGs, MSGs, and LSGs relative to competition meant H_7 and H_8 were accepted, and H_{07} and H_{08} were rejected.

The current study demonstrates the importance of analysing peak competitive demands. When comparing average total distance intensities of training games to competition, LSGs and MSGs were significantly higher than competition. However, when comparing the peak total distance intensities, all game formats were significantly lower than competition. This was also evident with very high-speed running and sprinting intensities. Comparison of average very high-speed running and sprinting intensities demonstrated no significant differences between LSGs and competition. However, when comparing peak very high-speed running and sprinting intensities, all game formats were significantly lower than competition. This concludes that despite certain game formats replicating average demands of competition, the peak demands of competition may not be replicated. From a performance optimisation and injury prevention perspective, it is vital that coaches prepare the athletes for peak intensities of competition. Focusing on average demands of competition will leave athletes underprepared when faced with the most demanding periods of competition, resulting in poor performance, or injury occurrence (Gabbett et al., 2016).

Results demonstrate specific training game formats replicate, and at times exceed, average and peak demands of competition. Consequently, game formats can be prescribed to playing positions based upon their positional demands. Central midfielders are associated with large volumes of moderate-intensity manoeuvres (Bradley et al., 2009), highlighting SSGs as a training modality. During SSGs, central midfielders produce significantly higher average and peak moderate-intensity acceleration distances compared to competition. Wide defenders and wide attackers are associated with high very high-speed running and sprinting, and high-intensity acceleration distances during competition (Ingebrigtsen et al., 2015). Current results highlight LSGs as a specific training stimulus for these positions. During LSGs, wide defenders and wide attackers produce significantly higher average and peak high-intensity acceleration distances compared to competition. Despite eliciting similar average very high-speed running and sprinting distances for wide defenders and wide attackers, LSGs do not replicate the peak demands of competition. For central defenders and strikers, competitive demands are multifaceted, and therefore multiple game formats should be periodised throughout a training block. For example, utilising SSGs to elicit a high frequency of moderate-intensity accelerations, and utilising LSGs to elicit high total distance or very high-speed running and sprinting activities. An issue highlighted by the current study is the inability of training games to stimulate peak competitive very high-speed running and sprinting intensities. Considering the importance of high-speed activities for all positions within soccer (Faude et al., 2012), it is recommended supplementary sprinting training is prescribed alongside training games to prepare athletes for peak competitive intensities.

It is important to note the limitations of the current study. Despite recent improvements in GPS hardware and software, there is still error associated with devices. Delaney et al. (2017) state 10-Hz devices exhibit coefficient of variations of 1.2 - 6.5% when assessing acceleration and deceleration, and requires acknowledgment from practitioners when applying results. Secondly, the current study was conducted using U23 professional soccer players at a Premier League academy. Consequently, findings may not be directly applicable to other levels or age groups. Finally, the study classified training games into 'small', 'medium, and 'large' formats. Small games were comprised of 1v1, 2v2, and 3v3 training games for example, of which the physical demands elicited by these variations may differ. As a result, caution must be exercised when applying current findings to training programmes.

7.5 Conclusion

The current study provides important information to coaches and scientists regarding the effect of training game formats upon physical outputs produced by soccer playing positions. Results highlight the necessity to analyse physical outputs of training games relative to peak demands of competition, and relative to individual playing position. Although certain game formats replicated average competition demands, they were unable to replicate the peak demands of competition. Prescribing training relative to average demands leads to under preparation for the most demanding periods of competition, potentially resulting in poor performance and an increased risk of injury. The current study demonstrates that specific game formats can overload competitive demands, but careful consideration of playing position and game format is required to provide an individualised training stimulus for athletes. Training games were unable to adequately stimulate peak competitive very high-speed running and sprinting intensities. Consequently, it is recommended that supplementary sprinting training is prescribed to prepare athletes for these demands.

8.0 Study Five - The effect of bio-banding upon physical and technical performance during soccer competition

Abstract

The aim of this study was to determine the effects of bio-banded competition on physical and technical performance metrics in elite youth soccer athletes. Twenty-five male soccer athletes (11 - 15 years) from an English Premier League Category One soccer academy participated in bio-banded and chronological match-play competition. Athletes were between 85 - 90% of predicted adult stature, and sub-divided into early, on-time and late developers. Physical and technical performance data was collected for each athlete during both bio-banded and chronological competition. For early developers, significantly more short passes, dribbles and a higher RPE were evident during bio-banded competition compared to chronological competition ($p < 0.05$). For on-time developers, significantly more short passes and dribbles, and significantly less long passes were evident during bio-banded competition compared to chronological ($p < 0.05$). For late developers, significantly more tackles, and significantly less long passes were evident in bio-banded competition when compared to chronological ($p < 0.05$). There were no significant differences identified for total, sprinting or acceleration distances between competition formats. It was concluded that bio-banded competition increased the opportunity for athletes of varying maturation status to develop technical skills and performance, without reducing the physical demands.

8.1 Introduction

Most sports utilise age-related cutoff criterion to group young athletes for competition (Albuquerque et al., 2015). The aim of this cutoff is to allow appropriate development, and equal opportunity for those participating. In soccer, asymmetries of birth date distributions have been reported for both youth and professional teams, with an increased incidence as the standard of play increases (Del Campo et al., 2010; Helsen et al., 2005; Meylan et al., 2010). This has resulted in a relative age effect, and bias in the distribution of birthdates towards those that occur earlier in the age classification period, usually September to November born athletes (Cobley et al., 2009; Musch & Hay, 1999). Although the relative age effect declines from childhood to the end of adolescence, with less variance in physical maturation, relative age effect still continues to have an influence (Albuquerque et al., 2012). By this time, relatively older athletes have already received greater opportunities to develop through early selection to high quality coaching and increased competitive levels. Consequently, they have had the ability to enhance psychological, physical, technical and tactical aspects to a greater extent when compared to their younger counterparts (Albuquerque et al., 2015).

In an attempt to allow equal opportunity and reduce injury risk, many combat sports have grouped athletes by age and weight (Figueiredo et al., 2010). Body size has a negligible impact upon soccer performance however, and grouping athletes in this manner would have limited practical value due to large variations in positional requirements (Cumming et al., 2018). An alternative solution involves bio-banding athletes into groups of similar levels of growth or maturation (Delorme, 2014; Spencer et al., 2011). Bio-banding is thought to reduce the variance in these physical attributes between teams, resulting in competitive equity and a reduced risk of injury for those less physically mature (Cumming et al., 2018). Additionally, bio-banding may help late developing athletes who could reach the highest level, but for the greater physical maturity of their peers preventing them from receiving quality coaching and opportunities for competition. Bio-banding is also suggested to reduce the selection bias towards early developing athletes, who may not be as competent when their physical attributes are controlled for (Simmons & Paull, 2001).

From a theoretical perspective, the positive effects of bio-banding can be understood using a constraints-based framework (Newell, 1986). According to this framework, an athlete's motor performance results from the interactions of the task, individual and environmental constraints. The task constraints relate to the specific performance context and may be the rules specifying behaviour, the goal of the task, or task-related implements. The individual constraints are made up of the individual's characteristics, all of which can influence performance at any given moment. Examples include developmental and maturational factors. Finally, the environmental constraints specify the general factors influencing motor performance and include weather conditions, as well as socio-culture and economic factors. From the interaction of these constraints the emergent behaviour is seen. Certain types of motor behaviour may only emerge when particular constraints limiting performance are removed. Here we argue that soccer athletes playing in chronologically grouped competition may lead to the motor performance of the late developers being constrained by the presence of the early developers. Consequently, if there is a change in the task constraint of athlete maturation as seen in bio-banded matches, then a different motor performance will emerge.

Despite the strong rationale for bio-banding, and its widespread adoption, there has been no experimental investigation into the effects of bio-banding on physical and technical performance within any sport. Buchheit and Mendez-Villaneuva (2014) investigated the effects of age, maturity, and body dimensions on competitive running performance in U15 soccer athletes. They concluded that older, more mature athletes consistently outperformed their younger, less mature teammates during chronologically aged competition. This complimented previous research suggesting age and maturation positively impact running performance (Buchheit et al., 2010). Subsequently, Buchheit and Mendez-Villaneuva (2014) called for more data on technical and tactical performance of athletes of differing maturation status. With differences in physical outputs between athletes of different maturation status evident during chronological competition, there is rationale for subsequent investigation into the physical effects of bio-banding competition.

Very little research has been published on bio-banding. Recently, Cumming et al. (2018) investigated Premier League academy players' experiences of participating in bio-banded soccer competition. Results identified that early developers cited bio-banded competition as a superior physical challenge and learning stimulus when compared to their chronological age group competition. Early developers felt there was an increased emphasis upon technique, tactics, and teamwork. Essentially, bio-banded competition exposed the early developers to the challenges typically encountered by late developers. Late developers described bio-banded competition as less physically challenging when compared to their chronological age group competition. Late developers stated bio-banded competition provided them with a greater opportunity to utilise their technical, physical, and psychological attributes, and exert their influence upon competition. These findings can be interpreted using the constraints based model of learning (Renshaw et al., 2010), whereby the constraint of maturation has an effect upon the emergent behaviour, in this case the style of play and tactics adopted. The novel study by Cumming et al. (2018) was the first providing feedback on the effect of bio-banded fixtures, focusing upon the qualitative views of participants. Research is yet to quantitatively investigate the effects of bio-banding upon physical and technical performance during competition however.

The current aim was to determine differences in physical and technical performance during bio-banded and chronological soccer competition. Physical and technical performance was assessed between competition format for early, on-time, and late developing athletes. Previously, researchers have demonstrated older, more mature athletes produced higher physical outputs when compared to younger, less mature teammates during chronologically aged competition (Buchheit & Mendez-Villaneuva, 2014). In this current study it was predicted that bio-banded competition would increase the physical demands elicited upon early developers, and reduce the demands elicited upon late developers when compared to chronological competition. This effect would be reflected by higher rating of perceived exertion (RPE) values reported for early developers and the effect reversed for the late developers. Furthermore, it was predicted that bio-banding would change the maturation constraint on technical performance, and as a result change the frequency that technical performance indicators were observed. Short passes were predicted to increase in early developers, and long passes decrease in late developers, when comparing bio-banded competition to chronological competition.

H_9 – There will be significant differences in physical performance metrics produced by bio-banded and chronological competition formats.

H_{09} – There will be no significant differences in physical performance metrics produced by bio-banded and chronological competition formats.

H_{10} – There will be no significant differences in technical performance metrics produced by bio-banded and chronological competition formats.

H_{010} – There will be no significant differences in technical performance metrics produced by bio-banded and chronological competition formats.

8.2 Methodology

Design

Physical and technical performance data was collected for 25 male soccer athletes. Athletes were aged 11 - 15 years, and 85 - 90% of predicted adult stature. Athletes were sub-divided into three maturation groups (early, on-time, and late developers) using Maturity Z-scores, and competed in both bio-banded and chronological age group competition. Bio-banded competition was against athletes grouped by the same maturation band, whilst chronological competition was against athletes of the same chronological age. Four physical performance metrics, and six technical performance metrics were analysed to determine differences between maturation status, competition format, and the interaction. Physical data was collected utilising 10-Hz global positioning system (GPS) and 100-Hz accelerometer devices (OptimEye S5B, Version 7.18; Catapult Innovations, Melbourne, Australia). Technical data was collected using video recordings (Sony HDR CX570) and coding (Version 10.3.36, Sportscode Elite Software).

Participants

Twenty-five male soccer athletes (age 12.7 ± 1.0 years, height 155.9 ± 2.9 cm, weight 44.6 ± 5.5 kg, predicted adult height achieved 86.6 ± 1.3%) were recruited from a Premier League Category One soccer academy to play in bio-banded, and chronologically aged fixtures. Athletes were aged 11 - 15 years, and between 85 - 90% of predicted adult stature. Athletes were grouped chronologically into under-12 (n = 8), under-13 (n = 9), under-14 (n = 4), and under-15 (n = 4) age groups. Participants were sub-divided into three maturation groups, early developers (Maturity Z-score > 1.0), on-time developers, (Maturity Z-score -1.0 – +1.0), and late developers (Maturity Z-score < -1.0). Maturity Z-scores were calculated using participant's percentage predicted adult height, and age and sex specific reference values as previously utilised by Cumming et al. (2018) (Bayer & Bailey, 1959; Malina et al., 2007a). Mean age and Maturity Z-scores for the groups were: early developers = 11.5 ± 0.2 years, Maturity Z-score = 1.7 ± 0.2. On-time developers = 12.3 ± 0.3 years, Maturity Z-score = 0.1 ± 1.0. Late developers = 13.8 ± 0.6 years, Maturity Z-score = -3.0 ± 1.2.

Data collection occurred during the competitive season, with athletes having trained two to three times and participated in competition once per week for a minimum of one season. All participants had been members of the academy for at least one year prior to the study, meaning they already had experience of competitive academy soccer. Prior to the commencement of the study, participants and parents/guardians were provided details on the nature of the study, and informed consent was collected. The study was conducted with the protocol being fully approved by the ethical review board at the institution prior to commencing. The study conformed to the requirements stipulated by the Declaration of Helsinki, and all health and safety procedures were complied with during the study.

Procedures

The Khamis-Roche equation was used to predict adult height, and calculate the subsequent percentage of predicted adult height for each participant. Following calculation, current height has typically been reported as a percentage of predicted adult height to provide an estimation of maturation status (Malina et al., 2015). This equation utilises current chronological age, height, weight, and mid-parent height, of which information was measured and recorded for each individual. Parental heights were self reported, and adjusted for over estimation as previously cited by Cumming et al. (2018). Adjustments were based upon measurements and self-reported heights of adults in the United States of America (Epstein et al., 1995). The error between predicted and actual height at 18 years of age is reported to be 2.1% (Khamis & Roche, 1994), with the equation validated against skeletal age in Portuguese soccer players (Malina et al., 2012). Trained academy staff measured participant's heights and weights within two weeks of competition. All staff were accredited with the International Society for the Advancement of Kinanthropometry, and used standardised measurement techniques.

