Peak Match Running Intensities in Australian Association Football

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LIST OF ABBREVIATIONS

%	Percentage
±	Plus/minus
=	Equals
~	Approximately
90% CI	90 percent confidence intervals
95% CI	95 percent confidence intervals
Acc	Accelerations
Acc/Dec	Acceleration and deceleration
accel·min^{-1}	Accelerations per minute
AL	Australian A-League
AM	Attacking midfielder
AMP	Average metabolic power
ATT	Attackers
AveAcc	Average acceleration
CD	Central defender
CI	Confidence interval
CM	Central midfielder
CV	Coefficient of variation
Dec	Decelerations
DEF	Defenders
DM	Defensive Midfielder
ES	Effect size

FIXED	Fixed window
GNSS	Global navigation satellite system
GPS	Global positioning system
HMLD	High metabolic load distance
HSD	High-speed distance
Hz	Hertz
ICC	Intraclass correlation coefficient
IQR	Interquartile range
km	Kilometres
$km{\cdot}h^{-1}$	Kilometres per hour
m	Meters
$m{\cdot}min^{-1}$	Metres per minute
$m{\cdot}s^{-1}$	Meters per second
$m{\cdot}s^{-2}$	Meters per second per second
MID	Midfielders
min	Minute
MMS	Maximal mean speed
MP	Metabolic power
MSD	Moderate speed distance
n	Number of participants
ROLL	Rolling window
SD	Standard deviation
S_{KP}	Skewness

SMD	Standardised mean difference
STR	Striker
SWD	Smallest worthwhile difference
TD	Total distance
TEE	Typical error of estimate
TEM	Typical error of measurement
U16	Under sixteens
U17	Under seventeens
U18	Under eighteens
U19	Under nineteens
U21	Under twenty-one
v	Version
VHSD	Very high-speed distance
vs	Versus
WD	Wide defender
WIN	Winger
WM	Wide midfielder
yr	Year
β_2	Kurtosis

ABSTRACT

The use of global positioning systems (GPS) in professional association football has become routine in quantifying the physical demands of training and matches. Such data provides crucial information for the on-going monitoring of player training loads, while also helping to guide the design and implementation of specific training stimuli. Contemporary monitoring practices that determine the most physically demanding periods of competition using a moving average technique have been coined "*peak match running intensities*". These peak match running intensities are also commonly referred to as the "*peak match running demands*" of competition and provide coaches with information on how to construct training drills and simulations to replicate match demands. However, contextual factors surrounding these metrics are yet to be fully explored. This series of studies aim to provide further context around the use of peak match running demands through initially quantifying the between-match variation of various running metrics to provide a framework by which to gauge meaningful changes in the physical performance of match play. Secondly, changes in peak match running demands between positions and match halves were quantified to determine acute changes in running peak running performance during matches. Next, the peak match running demands of elite youth and professional level competitions were quantified and compared to help inform transitional training practices for youth athletes transitioning into professional teams. Lastly, the distribution of peak match running demands timing within halves was analysed to help structure training sessions. Collectively, this series of studies provides coaches and practitioners with greater context around the peak match running demands of professional association football. As a result, the new information will help inform the prescription of training drills to better prepare players for the most

physically demanding periods of match play, while also helping to facilitate preparation of younger players for the demands of professional level competition.

STATEMENT OF AUTHORSHIP

This thesis includes work by the author that has been published or accepted for publication as described in the text. Except where reference is made in the text of the thesis, this thesis contains no other material published elsewhere or extracted in whole or in part from a thesis accepted for the award of any other degree or diploma. No other person's work has been used without due acknowledgment in the main text of the thesis. This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

The extent of collaboration with, and/or contribution by, others, including 'Jointly Authored Work' is outlined in Appendix C.

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LIST OF PUBLICATIONS ARISING FROM THIS THESIS

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Thoseby, B., Govus, A., Clarke, A., Middleton, K., & Dascombe, B. (2021). Temporal distribution of peak running demands relative to match minutes in elite football. *Biology of Sport*, 39(4), 985-994. doi:10.5114/biolsport.2022.110745 (Chapter 6).

The following work is currently under review.

Peer Reviewed Articles:

Thoseby, B., Govus, A., Clarke, A., Middleton, K., & Dascombe, B. (Under Review). Peak Match Acceleration Demands Differentiate Between Elite Youth and Professional Football Players. *PLOS One*. (Chapter 5).

Chapter One

General Introduction

BACKGROUND

Performance analysis in association football (soccer) is concerned with assessing the physical