Following calculations of predicted adult height, and percentage of predicted adult height achieved for each participant, maturation bands were devised. The current study focused upon 85 - 90% predicted adult height maturation band, of which all participants were 'bio-banded' into. Participants then competed in a bio-banded fixture against athletes grouped by the same maturation band. Bio-banded fixtures were played in 11v11 format, with four quarters of 20-minutes. Matches were played on full-sized standard grass pitches (100 x 64m), with full-sized goals (8 x 2.4m). Three substitutions were permitted in accordance with Football Association rules for youth competition, and standard officiating was applied. Prior to competition, participants completed a standardised warm up, ensuring adequate preparation for competition. This included physical, technical, and tactical preparation for the upcoming competition. Bio-banded fixtures were played on three separate occasions, within the same competitive season. Following the bio-banded fixtures, the participants reverted back to their chronological age groups (U12, n = 8, U13, n = 9, U14, n = 4, U15, n = 4). Within two weeks of the bio-banded fixture, participants played in a chronological fixture against athletes grouped by the same chronological age. Fixture format for the chronologically aged competition was identical to the bio-banded fixtures. Fixtures were played in 11v11 format, four quarters of 20-minutes, on a 100 x 64m pitch and with standard Football Association rules and officiating applied. The only exceptions were the U15 fixtures, which were divided into two halves of 40-minutes to comply with league rules for the age group. Physical and technical data was recorded for each participant for both bio-banded and chronologically grouped fixtures. Physical data was collected using a combination of GPS and RPE measures. Technical data was derived from video recordings (Sony HDR CX570) and coding (Version 10.3.36, Sportscode Elite Software) of the fixtures.

Data Analysis

Physical performance data was collected using portable 10-Hz GPS and 100-Hz accelerometer devices (OptimEye S5B, Version 7.18; Catapult Innovations, Melbourne, Australia). GPS devices were worn in a designated tight-fitting vest located between the scapulae. GPS devices were switched on 15-minutes prior to the warm up, in accordance with manufacturer's instructions, and switched off immediately following competition. Participants wore the same GPS device for competition, avoiding inter-device error. Following the collection of data, GPS devices were downloaded to a computer and analysed using Catapult Sprint software (Catapult Sprint 5.1.5, Catapult Innovations, Melbourne, Australia). Once downloaded, competition data was edited and split into four quarters of 20-minutes. Only participants completing the entire match were included within the analysis process. The mean number of satellites, and the horizontal dilution of position were recorded during data collection. If values ranged < 12 for number of satellites, or > 1 for horizontal dilution of position, data was excluded. Sessional RPE was recorded using the modified Borg

CR10-scale. RPE values were recorded 30-minutes following the cessation of competition. Participants were familiar with the RPE scale, having been exposed to the scale for at least a year prior to the data collection period. Descriptions of physical performance metrics recorded during the study are shown in Table 8.1.

Table 8.1. Descriptions of physical performance metrics collected during competition formats.

Physical Performance Metric	Description
Total Distance (m)	The total distance travelled.
Very high-speed running and sprinting distance (m)	The distance travelled above 100% maximum aerobic speed. Calculated using modified Montreal track test (Leger & Boucher, 1980). Protocol previously utilised by Hunter et al. (2015) and Mendez-Villanueva et al. (2013).
Acceleration Distance (m)	The distance travelled accelerating > 50% of an individual's maximum accelerative capacity (Sonderegger et al., 2016).
Rating of Perceived Exertion	Subjective rating of exertion using the modified Borg CR1-10-scale

Both bio-banded, and chronological fixtures were recorded using a camcorder (Sony HDR CX570). Fixtures were then coded and analysed by trained academy performance analysts using SportsCode (Version 10.3.36, Sportscode Elite Software). The technical performance metrics coded and analysed are shown in Table 8.2.

Table 8.2. Descriptions of technical metrics collected during competition formats.

Technical Performance Metric	Definition
Shot	A successful strike of the ball aimed at the opposing goal.
Short pass	A strike of the ball (< 20m in distance) directed at a teammate, and that was successfully controlled.
Long pass	A strike of the ball (> 20m in distance) directed at a teammate, and that was successfully controlled.
Cross	A successful long pass from the widest quarter of the pitch landing in the opposition penalty area.
Dribble	Successfully running past an opponent with the ball.
Tackle	A successful attempt to remove the ball from the opponent's possession through a physical challenge.

Statistical Analysis

Descriptive analyses were conducted on the data set, with normality values in the form of Kolmogorov-Smirnov and Shapiro-Wilk tests. Significance values $p < 0.05$ indicated data was normally distributed. Skewness and kurtosis values were assessed, with standard error between -2 and +2 indicating the data was normally distributed. To investigate differences in physical and technical performance between bio-banded and chronologically aged fixtures for early, on-time, and late developers, two-way mixed design ANOVAs were used where Competition Format (Bio-banded, Chronological) was the within-subjects variable, and Maturation Status (Early, On-Time, Late) was the between subjects variable. Partial eta-squared values were calculated to estimate the effect size for the ANOVA. A partial eta-squared effect size of $\eta_p^2 = .02$ was considered a small effect size, an effect size of $\eta_p^2 = .13$ was considered a medium effect size, whilst $\eta_p^2 = .26$ was considered a large effect size. Bonferroni tests were used post-hoc to assess where differences occurred, with Cohen's *d* tests used to calculate effect sizes. An effect size of $d = 0.2$ was considered a small effect size, an effect size of $d = 0.5$ was considered a medium effect size, whilst $d = 0.8$ was considered a large effect size. All statistical analyses were performed using the software IBM SPSS statistics (version 22; SPSS, Inc., Chicago, IL, USA). The level of statistical significance was set at $p < 0.05$.

8.3 Results

Physical Analysis

Figure 8.1 presents mean RPE produced during competition formats, by different maturation status. Significant differences were identified between maturation status ($F_{(2,22)} = 9.562$; $p < 0.05$, $\eta_p^2 = .47$). Follow up analysis demonstrated late developers produced significantly higher RPE when compared to early developers ($p < 0.05$). Significant differences were also identified in the interaction between competition format and maturation status ($F_{(2,22)} = 17.490$; $p < 0.01$, $\eta_p^2 = .61$). Results demonstrated that early developers produced significantly higher RPE in the bio-banded format compared to chronological format ($t = 9.295$; $p < 0.05$, $d = 1.2$). There were no significant differences between RPE produced by on-time developers, or late developers within the two competition formats.

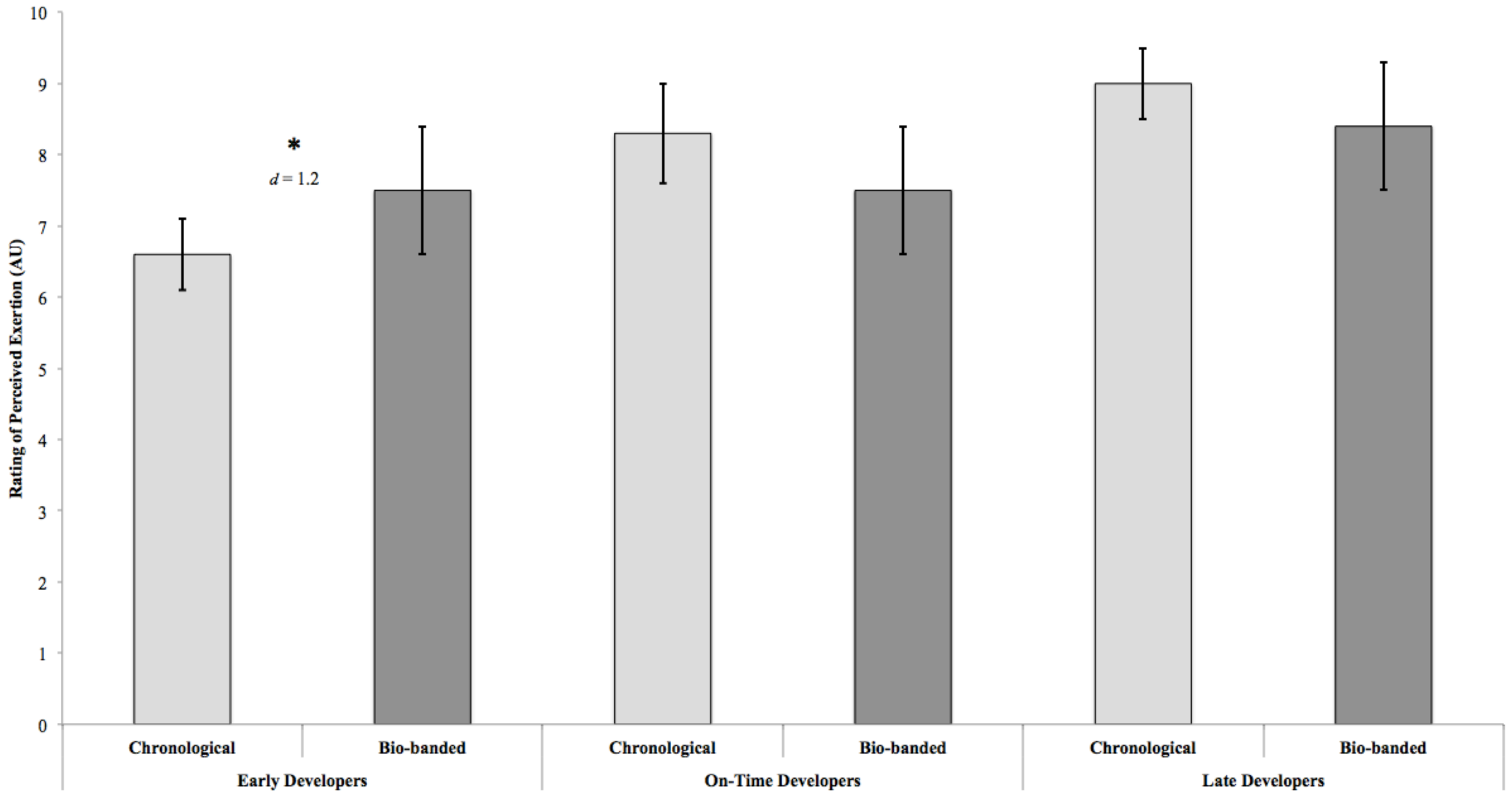

Figure 8.1. Rating of perceived exertion produced by early, on-time, late developing athletes during bio-banded and chronological competition formats. N.B. asterisk represents significant difference of $p < 0.05$, d represents effect size.

Table 8.3 presents mean total distance, very high-speed running and sprinting distance, and acceleration distance produced during competition formats for different maturation status. For total distance, no significant differences were identified between competition format, or the interaction between competition format and maturation status. Significant differences were identified between maturation status ($F_{(2,22)} = 43.921$; $p < 0.01$, $\eta_p^2 = .80$) however. Follow up analysis demonstrated late developers produced significantly higher total distances when compared to early developers ($p < 0.01$). There were no significant differences between late and on-time developers, or on-time and early developers. For very high-speed running and sprinting distance, no significant differences were identified between competition format, maturation status, or the interaction. For acceleration distance no significant differences were identified between competition format, or the interaction between competition format and maturation status. Significant differences were identified between maturation status ($F_{(2,22)} = 12.478$; $p < 0.01$, $\eta_p^2 = .53$), with late developers producing significantly higher acceleration distances when compared to early and on-time developers ($p < 0.05$).

Table 8.3. Total, very high-speed running and sprinting, and acceleration distances produced by early, on-time, late developing athletes during bio-banded and chronological competition formats. N.B. asterisk represents significant difference of $p < 0.05$.

Physical Metric	**Early Developers**			**On-Time Developers**			**Late Developers**		
	Chronological	Bio-Banded	All Formats	Chronological	Bio-Banded	All Formats	Chronological	Bio-Banded	All Formats
Total distance (m)	7942.9 ± 369.1	8254.6 ± 272.3	8098.7 * ± 351.1	8583.1 ± 337.7	8656.8 ± 281.3	8620.0 ± 304.9	9083.8 ± 248.9	8971.9 ± 329.5	9027.8 * ± 287.9
VHSR and SPR distance (m)	757.1 ± 94.2	783.4 ± 75.7	770.3 ± 83.2	773.8 ± 104.9	755.5 ± 78.8	764.7 ± 90.8	848.3 ± 92.7	813.5 ± 81.2	830.9 ± 86.5
Acceleration distance (m)	256.3 ± 33.4	282.6 ± 27.5	260.5 * ± 32.6	295.2 ± 26.3	303.7 ± 32.3	298.3 ± 27.3	354.7 ± 40.4	326.4 ± 35.2	339.3 * ± 38.2

Technical Analysis

Figure 8.2 presents mean short passes produced during competition formats, for different maturation status. Significant differences were identified between competition formats ($F_{(1,22)} = 16.064$; $p < 0.05$, $\eta_p^2 = .42$), and the interaction between competition format and maturation status ($F_{(2,22)} = 4.175$; $p < 0.05$, $\eta_p^2 = .53$). Follow up analysis demonstrated the bio-banded format produced significantly more short passes than chronological, specifically for early ($t = 4.993$; $p < 0.05$, $d = 1.3$) and on-time developers ($t = 5.125$; $p < 0.05$, $d = 1.4$).

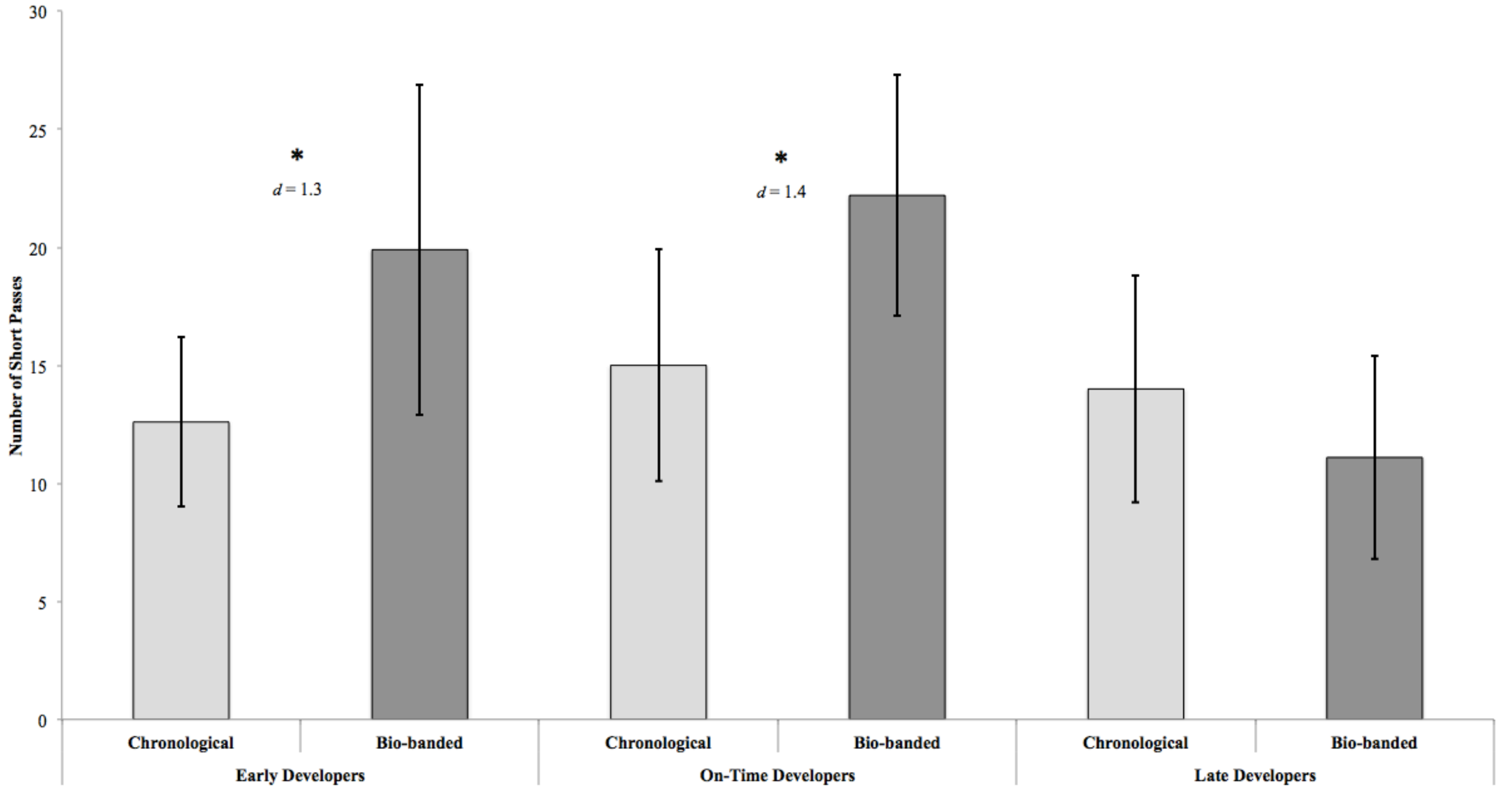

Figure 8.2. Number of short passes produced by early, on-time, late developing athletes during bio-banded and chronological competition formats. N.B. asterisk represents significant difference of $p < 0.05$, d represents effect size.

Figure 8.3 presents mean long passes produced during competition formats, for different maturation status. As with short passes, significant differences were identified between competition formats ($F_{(1,22)} = 19.284$; $p < 0.01$, $\eta_p^2 = .47$), and the interaction between competition format and maturation status ($F_{(2,22)} = 3.091$; $p < 0.01$, $\eta_p^2 = .22$). Follow up analysis demonstrated the chronological format produced significantly more long passes than bio-banded, for on-time ($t = 3.553$; $p < 0.01$, $d = 1.1$) and late developers ($t = 3.320$; $p < 0.05$, $d = 1.0$).

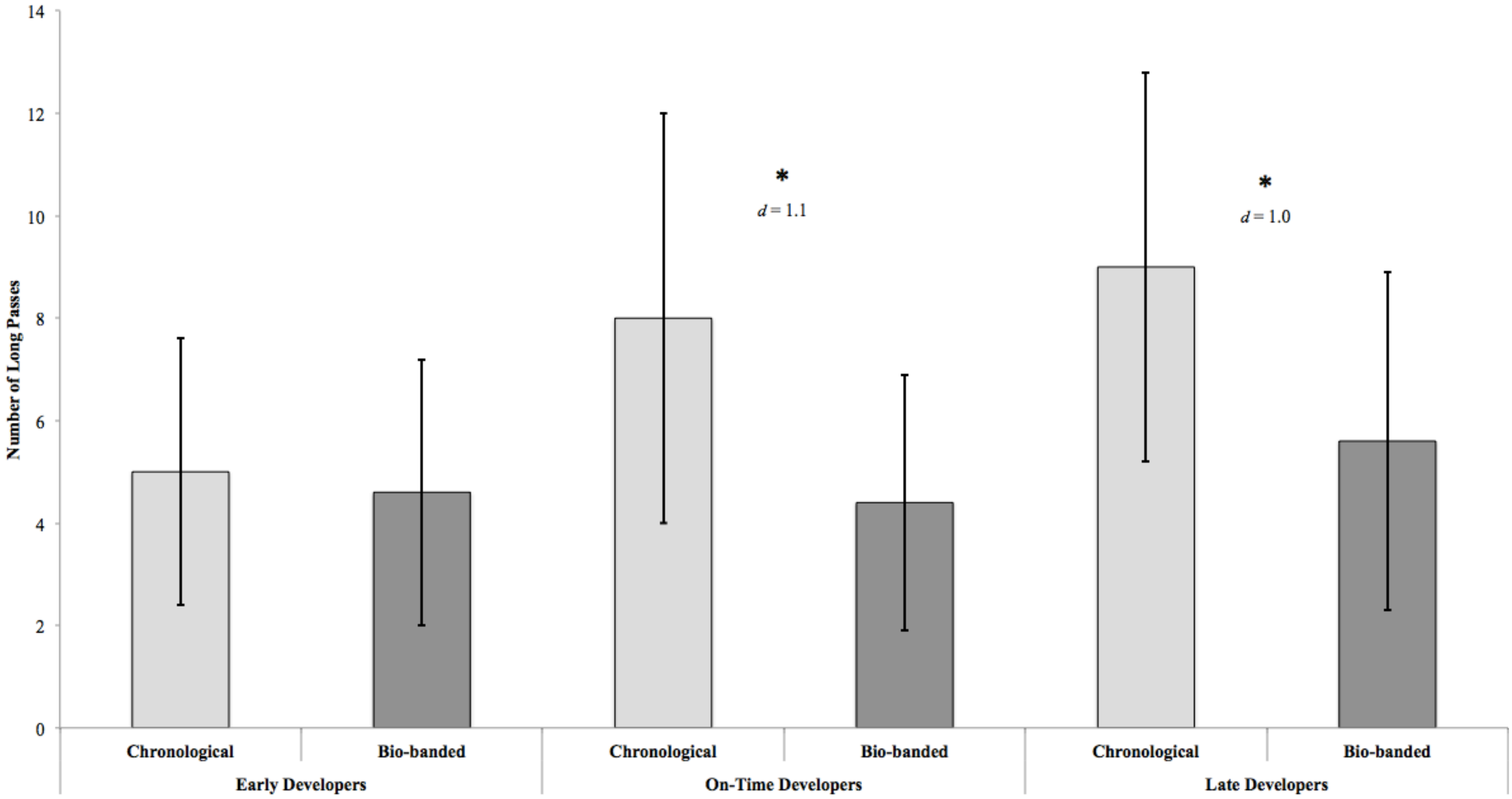

Figure 8.3. Number of long passes produced by early, on-time, late developing athletes during bio-banded and chronological competition formats. N.B. asterisk represents significant difference of $p < 0.05$, d represents effect size.

Figure 8.4 presents mean number of dribbles produced during competition formats, for different maturation status. Significant differences were identified for the interaction between competition formats and maturation status ($F_{(2,22)} = 8.693$; $p < 0.01$, $\eta_p^2 = .44$). Follow up analysis demonstrated the bio-banded format produced significantly more dribbles than the chronological competition format for early ($t = 2.517$; $p < 0.05$, $d = 0.8$), and on-time developers ($t = 7.236$; $p < 0.01$, $d = 0.7$). There was no significant difference between the number of dribbles produced by late developers during competition formats.

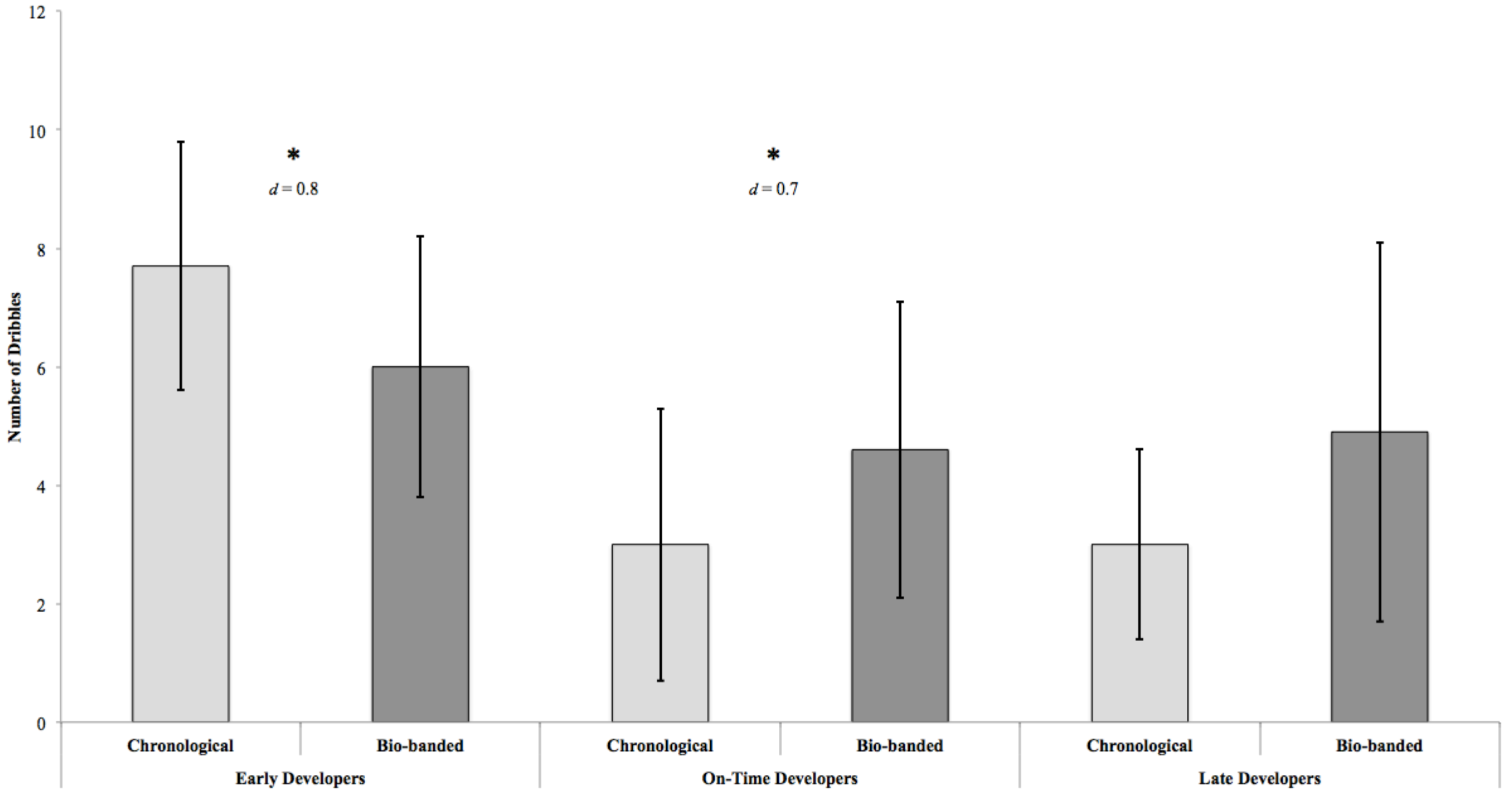

Figure 8.4. Number of dribbles produced by early, on-time, late developing athletes during bio-banded and chronological competition formats. N.B. asterisk represents significant difference of $p < 0.05$, d represents effect size.

Figure 8.5 presents mean number of tackles produced during competition formats, for different maturation status. Significant differences were identified for the interaction between competition formats and maturation status ($F_{(2,22)} = 6.195$; $p < 0.01$, $\eta_p^2 = .36$). Follow up analysis demonstrated the bio-banded format produced significantly more tackles than the chronological competition format for late developers ($t = 3.571$; $p < 0.01$, $d = 1.0$). No significant differences were identified between competition formats for early or on-time developers.

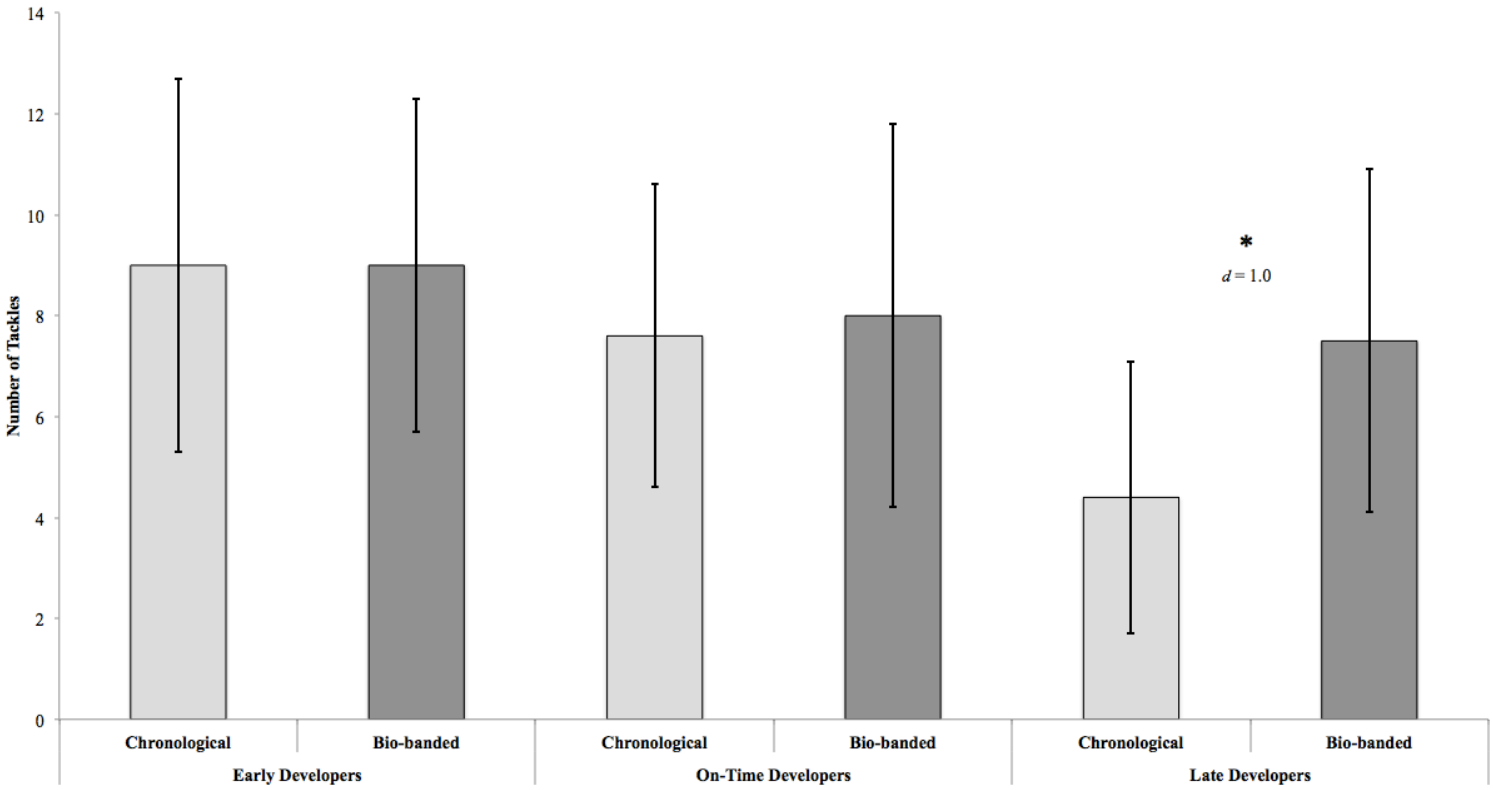

Figure 8.5. Number of tackles produced by early, on-time, late developing athletes during bio-banded and chronological competition formats. N.B. asterisk represents significant difference of $p < 0.05$, d represents effect size.

Table 8.4 presents mean number of shots, and crosses, produced during competition formats for athletes of differing maturation status. For both technical metrics, no significant differences were identified between competition formats, maturation status, or the interaction.

Table 8.4. Number of shots and crosses produced by early, on-time, late developing athletes during bio-banded and chronological competition formats. N.B. asterisk represents significant difference of $p < 0.05$.

Technical Performance Metric	Early Developers		On-Time Developers		Late Developers	
	Chronological	Bio-Banded	Chronological	Bio-Banded	Chronological	Bio-Banded
Shots	1.9 ± 1.5	2.7 ± 1.6	2.5 ± 1.8	2.5 ± 2.0	2.4 ± 1.7	2.5 ± 1.6
Crosses	1.9 ± 1.9	2.0 ± 1.7	1.9 ± 2.1	1.6 ± 1.6	2.0 ± 1.9	0.8 ± 0.9

8.4 Discussion

The aim of the current study was to determine the differences in physical and technical performance during bio-banded and chronological competition. This was the first study to objectively assess the effect of bio-banding upon physical and technical performance. In line with our predictions concerning physical performance, early developers produced significantly higher RPE during bio-banded competition when compared to chronological. However, no significant differences were identified in RPE produced between competition formats, for on-time or late developers. Additionally, no significant differences were identified in total, very high-speed running and sprinting, or acceleration distance produced between competition formats for any maturation status. Considering the limited differences in physical performance between bio-banded and chronological competition formats, H_9 was rejected and H_{09} accepted. In accordance with our predictions concerning technical performance, there were significant differences between competition formats. There was an increased number of short passes in early and on-time developers and a decrease in long passes for on-time and late developers between bio-banded and chronological formats. Dribbles decreased in early developers and increased in on-time developers. There were increased tackles performed by late developers in bio-banded competition compared to chronological. As a result of the significant differences in technical performance metrics between competition formats, H_{10} was accepted and H_{010} rejected.

It was demonstrated that late developers produced significantly higher RPE when compared to early developers overall. The higher RPE produced by late developers is likely the result of a habitual exertion response to competing with and against athletes of a higher relative physical development during usual chronological competition. When investigating differences in RPE between competition formats, results demonstrated early developers produced significantly higher RPE during bio-banded competition when compared to chronological. But no differences between competition formats were found in other maturation statuses. Higher RPE during bio-banded competition is likely the result of the increased perceived physical demands when competing with and against other early developers. Consistent with these results, significant differences were identified between the physical outputs of the maturation statuses. Late developers produced significantly higher total and acceleration distance when compared to early developers overall. From a constraints-based framework (Renshaw et al., 2010), the learnt response towards higher total and acceleration distances found late developers would emerge from the task constraints imposed by the early developers in competition. In order for late developers to maintain their competitiveness they would be required to produce higher total and acceleration distances, whereas the early developers would not need to do so.

No significant differences were identified for total distance, very high-speed running and sprinting distance and acceleration distance between competition formats for any maturation status. When considering the prescription of bio-banded competition, current results demonstrate that the bio-banded format does not significantly reduce the physical demands elicited upon athletes of any maturation status when compared to chronological competition. Although, there was a difference in the mean values for all physical performance metrics in the predicted direction. Current results compliment research conducted by Cumming et al. (2018) to some degree, investigating Premier League academy soccer players' experiences during bio-banded competition. Cumming et al. (2018) found that early developers described bio-banded competition format as a superior physical challenge when compared to chronological format. It was also found that late developers described bio-banded competition as less physically challenging in comparison to chronological competition. Although, these findings were derived from athletes' perceptions.

When investigating short and long passes produced between competition formats, significant differences were identified. The bio-banded format produced significantly higher number of short passes for early, and on-time developers, when compared to the chronological format. For long passes, bio-banded competition produced significantly less for on-time, and late developers, when compared to chronological competition. When focusing on number of dribbles and tackles produced during bio-banded and chronological competition formats, significant differences were also identified. For the number of dribbles, bio-banded competition produced significantly more dribbles compared to the chronological format, for early and on-time developers. For number of tackles, bio-banded produced significantly more tackles for late developers only. Referring to the constraints-based model, bio-banding competition resulted in more tackles and less long passes performed by late developers because of the reduced physical maturation of opponents compared to usual chronological competition. Presumably, decreased relative strength of opponents enable tackling behaviour to emerge. Likewise, the advantage of a long pass to a more physically mature teammate is no longer an option. Consequently, this tactical option is no longer exploited. In the case of early developers, the opportunity to dribble around less physically mature opponents is reduced, and therefore this behaviour is less frequent. The necessity to produce more short passes to move the ball towards the opponent's goal is required, and emerges in this competition format.

The finding of changes in frequency of certain technical skills can be seen as a potential method of improving technical performance in soccer. Rampanini et al. (2009) identified successful short passes, dribbles and tackles as important technical skill parameters for success in top level professional soccer. Additionally, Bradley et al. (2013) identified a superior technical proficiency in the Premier League when comparing to the lower English leagues. This was characterised by significantly higher numbers of total passes in the Premier League, in comparison to a more transient long ball tactic utilised at lower standards of soccer (Barnes et al., 2014). Current results compliment research by Cumming et al. (2018), suggesting the bio-banded formats place an increased emphasis upon technical ability. This is reflected by an increased frequency of short passes, and dribbles for early and on-time developers, supporting findings that bio-banded competition encouraged early developers to emphasise technique over physicality (Cumming et al., 2018). Furthermore, an increased technical emphasis was also apparent for late developers, with a decreased frequency of longer passing in bio-banded competition formats. In addition, late developers produced significantly more tackles in bio-banded formats, supporting previous findings that late developers were allowed a great opportunity to exert and develop their physicality during bio-banded formats (Cumming et al., 2018).

The trend for differences between bio-banded and chronological competition formats was not apparent when investigating the number of shots and crosses performed. For number of shots, there were no significant differences between competition formats, for early, on-time, or late developers. This was the same for number of crosses, with no significant differences between competition formats for any maturation status. The lack of significant differences identified between competition formats for these two technical metrics is likely the result of the specificity of actions to playing positions. Shooting is an action more commonly associated with strikers and attacking playing positions, and infrequently seen in defenders. Crossing is a technical action frequently exhibited in wide attacking and wide defending playing positions, and rarely seen for central defenders. Due to the limited sample size, analysis was not conducted for individual playing position, and therefore the large variations between playing positions may have resulted in no significant differences being identified. This is a topic requiring further investigation.

The current study provides applied practitioners with valuable insights regarding the physical and technical differences between bio-banded and chronological competition formats for athletes of differing maturation status. This study was the first to provide objective evidence on the effect of bio-banding upon physical and technical performance. Results can be used to individualise the prescription of competition format to different maturation statuses, dependent upon their physical and technical development needs. For early developers, bio-banded competition produced more short passes, more dribbles, and a higher RPE than chronological competition. For on-time developers, bio-banded competition produced more short passes, more dribbles, and less long passes than chronological competition. For late developers, bio-banded competition produced more tackles, and less long passes than chronological competition. For all maturation status, bio-banded competition increased the occurrence of key technical performance metrics when compared to chronological competition. Despite increases in technical demands, the physical demands placed upon athletes during bio-banded competition were similar when compared to chronological competition.

It is important to consider the limitations of the current study. Firstly, despite recent improvements in GPS hardware and software, there is still associated error with the devices. For example, Delaney et al. (2017) demonstrate that 10-Hz devices exhibit coefficient of variations of 1.2 - 6.5% when assessing acceleration and deceleration, and must be acknowledged when applying current results. The large effect sizes demonstrated within the current study suggest the sizes of the differences were larger than the error associated with measurement. Therefore, it can be stated with confidence that the effects are not the result of chance. Secondly, the study was conducted using soccer athletes at a Premier League academy, and consequently may not be directly applicable to other clubs or levels. Finally, due to the nature of the study, a small sample size was recruited, and each athlete only completed one bio-banded and chronological fixture. This prevented further study into the effect of bio-banded and chronological competition formats for different playing positions and maturation statuses. The current study found no significant differences in shooting and crossing metrics between competition formats. Considering the specificity of these two technical metrics to playing positions, conducting positional analysis may have resulted in further findings.

8.5 Conclusion

The current study provides support for bio-banding as an intervention to alter the task constraints of soccer match-play. The consequence of bio-banded competition was an increase in performance indicators associated with technical skill. Significant differences were identified between competition formats for several technical performance metrics, which varied for athletes of differing maturation status. Current results can aid applied practitioners in prescribing competition formats, dependent upon an athlete's maturation status and developmental needs. For all maturation status, bio-banded competition increased the emphasis placed upon technical performance when compared to chronological competition. The exact technical demands varied dependent upon maturation status. Interestingly, early developers perceived bio-banded competition as more physically exerting compared to chronological competition, as demonstrated by RPE. Despite increased technical demands, and the increased perception of exertion, distances travelled during bio-banded formats were similar when compared to chronological formats. Consequently, it can be concluded that bio-banded competition format increases the technical emphasis placed upon athletes of varying maturation status, without reducing the physical demands elicited.

9.0 General Discussion

9.1 Introduction

The focus area of the current thesis was the use of global positioning systems (GPS) as a training load monitoring tool within professional soccer. The studies focused upon an individualised approach to monitoring and prescribing training loads in elite academy soccer players. Study One, Study Two, and Study Three examined the processes associated with the individualised monitoring of training load. These processes involved the use of individual speed and acceleration thresholds, and identifying the positional demands of soccer competition. Study Four and Study Five focused upon how training games and competition formats could be prescribed to athletes of different playing positions, and maturation status respectively.

Specifically, Study One analysed the discrepancies between individual and global speed analysis methods in monitoring high-speed locomotion for athletes of differing physical capacities. Individual speed thresholds were determined utilising individual's maximum aerobic speed, and maximum sprint speed performance, assessed utilising field based tests.

Study Two analysed discrepancies between low-, moderate-, and high-intensity acceleration distances produced using individual and global acceleration analysis methods for athletes of varying maximal capacities. Individual acceleration thresholds were determined utilising a field based test assessing individual's maximum acceleration capacity.

Study Three quantified the physical demands elicited by soccer competition, and the relationship between physical outputs and match outcome. The physical demands placed upon soccer playing positions during competition were analysed and compared. The association between the physical demands of individual playing positions and match outcome was also investigated.

Study Four examined the effect of training game format upon physical outputs produced by soccer playing positions. Physical outputs produced by playing positions during different training game formats were analysed relative to the positional demands of competition. Both average and peak demands of training games and competition were investigated.

Study Five quantified the effects of bio-banded competition upon physical and technical performance in academy soccer players. Differences in physical and technical performance metrics were compared between bio-banded and chronologically grouped competition. Analysis was sub-divided for maturation status, with differences between competition format investigated for early, on-time, and late developing athletes.

Findings of the current thesis demonstrate the importance of individualising the training load monitoring process. In addition, findings highlight the need for specific prescription of training and competition formats for athletes of different playing positions and maturation statuses.

9.2 Experimental Hypotheses Tested

Table 9.1 presents the experimental hypotheses tested with the current thesis, and details whether the individual hypothesis was accepted or rejected.

Table 9.1 Experimental hypotheses tested with the current thesis.

Hypothesis Number	Description of Hypothesis	Accepted / Rejected
H_1	There will be a significant difference in high-speed locomotion distances produced by global and individual analysis methods.	Accepted
H_2	Differences in high-speed locomotion distances produced by global and individual analysis methods will vary dependent upon an athlete's physical capacity.	Accepted
H_3	There will be significant differences in acceleration distances produced by global and individual analysis methods.	Accepted
H_4	Differences in acceleration distances produced by global and individual analysis methods will vary dependent upon an athlete's maximum accelerative capacity.	Accepted
H_5	There will be significant differences in the physical outputs produced by soccer playing positions.	Accepted
H_6	There will be significant differences in the physical outputs produced during matches of differing match outcome.	Rejected
H_7	There will be significant differences in the average physical outputs produced by small, medium and large training games relative to competition.	Accepted
H_8	There will be significant differences in the peak physical outputs produced by small, medium and large training games relative to competition.	Accepted
H_9	There will be significant differences in physical performance metrics produced by bio-banded and chronological competition formats.	Rejected
H_{10}	There will be no significant differences in technical performance metrics produced by bio-banded and chronological competition formats.	Accepted

9.3 Use of Field Tests to Individualise Speed and Acceleration Thresholds

When previously attempting to individualise speed and acceleration thresholds for athletes, numerous methodologies have been utilised. Examples include ventilatory thresholds (Clarke et al., 2015; Lovell & Abt, 2013), maximum aerobic speed (Hunter et al., 2015; Mendez-Villanueva et al., 2013), maximum sprint speed (Gabbett, 2015; Reardon et al., 2015), and maximum accelerative capacity (Sonderegger et al., 2016). For practitioners working in applied sport, it is vital the methods utilised are cost-effective, time-efficient, and feasible. Typically, practitioners are working with large squads of athletes, and have limited time and budgets dedicated to physical testing procedures. Lovell and Abt (2013) utilised an incremental treadmill test to determine individual athlete's ventilatory thresholds. Although making theoretical sense, with the second ventilatory threshold representing the transition from moderate to high-intensity work, this procedure is infeasible to the majority of applied practitioners. This methodology is time-intensive, expensive and requires access to facilities and expertise to administer. Due to the aforementioned limitations, Study One and Study Two utilised field tests to determine the physical capacities of athletes. The field tests utilised had previously been administered in team sport environments, and conformed to current testing procedures utilised by Premier League soccer academies.

Alongside being feasible to conduct, it is vital that tests are valid and reliable. Within Study One, Study Three, Study Four, and Study Five, maximum sprint speed and maximum aerobic speed testing protocols were used to determine peak speed and estimate $v\dot{V}O_{2max}$ respectively. The maximum sprint speed protocol involved each athlete completing three maximal 40m linear sprints, with a minimum of three minutes rest between repetitions. Maximum sprint speed was identified as the average speed recorded over the quickest 10m sector, and measured using electronic light gates (Brower TC Timing System) to the nearest 0.01s. Mendez-Villanueva et al. (2013) demonstrated the intraclass correlation coefficient for the maximum sprint speed protocol as 0.94 - 0.99. The protocol used to identify maximum aerobic speed was a modified version of the University of Montreal Track Test (Leger & Boucher, 1980). Mendez-Villanueva et al. (2013) had previously used this protocol to estimate maximum aerobic speed. The correlation coefficient for the protocol has been demonstrated as 0.97 (Leger & Boucher, 1980). The modified University of Montreal Track Test begins with an initial running speed of 8 $km.h^{-1}$, with the speed increasing by 0.5 $km.h^{-1}$ each minute. Athletes run around a 200m athletics track, marked with 20m intervals, in time with an audible cue, until either exhaustion or three consecutive cones are missed. Maximum aerobic speed was estimated using the speed of the final one-minute stage completed. Both maximum sprint speed and maximum aerobic speed protocols had previously been utilised by Mendez-Villanueva et al. (2013) and Hunter et al. (2015) to determine soccer player's maximum sprint and maximum aerobic speeds, and individualise speed thresholds. Within Study Two, Study Three, Study Four, and Study Five, maximum accelerative capacity was determined using a maximum acceleration protocol. The protocol required athletes to complete three maximal 40m linear sprints, with a minimum of three minutes rest between repetitions. The maximum rate of acceleration was calculated utilising 10-Hz portable GPS devices (OptimEye S5B, Version 7.18; Catapult Innovations, Melbourne, Australia), with the highest acceleration values recorded for each athlete. This was identical to the protocol utilised by Mendez-Villanueva et al. (2013) to determine maximum sprint speed, and a similar protocol utilised by Sonderegger et al. (2016) to determine maximum accelerative capacity and individualise acceleration thresholds. Delaney et al. (2017) reported coefficient of variations of 1.2 - 6.5% when using 10-Hz GPS to assess acceleration, which must be acknowledged by practitioners. Prior to each of the physical performance tests, athletes completed a standardised warm up. The maximum sprint speed and maximum acceleration protocols were completed on an indoor artificial grass surface with football boots. The maximum aerobic speed protocol was completed on a grass surface with football boots. The protocols utilised within the current thesis provided valid representations of physical performance, and had previously been used within similar investigations. In addition, each of the protocols demonstrated an acceptable level of reliability.

Study One was the first to individualise speed thresholds using field tests, and to sub-divide athletes dependent upon physical capacity, whilst investigating discrepancies between analysis methods. Results demonstrate the discrepancies between analysis methods vary significantly for athletes of differing physical capacities. For athletes with low maximum aerobic speed capacities, the individual analysis method produced significantly higher high-speed running, very high-speed running, and sprinting distances when compared with the global analysis method. For athletes with medium maximum aerobic speed capacities, the differences were less marked. The only significant difference for medium maximum aerobic speed athletes was the individual analysis method produced significantly higher sprinting distances than the global method. When focusing upon athletes with high maximum aerobic speed capacities, discrepancies followed the opposite trend to those demonstrated with low maximum aerobic speed capacities. High-speed running and very high-speed running distances produced by the individual analysis method were significantly lower when compared to the global analysis method. Sub-dividing athletes by physical capacity provides additional insight into the discrepancies between analysis methods. Varying discrepancies between athletes of differing physical capacities (Gabbett, 2015) and playing positions (Reardon et al., 2015) have previously been reported within literature, with comparable results to the current study. Gabbett (2015) concluded individual thresholds increased high-speed running attributed to relatively slower athletes, and decreased high-speed running attributed to relatively faster athletes. Similarly, Reardon et al. (2015) demonstrated that global speed thresholds underestimated the high-speed running performed by Rugby forwards by 22%, and overestimated high-speed running performed by Rugby backs by 18%. These results compliment the findings of Study One, highlighting the discrepancies in high-speed locomotion distances produced by differing analysis methods for a squad athletes with varying physical capacities.

To date, there is no research investigating the discrepancies between global and individual analysis methods in quantifying acceleration. Study Two was the first to examine the discrepancies between analysis methods, sub-dividing athletes dependent upon maximum accelerative capacity. Findings demonstrated significant discrepancies between analysis methods, with discrepancies varying between athletes of differing maximal accelerative capacities. For athletes with low maximum accelerative capacities, no significant differences were identified between analysis methods for any acceleration intensity. When focusing upon athletes with medium maximum accelerative capacities, significantly higher moderate- and high-intensity acceleration distances were produced utilising the global analysis method. For athletes with high maximum accelerative capacities, significantly higher acceleration distances were produced when utilising the global analysis method compared to the individual, for all acceleration intensities. Considering Study Two was the first to investigate discrepancies in acceleration distances produced by global and individual analysis methods, current results cannot be compared to previous research. However, comparisons can be made to previous research investigating discrepancies between global and individual speed thresholds. Lovell and Abt (2013) reported significantly lower high-intensity distances produced utilising global speed thresholds compared to individual. Whilst Clarke et al. (2015) concluded that global thresholds underestimated high-intensity running distances by up to 30% when compared to individual thresholds. Notably, the direction of the discrepancies within both investigations differed in comparison to Study Two. However, neither Lovell and Abt (2013) nor Clarke et al. (2015) sub-divided athlete groups within their analyses. Current results are comparable to previous research sub-dividing athlete groups. Gabbett (2015) demonstrated that individual speed thresholds decreased high-speed running attributed to relatively faster athletes, whilst Reardon et al. (2015) concluded that global speed thresholds overestimated the high-speed running performed by Rugby backs. Both conclusions compliment current results, with significant differences identified between analysis methods, and varying differences identified between athlete groups. Interestingly, within the current study, discrepancies between analysis methods were more pronounced at higher acceleration intensities, and the extent of the discrepancies were higher than those reported by Reardon et al. (2015) in Rugby backs.

Findings from Study One and Study Two have significant implications for applied practitioners aiming to monitor the relative demands of high-speed and accelerative tasks for athletes. Global thresholds are frequently utilised in team sport environments due to their feasibility, as they require no physical capacity testing (Akenhead & Nassis, 2016). Considering the same thresholds are utilised for all athletes, global thresholds allow for comparisons between external workloads completed by athletes. This is important for coaches, given success within competition is determined by what an athlete can produce in absolute terms. However, it is vital to note that global thresholds do not account for the relative intensity an athlete is working. Therefore, if the aim is to quantify and monitor the intensity of the activity being performed it is recommended individual thresholds are utilised. Without acknowledging an athlete's physical capacities, both current and previous results (Gabbett, 2015; Lovell & Abt, 2013) demonstrate there are large errors associated with estimating intensity using global thresholds.

9.4 Identifying Positional Demands and Prescribing Training Game Formats

The aim of soccer training sessions is to develop and improve competitive performance. From a physical perspective, this requires the session to replicate or overload the demands an athlete encounters during competition. Considering the physical demands placed upon individual playing positions vary significantly, an individual's training prescription should be specific to their positional requirements. A high frequency of specific actions and activities may overload certain muscle groups, and have implications for how individuals are conditioned. In addition, training load is extremely individual in nature, with athletes responding differently dependent upon numerous internal and external variables (Casamichana et al., 2012; Scott et al., 2013). Therefore, to ensure training is efficient, and that individual requirements are being met, it is vital that training techniques are specific to individual athletes.

Study Three was the first to investigate the holistic physical demands placed upon soccer playing positions utilising an individual approach to monitoring. Individual speed and acceleration thresholds were administered, demonstrating significant variations in physical demands elicited upon playing positions within the current subject group. When investigating the physical demands placed upon the central defender, this playing position produced the lowest total distances, high-speed distances, and moderate- and high-intensity acceleration distances. This corresponds to results reported by Dellal et al. (2011c) and Guadino et al. (2010), stating the central defender position is associated with the least physical demand. Wide defender and wide attackers produced the highest high-speed distances, maximum speed, and high-intensity acceleration distances during competition. This complimented findings from Bradley et al. (2010) and Ingebrigtsen et al. (2015), and is suggested to be a result of operating on the flanks of the pitch. Due to their varying competitive demands, the training methodologies selected to train central defenders will differ significantly from those selected to train wide attackers and defenders. Training for wide attackers and defenders should focus upon developing high-speed locomotion and high-intensity acceleration capacities, whilst training for central defenders should have a greater technical and tactical focus, highlighted as important for the position (Bangsbo et al., 2006). Central midfielders produced the highest total distances and moderate-intensity acceleration distances during competition, as previously reported by Bradley et al. (2009) and O'Donoghue et al. (2005). The demands elicited upon a central midfielder are specific to this playing position, and consequently require different training methodologies compared to the playing positions previously described. Based upon their competitive demands, specific training for central midfielders would include a high volume of total distance, and frequent moderate-intensity manoeuvers. Strikers produced significantly lower total distance travelled compared to all playing positions, excluding central defenders. However strikers have a significant high-speed demand placed upon the position, consequently requiring specific training methodologies. Considering the significant differences in physical demands placed upon soccer playing positions, uniform training methods would be impractical. There is therefore rationale for specific training prescription for individuals within the same team.

Previous research had investigated the effect of training game format upon the average demands elicited upon soccer players. However, Study Four was the first to investigate the effect of training game size on average and peak physical demands elicited upon individual playing positions relative to competition. Small training games produced the lowest average and peak total distance intensities when compared to medium and large training games. The average total distance intensities were not significantly different to competition, however peak intensities were significantly below competitive intensities for all playing positions. The trend was similar for average and peak very high-speed running and sprinting intensities. Current findings compliment research conducted by Brandes et al. (2012) and Castellano et al. (2013), demonstrating small training games produce lower total and high-speed distances when compared to large training game formats. When comparing small training games to competition, both average and peak intensities for very high-speed running and sprinting were significantly below competitive intensities for all playing positions. For moderate-intensity acceleration distances, small training games produced the highest average and peak intensities when compared to all other game formats. Both average and peak intensities were significantly higher than competition for all playing positions. Current results were in contrast to those reported by Castellano et al. (2013), who concluded that large game formats were associated with more frequent accelerations. However, Davies et al. (2013) reported agility manoeuvres were more frequent during small formats when compared to large, complimenting current findings. For high-intensity acceleration distances the trend was reversed, with small training games producing the lowest average and peak intensities compared to all other game formats. These findings mirrored Castellano et al. (2013), suggesting the authors may only have recorded high-intensity accelerations during their investigation. When comparing average high-intensity acceleration distance intensities to competition, all playing positions excluding central defenders produced significantly lower intensities relative to competition. For peak high-intensity acceleration distances, intensities were significantly lower than competition for all playing positions. For RPE, small training games produced the highest values when compared to all other training game formats, mirroring findings from previous research (Aguiar et al., 2012; Hill-Haas et al., 2009). When compared to competition, small training games produced significantly higher RPE values for all playing positions. Considering the specific demands of small training games, this game format would be a training modality best suited to overloading moderate-intensity acceleration distances, and perceived exertions relative to competition.

The average and peak demands elicited upon playing positions by medium training games differed significantly from those elicited by small training games. This has been demonstrated in previous research for total distance travelled (Castellano et al., 2013), high-speed running (Brandes et al., 2012), and agility manoeuvres (Davies et al., 2013). Average total distance produced by medium training games was significantly higher than competition for all playing positions. However, when analysing peak total distance, medium training games produced an intensity significantly below those elicited during competition, for all playing positions. For very high-speed running and sprinting distances, average and peak intensities produced during medium training games were significantly below competitive intensities, for all playing positions. When focusing upon moderate-intensity acceleration distances, a different trend was identified. Medium training games produced significantly higher average and peak intensities than competition, for all playing positions. For high-intensity acceleration distances, there were no significant differences between average and peak intensities produced during medium training games and competition, for any playing position. When comparing RPE values produced during medium training games to competition, there were no significant differences in values produced by any playing position. When considering the specific demands of medium training games, this game format would be a training modality best suited to overloading moderate-intensity acceleration distances, and replicating high-intensity acceleration distances relative to competition.

Large training games produced the highest average and peak total distance intensities when compared to other training game formats. Average total distance was significantly higher than competition for all playing positions. However, when analysing peak total distance, large training games produced significantly lower intensities than competition for all playing positions, excluding central defenders. For very high-speed running and sprinting distance, large training games produced higher intensities than both small and medium training games, complimenting previous research investigating average demands (Brandes et al., 2012; Castellano et al. 2013). For average very high-speed running and sprinting distance intensities, there was no significant difference between large training games and competition, for all playing positions. However peak very high-speed running and sprinting distance intensities followed the same trend as peak total distance, with significantly lower intensities relative to competition, for all playing positions. When focusing upon moderate-intensity acceleration distances, large training games produced the lowest intensities compared to other training games. However, despite producing the lowest moderate-intensity acceleration distances, average intensities were significantly higher than competition for central defender, central midfielder and wide attacker positions. Additionally, there were no significant differences between peak intensities produced during competition and large training games, for any playing position. When focusing upon high-intensity acceleration distances, large training games produced the highest intensities when compared to other training game formats. Both average and peak intensities were significantly higher than competition for all playing positions. The occurrence of high-intensity accelerations within the current study corresponded with the suggestion of Castellano et al. (2013) that large training games produce a higher acceleration demand when compared to smaller formats. This is despite differences in methodology, with Castellano et al. (2013) not sub-dividing acceleration tasks dependent upon intensity as in the current study. For RPE, as cited within previous research, large training games produced the lowest values for all game formats (Aguiar et al., 2012; Hill-Haas et al., 2009). When compared to competition, there were no significant differences in RPE values produced between large training games and competition for central defender, wide defender, and striker positions. However, RPE values produced by central midfielder and wide attacker playing positions were significantly lower during large training games compared to competition. When considering the specific demands of large training games, this game format would be a training modality best suited to overloading high-intensity acceleration distances, and replicating total distances, very high-speed running and sprinting distances, and moderate-intensity acceleration distances. However, it must be noted that peak total distance, and peak very high-speed running and sprinting distances were not replicated by large training games, with only average intensities replicated.

The results of Study Four conclude that different training game formats elicit specific physical stimuli upon athletes. Considering the results of Study Three, which demonstrate each soccer playing position has differing physical demands elicited upon them during competition, certain game formats can be used as specific training modalities to individual playing positions. When assessing small training games, this game format overloaded moderate-intensity acceleration distances, and perceived exertions relative to competition. Considering the central midfielder position produces the highest frequency of moderate-intensity accelerations during competition, small training games are a modality that provides a specific stimulus to this playing position. In addition, small training games were the only format that overloaded perceived exertion for the central midfielder position. When assessing large training games, this game format overloaded high-intensity acceleration distances, and average total distances, whilst replicating average very high-speed running and sprinting distances. Wide defender and wide attacker playing positions are characterised by producing high-speed distances, and high-intensity acceleration distances during competition. Consequently, large training games produce a stimulus specific to the physical demands elicited upon these positions during competition. When focusing upon medium training games, this format overloaded moderate-intensity acceleration distances, and replicated high-intensity acceleration distances relative to competition. The physical demands placed upon the striker playing position are multifaceted, with the need to produce moderate- and high-intensity acceleration manoeuvres during competition. Considering the aforementioned, medium training games produce a specific stimulus for this playing position. In addition, this game format overloads the average total distance intensities produced by the striker position during competition.

Findings from Study Four and Study Five have significant implications for applied practitioners. Results demonstrate the vast differences in physical demands placed upon soccer playing positions during competition. Analysis of the demands of training game formats provide vital information to practitioners regarding the specific physical stimuli placed upon playing positions relative to their competitive demands. Having identified the specific physical demands elicited by training games, current results allow practitioners to prescribe game formats to playing positions dependent upon their specific training needs, improving the specificity of soccer training. An issue highlighted by the current results is the inability of all training game formats to replicate or overload peak very high-speed running and sprinting distances produced during competition. This was evident for all playing positions. Given the importance of high-speed activities for soccer performance, practitioners are recommended to prescribe supplementary maximal speed training alongside their chosen training games.

9.5 Prescription of Bio-banded and Chronological Competition Formats

Soccer is a sport characterised by intermittent explosive activities such as sprinting, jumping, tackling, and change of pace and direction (Meylan et al., 2010). Increased muscle mass, associated with maturation, contributes towards maximal strength, maximum power output, and performance in field tests. With successful soccer performance determined by an individual's ability to perform the aforementioned tasks, advantages are therefore provided to early developing males, whilst late developers are disadvantaged. Large variation in maturity status within chronological age groups provides issues for youth soccer. Early developers, possessing increased size, weight and strength are perceived as talented and of higher potential to coaches and scouts. Consequently, early developers have an increased likelihood of selection and retention within the system, whilst late developers experience higher levels of failure, and reduced playing opportunities. This leads to high dropout rates for late developers. Interestingly, the physical advantages initially experienced by early developers may be detrimental to their long-term development. Progressing through the age groups using their physical attributes results in decreased emphasis placed upon technical and tactical development. Following maturation, the physical advantages once experienced are no longer present, and technical ability becomes a larger determinant of success. The result is that early developers no longer progress at the same rate, and are less effective (Meylan et al., 2010).

Bio-banding is suggested to have beneficial effects for both early and late developing athletes. For early developers, being matched against more physical athletes results in a larger emphasis being placed upon technical and tactical attributes. For late developers, being exposed to a physically balanced environment results in the opportunity to have a greater impact upon competition, and develop both physical and technical attributes. Using a constraints-based framework, it is argued that playing in chronologically equivalent competition may lead to the motor performance of the late developers being constrained by the presence of the early developers. If there is a change in the task constraint of player maturation, as seen in bio-banded matches, then a different motor performance will potentially emerge. Bio-banded competition has the potential to improve the talent identification process for scouts, providing the opportunity to evaluate athletes with the effects of maturation removed. The desired result would be less late developers being released prematurely, and less early developers being retained as a result of their superior maturation status. Despite having significant implications for the development of youth soccer athletes, there has been limited research focusing upon differences in physical and technical performance between bio-banded and chronological competition. Cumming et al. (2018) investigated the perceived experiences of athletes participating in bio-banded competition, however only qualitative data was collected. Study Five was the first to compare physical and technical performance during bio-banded and chronological competition, for athletes of differing maturation status.

When focusing upon the effect of bio-banded competition upon physical performance, there were limited differences in GPS metrics identified between competition formats for athletes of all maturation statuses. No significant differences were identified between bio-banded and chronological competition for total distance, sprinting distance, or acceleration distance, for early, on-time, or late developers. When investigating differences in RPE between competition formats however, significant differences were identified for early developers. Early developers produced significantly higher RPE values during bio-banded competition compared to chronological. This compliments research conducted by Cumming et al. (2018), concluding early developers described bio-banded competition formats as a superior physical challenge when compared to chronological formats. The higher RPE values produced by early developers during bio-banded competition are likely the result of being matched with other early developing athletes. This is in contrast to being matched against on-time or late developers during chronological competition. The current study identified no significant differences in RPE values between bio-banded and chronological competition for on-time, or late developers. This is in contrast to findings by Cumming et al. (2018), who concluded late developers described bio-banded competition as less physically challenging compared to chronological.

The effect of bio-banded competition upon technical performance produced significant differences for athletes of all maturation statuses. For short passes, bio-banded competition produced significantly higher values than chronological competition for early, on-time, and late developers. The opposite was true for long passes, with the chronological format producing significantly higher values than bio-banded for on-time and late developers. For the number of dribbles, significantly higher values were demonstrated during the bio-banded format for early and on-time developers. For the number of tackles, bio-banded competition produced significantly higher values than chronological competition for late developers. Current results fall in line with research by Cumming et al. (2018), suggesting bio-banded formats result in an increased emphasis placed upon technical ability. This is demonstrated by a higher frequency of short passes, and dribbles for early and on-time developers, and a lower frequency of longer passes for on-time and late developers. Late developers were also demonstrated to produce more tackles during bio-banded competition, complimenting suggestions from Cumming et al. (2018) that late developers were better able to exert their physicality during bio-banded competition. Results for number of shots, and number of crosses during the two competition formats did not follow the same trend, with no significant differences being identified between competition format. This is likely the result of the specificity of these actions to individual playing positions. Crossing is an action frequently produced by wide attacking and wide defending positions, whilst shooting is an action most frequently observed by strikers. Due to the nature of the study, a limited sample size was available. This prevented further investigation into the effect of bio-banded and chronological competition formats for different playing positions.

The findings from Study Five provide practitioners with valuable information regarding the physical and technical effects of bio-band competition. Results indicate that the effects of bio-banded competition differ dependent upon the individual athlete's maturation status. For early developers, bio-banded competition produced more short passes, more dribbles, and a higher RPE compared to chronological. A higher RPE (Bio-banded Mean ± SD = 7.5 ± 0.9 RPE, Chronological Mean ± SD = 6.6 ± 0.5 RPE) would suggest the early developers found bio-banded competition more physically demanding. The ease at which early developers can exert their physicality has previously been a criticism of chronological competition. For on-time developers, bio-banded competition produced more short passes, more dribbles, and less long passes than chronological. For late developers, bio-banded competition produced more tackles, and less long passes than chronological. The increases in tackles (Bio-banded Mean ± SD = 7.5 ± 3.4 tackles, Chronological Mean ± SD = 4.4 ± 2.7 tackles) suggest bio-banded competition allows late developers to exert their physicality to a larger extent. The inability for late developers to exert their physicality has previously been a criticism of chronological competition. Results allow coaches to individually prescribe competition formats to athletes of differing maturation statuses, dependent upon their physical and technical developmental needs. These findings follow the theme identified by previous studies within the thesis, providing rationale for an individual approach to the prescription of training load.

9.6 Limitations

The advantages of utilising individual thresholds to monitor both high-speed and accelerative training load are clear. Accounting for individual athletes' physical capacities allow for the relative intensity of activities to be determined. An issue associated with determining individual thresholds using physical capacities, is that physical capacities are demonstrated to fluctuate throughout a season. For example, Meckel et al. (2018) demonstrated improvements of 6 - 10% in a range of physical capacities throughout the course of a soccer season. Physical capacities may increase as a result of a training emphasis, or decrease as a result of a deconditioning or injury. As a consequence, it is important that physical capacity testing (e.g maximum aerobic speed, maximum sprint speed, and maximum accelerative capacity) is performed regularly, and individual thresholds are updated. Otherwise, the individual thresholds utilised may provide an inaccurate representation of the load elicited upon an individual. Currently, there are no recommendations for the frequency of re-testing when utilising individual thresholds. During Study One and Study Two, physical performance tests were conducted the day prior to the commencement of data collection to individualise thresholds for the respective studies. From this point forward, individual thresholds utilised during the respective studies were kept constant and not updated during the course of the investigation, acting as a potential limitation.

The following points discuss the external validity of the approaches utilised within the thesis studies. Participants within the current thesis were recruited from a professional soccer academy. For Study One, Study Two, Study Three, and Study Four, participants were full-time professional soccer players within a Premier League U23 squad. For Study Five, due to the focus upon bio-banding and maturation, participants were part-time soccer players within Premier League U16 - U12 squads. Previous research has demonstrated that the physical outputs produced during competition vary dependent upon competitive level, and age (Bradley et al., 2010; Mendez-Villanueva et al., 2013). As a consequence of the elite participant level, and that the population studied were relatively homogenous, findings from the current thesis may not be directly applicable to other genders, levels or across age groups. In addition, the positional match data collected during Study Three and Study Four was recorded for a 4-3-3 formation. Previous research has demonstrated the physical demands elicited upon specific playing positions may vary dependent upon team formation (Bradley et al., 2011). Bradley et al. (2011) identified that attackers produced ~30% more high-intensity running within a 4-3-3 formation compared to a 4-4-2 or 4-5-1 formation. Different formations place different tactical roles and responsibilities upon playing positions, influencing the physical demands elicited.

The data collection periods for Study Three and Study Four spanned two and one seasons respectively. Whilst producing large data sets, with a total of 343 match observations for Study Three, and 735 match and training game observations for Study Four, long data collection periods have issues associated. The issues relate to the maturational threat upon internal validity. Despite large efforts to standardise data collection procedures, the nature of research within applied environments result in the potential for external factors to affect data collection. For example, the weather varied throughout the season, and consequently affected the quality of the training and match pitches, in addition to athlete motivation. Although effort was made to ensure athlete motivation was high (e.g coach encouragement, recorded scores during training games), motivation may have varied throughout the season due to personal or work related issues. Although these external factors may have affected the data collected, the large data set ensured the effects were negligible.

The final limitation relates to the instrumentation threat upon internal validity. Within the current thesis 10-Hz GPS devices were utilised. Advances in the hardware and software associated with 10-Hz devices have allowed for greater accuracy and reliability when compared to 1-Hz and 5-Hz devices. Caution was applied during data collection and analysis processes to ensure procedures were standardised, and that accuracy was maintained. Additionally, athletes consistently wore the same devices to reduce inter-unit error. As with all technology however, there is associated error. 10-Hz devices are demonstrated to exhibit coefficient of variations of 1.2 - 6.5% when assessing acceleration and deceleration. Although this is suggested to provide sufficient accuracy to quantify acceleration and deceleration within team sports, it requires acknowledgment from practitioners when applying the current results. With GPS hardware and software constantly advancing, it is vital future research validates new technology, ensuring practitioners are aware of the associated error within results.

The aim of the thesis was to provide recommendations for training load monitoring and prescription to both coaches and applied sport scientists. Therefore, it is vital that the studies were conducted within an applied environment to ensure ecological validity. All of the studies within the current thesis were conducted within a professional soccer club environment, with professional soccer players. As a result of the high ecological validity, and operating within a professional soccer club with specific daily objectives, at times the study designs had to be compromised. An example is that randomised control trials utilising an intervention and control group could not be administered within this environment. Within the soccer academy, a large importance is placed upon providing equal opportunities for each of the athletes. Progression to the next age group, or release from the soccer club at the end of the season, has a significant effect upon the individual's career and life. As a consequence, it was deemed unethical to provide certain individuals access to specific training modalities and opportunities, and not others. The result is that during Study Four, participants were exposed to all training game formats, instead of being assigned a single modality. In addition, during Study Five, participants played in both bio-banded and chronologically aged competition, instead of being assigned a single competition format. Despite the current thesis being conducted within an applied environment, a large emphasis was placed upon maintaining scientific rigour, standardising testing procedures, and ensuring the data and conclusions obtained were accurate. The ability to balance the internal and external validity of investigations is a significant challenge within applied research. However, considering the implications of the current thesis to applied environments, the balance was considered achieved.

9.7 Future Directions

Considering physical performance has been demonstrated to fluctuate over the course of a season, the individual thresholds used for monitoring high-speed locomotion and acceleration should be reassessed regularly to reflect this. If physical performance testing, and consequential update of individual thresholds, is not performed on a regular basis, an inaccurate representation of training load may be provided. Currently however, there are no recommendations for the frequency of re-testing. Considering the testing protocols utilised within the current thesis were field tests, and often conducted within applied environments, frequent re-testing would not be a significant inconvenience for applied practitioners. This is an advantage of field tests when compared to laboratory tests, where frequent re-testing would incur significant financial and time costs. To ensure that accurate information is obtained, the frequency of re-testing should be investigated. Future research should aim to identify the optimal frequency of re-testing for speed and acceleration thresholds, in order to accurately reflect the relative load elicited upon individual athletes.

The participants recruited within the current thesis were all enrolled within a professional soccer academy. There is a very small success rate within academy soccer, with as little as 0.5% of U9s graduating through to play for a first team (Wilson, 2015). With the physicality of modern day soccer increasing, an increased emphasis has been placed upon developing the physical attributes of athletes (Barnes et al., 2014; Carling, 2013). Further research is required to identify which physical attributes (e.g. speed, strength, power, and endurance), if any, correlate towards successfully graduating through the academy age groups into the first team. This would be invaluable for talent identification, and benchmarking purposes. In addition, practitioners and coaches could benefit from identification of the physical outputs produced by first team playing positions. Identifying the physical attributes and physical outputs required by first team soccer players will provide coaches and sport science practitioners with a reference point, and the ability to benchmark current athletes against the finished product.

Within the current thesis, Study Four investigated the effect of training game size upon the average and peak demands elicited upon soccer playing positions. Results have significant implications for applied practitioners looking to prescribe training games as conditioning tools. Significant research has focused upon identifying the physical demands associated with training games, and how they can be manipulated to affect the physical demands elicited. Training games are only one of numerous training methodologies utilised by soccer coaches however. Examples of other training methodologies include possessions, passing drills, crossing and finishing, and phases of play. There has been limited research on the physical demands elicited by other training methodologies, and how they can be utilised for soccer playing positions. It is recommended future studies investigate the average and peak physical demands elicited by these methodologies, and how they can potentially be manipulated.

Within both research and applied practice, there has been an increased use of models aiming to identify the association between training load and injury occurrence. An example is Gabbett (2016), and the use of the acute:chronic workload ratio. Gabbett (2016) cites a ‘sweet spot’ of optimal training load associated with a reduced injury risk. Training loads that were higher or lower than the prescribed ratio were suggested to be associated with an increased risk of injury. More recently, the acute:chronic workload ratio has been refined to include exponentially weighted moving averages, suggested to provide greater sensitivity in detecting injury likelihood (Murray et al., 2017; Williams et al., 2017). Research has raised issues with the acute:chronic workload ratio, specifically regarding the integration of data from different tracking systems, difficulties associated with monitoring athletes during international or off-season periods, and which marker of training load should be utilised (Buchheit, 2017). Previous research has incorporated a range of training load metrics when utilising the aforementioned workload ratio. Examples include ratings of perceived exertion, total distance, high-speed distance, number of exposures to maximum velocity, player load, and the number of acceleration tasks (Bowen et al., 2017; Hulin et al., 2014; Malone et al., 2017; Murray et al., 2017). When utilising workload ratios to calculate injury risk, it is vital that valid representations of workload are incorporated within the models. If the training load data input within the model is not a valid representation of load elicited upon an individual athlete, then inaccurate data will be obtained from the model, and false assumptions regarding the likelihood of injury will be made. Current research utilising the acute:chronic workload ratio has used global thresholds to quantify high-speed and acceleration activities (Bowen et al., 2017; Murray et al., 2017). A criticism highlighted by Buchheit (2017) is given the large variations in physical capacity profiles between athletes within the same team, the use of global speed thresholds may limit the sensitivity of the ratio to detect the individual locomotion demand, and consequently, injury risk. The same is true when utilising global acceleration thresholds to integrate acceleration training load data within the acute:chronic workload ratio. Consequently, there is rationale for future research to investigate the association between training load and injury occurrence whilst incorporating individual speed and acceleration thresholds.

There has been an increased occurrence of practitioners utilising real-time GPS data (Malone et al., 2017). This demonstrates the increasing influence of technology, and training load monitoring and prescription processes within applied sport. Coaches and practitioners may seek information on the current training load elicited upon an athlete, relative to pre-determined prescriptions. This information can be used to inform decisions during training sessions, as opposed to retrospectively following the training session occurring and data being downloaded. Previous research identified discrepancies between real-time and post-download data, and has suggested caution be applied when utilising real-time GPS (Aughey & Falloon, 2010). Real-time GPS technology has since improved, however still requires further research to establish accuracy (Malone et al., 2017). In addition, current real-time technology only presents select training load metrics (e.g total distance travelled, high-speed running and sprinting distance), and does not allow for real-time acute:chronic workload ratios to be determined. Further improvements in technology, and incorporation of custom training load variables and ratios, would allow the ability to accurately monitor training load and influence training decisions in real-time. The consequence would be increased opportunities to prescribe training loads specific for individual athletes.

9.8 Practical Recommendations

Findings from the current thesis provide applied practitioners with a number of recommendations for monitoring and prescribing training load to elite soccer athletes.

Whilst monitoring the training load of individual athletes, it is important to account for individual physical capacities. Accounting for an athlete's relevant physical capacities will allow training load to be expressed relative to the individual, and a true reflection of the intensity obtained. Global thresholds allow for comparisons in external workload completed between athletes, however must be utilised with caution. Results from the current thesis demonstrate significant discrepancies between distances produced by global and individual analysis methods for both high-speed locomotion and acceleration tasks. Global speed thresholds produced significant differences in high-speed locomotion distances for 47% of athletes when compared to individual speed thresholds. Similarly, global acceleration thresholds produced significantly different acceleration distances for 57% of athletes when compared to individual acceleration thresholds. Considering the increased use of workload ratios to predict injury risk of athletes within applied environments, current findings will be of significant interest to practitioners. Integrating physical capacities within speed and acceleration thresholds increases the validity of training load data, and the consequential assumptions derived from workload ratios. Within the current thesis, protocols used to determine the individual athletes' physical capacities were field-based tests, with the ability to be conducted with large squads. Protocols required minimal equipment, and elicit minimal financial and time-cost. Additionally, protocols typically exist as part of routine testing batteries in professional team sport environments. Consequently, it is feasible for applied practitioners to directly incorporate the current methodologies within their environment, and administer an individualised approach to monitoring training load.

When prescribing training load, it is vital to quantify the physical demands elicited by competition. This allows coaches and practitioners to design training sessions preparing the athletes for, and developing, competitive performance. The holistic physical demands placed upon individual playing positions vary significantly, as demonstrated by novel findings within the current thesis. Central defenders have least physical demand placed upon them during competition. Central midfielders travel the highest total distance, and produced the most moderate-intensity accelerations. Wide defenders and attackers have a large high-speed demand placed upon them during competition. The physical demands placed upon strikers are multifaceted. Considering the significant variations in physical demands placed upon soccer playing positions, it is vital that training prescription focuses upon the specific requirements of athletes, instead of adopting a one-size-fits-all approach.

The current thesis demonstrates that training game format can be manipulated to alter the physical demands elicited upon athletes. Small training games elicited the highest moderate-intensity acceleration distances, and perceived exertions for all playing positions. Large training games elicited the highest total, and high-speed distances, in addition to high-intensity acceleration distances. Medium training games stimulated a number of physical demands relative to competition. By highlighting the physical demands elicited upon playing positions during both competition and training games, it is possible for the current thesis to prescribe specific training game formats to playing positions based upon their physical requirements. Considering central midfielders are associated with large volumes of moderate-intensity accelerations, small training games are recommended. For wide defenders and attackers, positions with a high sprinting and high-intensity acceleration demand, large training games are recommended. For strikers, with a multitude of physical demands elicited during competition, medium sized training games are recommended. It is important to note however, that no specific training game format develops overall soccer fitness for all, or individual, playing positions. Instead, each training game format elicits a unique physical load. Caution must also be applied when prescribing training games relative to the average demands of competition. The current thesis demonstrates that certain game formats replicated the average demands of competition, however they were unable to replicate peak competitive demands. This was true for high-speed running and sprinting intensities within all training game formats. As a consequence, supplementary sprinting training is recommended to prepare athletes for peak high-speed running and sprinting demands during competition.

Considering there had been no prior investigation into the peak demands elicited by training game formats, these novel findings have significant implications upon training load prescription for soccer playing positions.

When investigating the effect of bio-banded competition upon the physical and technical performance of youth athletes, significant implications were identified for applied practitioners. Findings indicated that the effect of bio-banded competition varied dependent upon an athlete's maturation status. For early developers, bio-banded competition produced increases in numbers of short passes and dribbles, and a higher RPE when compared to chronological competition. In the past, a criticism of chronological competition was the ease at which early developers could exert their physicality. This reliance on physicality resulted in a reduced emphasis on technique, hindering development. The increase in number of short passes and dribbles indicates an increase in the technical emphasis placed upon early developers. In addition, a higher RPE during bio-banded competition indicates early developers found it more physically demanding. The increased technical emphasis represented by higher numbers of passes and dribbles were also evident for on-time developers. For late developers, bio-banded competition provided a different emphasis. More tackles, and less long passes were demonstrated during bio-banded competition when compared to chronological competition. The inability for late developers to exert their physicality has previously been a criticism of chronological competition. However, increases in number of tackles suggest bio-banded competition allows late developers to exert their physicality to a larger extent. For all maturation statuses, there were no significant differences in total distance, sprinting distance, or acceleration distance. This demonstrates that the increased emphasis technical performance associated with bio-banded competition is not at the detriment to physical performance. Considering there had been no previous investigation into the physical and technical effects of bio-bandied competition, these novel findings have significant implications for practitioners working with athletes of differing maturation statuses and developmental levels. Findings allow coaches to individually prescribe competition formats to athletes dependent upon their maturation status, and their individual physical and technical developmental needs.

In summary, the current thesis provides significant contributions to the current body of literature focusing upon monitoring and prescribing GPS training load. The overarching aim of the thesis was to create an individualised approach to the methodologies employed within elite academy soccer training and competition. Findings emphasised the importance of individualising the training load monitoring process, and providing specific training and competition formats to address the demands placed upon different playing positions and maturation statuses. Whilst initially investigating the training load monitoring process, findings demonstrated the significant discrepancies between global and individual analysis methods when analysing both high-speed locomotion and acceleration. Findings also demonstrated the extent to which the discrepancies varied between athletes of differing physical capacities. Importantly, the current studies utilised field tests to determine individual thresholds. Allowing applied practitioners the ability to incorporate an individualised monitoring process without large time or financial costs. When progressing the focus from training load monitoring to training load prescription, the current thesis demonstrated the individual nature of soccer competition, and the specific demands placed upon playing positions. Significant differences in positional demands provide rationale for specific training methodologies for individuals. Current findings provide recommendations of specific training modalities for soccer playing positions. Finally, the thesis focus shifted from training to competition, investigating the effect of bio-banded competition upon physical and technical demands placed upon different maturation statuses. Findings demonstrated that competition formats could be prescribed to early, on-time, and late developing athletes dependent upon their physical and technical developmental needs. In conclusion, thesis findings have significant implications for applied sport scientists operating in elite soccer environments. By incorporating current recommendations, applied practitioners can improve the accuracy of the training monitoring process, and the specificity of training and competition prescription.

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11.0 Appendices

11.1 Participant Information Sheet and Consent Form – Study One

Participant Information Sheet

Date:

Study Leader: Will Abbott

Telephone: 07944103012

Email: Will.Abbott@brighton.ac.uk

University of Brighton

BRIGHTON & HOVE ALBION

Study Title: - An individual approach to monitoring locomotive training load in English Premier League academy soccer players

You are requested to read this form carefully. If you are willing to participate in the study, please sign the consent form. If you have any queries, or are unsure or uncertain about anything, then you should not sign until your problem has been resolved and you are completely happy to volunteer.

U23 male professional soccer athletes are required for an investigation of the efficacy of GPS training load monitoring methods in quantifying high-speed locomotion within soccer training and competition. As a volunteer you should be free from any injury or illness that might interfere with the study. By taking part in this study, your performance shall in no way be affected, only observed and analysed.

The aim of this study is to determine the discrepancies between high-speed distances produced using two analysis methods; global or individual. You will complete your regular pre-season training sessions and matches, with your GPS data being collected as normal, and analysed using the two analysis methods. The high-speed distances produced by each method will be analysed to determine the efficacy of global and individual speed thresholds in quantifying high-speed locomotion for individual athletes.

A qualified first-aider will be in attendance during the training sessions and matches. You may at any time withdraw from participating in the study. You do not have to give any

reason, and no one can attempt to dissuade you. If you ever require any further explanation, please do not hesitate to ask.

Any information obtained during this study will remain confidential as to your identity, although we will have access to the data for the study write-up. If data can be specifically identified with you, your permission will be sought in writing before it is published. Other material, which cannot be identified with you, may be published or presented at meetings with the aim of benefiting others. All information will be stored in accordance with the conditions required of the Data Protection Act 1998 and subsequent statutory instruments.

This study has received ethical and scientific approval to be undertaken, in accordance with current University regulations.

Consent Form

Study Leader: Will Abbott

Telephone: 07944103012

Email: W.Abbott@brighton.ac.uk

University of Brighton

Study Title: - An individual approach to monitoring locomotive training load in English Premier League academy soccer players

Please initial each box if content

1. I confirm that I have read and understood the attached information sheet. I confirm that I have had the opportunity to consider the information, ask questions and that these have been answered satisfactorily. ☐

2. I confirm that I am well and free from injury and am capable of undertaking the activities described in the information sheet ☐

3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason without my legal rights being affected. ☐

4. I allow for my training and match GPS data to be used in this study. ☐

Name of Participant:	**Date:**	**Signature:**
Name of Parent (if U18)	**Date:**	**Signature:**
Name of Person taking Consent:	**Date:**	**Signature:**

11.2 Participant Information Sheet and Consent Form – Study Two

Participant Information Sheet

Date:

Study Leader: Will Abbott

Telephone: 07944103012

Email: W.Abbott@brighton.ac.uk

University of Brighton

BRIGHTON & HOVE ALBION

Study Title: - Individualising acceleration in English Premier League academy soccer players

You are requested to read this form carefully. If you are willing to participate in the study, please sign the consent form. If you have any queries, or are unsure or uncertain about anything, then you should not sign until your problem has been resolved and you are completely happy to volunteer.

U23 male professional soccer athletes are required for investigation into the efficacy of GPS training load monitoring methods in quantifying acceleration within soccer training and competition. As a volunteer you should be free from any injury or illness that might interfere with the study. By taking part in this study, your performance shall in no way be affected, only observed and analysed.

The aim of this study is to determine the discrepancies between acceleration distances of varying intensity produced using global or individual analysis methods. You will complete your regular pre-season training sessions and matches, with your GPS data being collected as normal, and analysed using two different analysis methods. The acceleration distances produced by each method will be analysed to determine the efficacy of global and individual thresholds in quantifying accelerations of varying intensities.

A qualified first-aider will be in attendance during the training sessions and matches. You may at any time withdraw from participating in the study. You do not have to give any

reason, and no one can attempt to dissuade you. If you ever require any further explanation, please do not hesitate to ask.

Any information obtained during this study will remain confidential as to your identity, although we will have access to the data for the study write-up. If data can be specifically identified with you, your permission will be sought in writing before it is published. Other material, which cannot be identified with you, may be published or presented at meetings with the aim of benefiting others. All information will be stored in accordance with the conditions required of the Data Protection Act 1998 and subsequent statutory instruments.

This study has received ethical and scientific approval to be undertaken, in accordance with current University regulations.

Consent Form

Study Leader: Will Abbott

Telephone: 07944103012

Email: W.Abbott@brighton.ac.uk

University of Brighton

Study Title: - Individualising acceleration in English Premier League academy soccer players

Please initial each box if content

1. I confirm that I have read and understood the attached information sheet. I confirm that I have had the opportunity to consider the information, ask questions and that these have been answered satisfactorily.

2. I confirm that I am well and free from injury and am capable of undertaking the activities described in the information sheet

3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason without my legal rights being affected.

4. I allow for my training and match GPS data to be used in this study.

Name of Participant:	**Date:**	**Signature:**
Name of Parent (if U18)	**Date:**	**Signature:**
Name of Person taking Consent:	**Date:**	**Signature:**

11.3 Participant Information Sheet and Consent Form – Study Three

Participant Information Sheet

Date:

Study Leader: Will Abbott

Telephone: 07944103012

Email: W.Abbott@brighton.ac.uk

Study Title: - Physical demands of playing position within English Premier League academy soccer

You are requested to read this form carefully. If you are willing to participate in the study, please sign the consent form. If you have any queries, or are unsure or uncertain about anything, then you should not sign until your problem has been resolved and you are completely happy to volunteer.

U23 male professional soccer athletes are required for an investigation into the physical demands placed upon soccer playing positions during competition. As a volunteer you should be free from any injury or illness that might interfere with the study. By taking part in this study, your performance shall in no way be affected, only observed and analysed.

The aim of this study is to determine the physical demands placed upon playing positions during English Premier League academy soccer competition. You will complete your regular competitive matches, with your GPS and RPE data being collected as normal. GPS metrics produced during competition will be collected and analysed relative to other soccer playing positions. This will determine the specific physical demands placed upon each playing position, helping to identify specific training modalities for each individual.

A qualified first-aider will be in attendance during the training sessions and matches. You may at any time withdraw from participating in the study. You do not have to give any reason, and no one can attempt to dissuade you. If you ever require any further explanation, please do not hesitate to ask.

Any information obtained during this study will remain confidential as to your identity, although we will have access to the data for the study write-up. If data can be specifically identified with you, your permission will be sought in writing before it is published. Other material, which cannot be identified with you, may be published or presented at meetings with the aim of benefiting others. All information will be stored in accordance with the conditions required of the Data Protection Act 1998 and subsequent statutory instruments.

This study has received ethical and scientific approval to be undertaken, in accordance with current University regulations.

Consent Form

Study Leader: Will Abbott
Telephone: 07944103012
Email: W.Abbott@brighton.ac.uk

University of Brighton

Study Title: - Physical demands of playing position within English Premier League academy soccer

Please initial each box if content

1. I confirm that I have read and understood the attached information sheet. I confirm that I have had the opportunity to consider the information, ask questions and that these have been answered satisfactorily. ☐

2. I confirm that I am well and free from injury and am capable of undertaking the activities described in the information sheet. ☐

3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason without my legal rights being affected. ☐

4. I allow for my match GPS data to be used in this study. ☐

Name of Participant:	**Date:**	**Signature:**
Name of Parent (if U18)	**Date:**	**Signature:**
Name of Person taking Consent:	**Date:**	**Signature:**

11.4 Participant Information Sheet and Consent Form – Study Four

Participant Information Sheet

Date:

Study Leader: Will Abbott

Telephone: 07944103012

Email: W.Abbott@brighton.ac.uk

University of Brighton

Study Title: - Positional differences in GPS outputs and perceived exertion during soccer training games and competition

You are requested to read this form carefully. If you are willing to participate in the study, please sign the consent form. If you have any queries, or are unsure or uncertain about anything, then you should not sign until your problem has been resolved and you are completely happy to volunteer.

U23 male professional soccer athletes are required for investigation into the effect of different sized training games upon average and peak physical demands elicited upon soccer playing positions. As a volunteer you should be free from any injury or illness that might interfere with the study. By taking part in this study, your performance shall in no way be affected, only observed and analysed.

The aim of this study is to determine the physical effect of different sized training games upon the average and peak demands elicited upon soccer athletes relative to their positional competitive demands. You will complete your regular training sessions and matches, with your GPS and RPE data being collected as normal. GPS metrics produced during small, medium, and large sized training games will be collected and analysed relative to competition data. This will determine the effect of different training game formats in replicating the average and peak demands of competition for soccer playing positions.

A qualified first-aider will be in attendance during the training sessions and matches. You may at any time withdraw from participating in the study. You do not have to give any

reason, and no one can attempt to dissuade you. If you ever require any further explanation, please do not hesitate to ask.

Any information obtained during this study will remain confidential as to your identity, although we will have access to the data for the study write-up. If data can be specifically identified with you, your permission will be sought in writing before it is published. Other material, which cannot be identified with you, may be published or presented at meetings with the aim of benefiting others. All information will be stored in accordance with the conditions required of the Data Protection Act 1998 and subsequent statutory instruments.

This study has received ethical and scientific approval to be undertaken, in accordance with current University regulations.

Consent Form

Study Leader: Will Abbott
Telephone: 07944103012
Email: W.Abbott@brighton.ac.uk

University of Brighton

Study Title: - Positional differences in GPS outputs and perceived exertion during soccer training games and competition

Please initial each box if content

1. I confirm that I have read and understood the attached information sheet. I confirm that I have had the opportunity to consider the information, ask questions and that these have been answered satisfactorily.

2. I confirm that I am well and free from injury and am capable of undertaking the activities described in the information sheet.

3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason without my legal rights being affected.

4. I allow for my training and match GPS data to be used in this study.

Name of Participant:	**Date:**	**Signature:**
Name of Parent (if U18)	**Date:**	**Signature:**
Name of Person taking Consent:	**Date:**	**Signature:**

11.5 Participant Information Sheet and Consent Form – Study Five

Participant Information Sheet

Date:

Study Leader: Will Abbott

Telephone: 07944103012

Email: W.Abbott@brighton.ac.uk

University of Brighton

BRIGHTON & HOVE ALBION

Study Title: - The effect of bio-banding upon physical and technical performance during soccer competition

You are requested to read this form carefully. If you are willing to participate in the study, please sign the consent form. If you have any queries, or are unsure or uncertain about anything, then you should not sign until your problem has been resolved and you are completely happy to volunteer.

U16-U12 male soccer athletes, between 85 – 90% of predicted adult stature, are required for an investigation the physical and technical effects of bio-banded competition. As a volunteer you should be free from any injury or illness that might interfere with the study. By taking part in this study, your performance shall in no way be affected, only observed and analysed.

The aim of this study is to determine the physical and technical effects of bio-banding soccer competition relative to normal chronologically aged competition. You will take part in one bio-banded match, where you will be matched with other athletes dependent upon your maturation status. You will also take part in your regular competitive matches, with your GPS and RPE data being collected as normal. Physical and technical metrics collected during bio-banded and chronological competition will be analysed to determine the effect of bio-banded competition upon physical and technical performance.

A qualified first-aider will be in attendance during the training sessions and matches. You may at any time withdraw from participating in the study. You do not have to give any

reason, and no one can attempt to dissuade you. If you ever require any further explanation, please do not hesitate to ask.

Any information obtained during this study will remain confidential as to your identity, although we will have access to the data for the study write-up. If data can be specifically identified with you, your permission will be sought in writing before it is published. Other material, which cannot be identified with you, may be published or presented at meetings with the aim of benefiting others. All information will be stored in accordance with the conditions required of the Data Protection Act 1998 and subsequent statutory instruments.

This study has received ethical and scientific approval to be undertaken, in accordance with current University regulations.

Consent Form

Study Leader: Will Abbott

Telephone: 07944103012

Email: W.Abbott@brighton.ac.uk

Study Title: - The effect of bio-banding upon physical and technical performance during soccer competition

Please initial each box if content

1. I confirm that I have read and understood the attached information sheet. I confirm that I have had the opportunity to consider the information, ask questions and that these have been answered satisfactorily.

2. I confirm that I am well and free from injury and am capable of undertaking the activities described in the information sheet.

3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason without my legal rights being affected.

4. I allow for my physical and technical match data to be used in this study.

Name of Participant:	Date:	Signature:
Name of Parent (if U18)	Date:	Signature:
Name of Person taking Consent:	Date:	Signature:

11.6 Appendix Six – Club Permission For Data Collection

July 2018

To Whom It May Concern:

This letter herby states that Mr William Abbott, has followed appropriate and authorised processes within Brighton & Hove Albion Football Club throughout the completion of his PhD study.

I can confirm:

- Informed consent was obtained from all participants
- All data collected (GPS) was part of routine monitoring at the club, and is a normal daily procedure
- Club permission was authorised to publish the data collected, due to its anonymity

If any further information is required, please do not hesitate to contact me.

Kind regards,

Adam Brett
Head of Medical Services
Brighton & Hove Albion FC

E-Mail: adam.brett@bhafc.co.uk

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*Calls cost your normal landline rate

Official club website
BrightonAndHoveAlbion.com

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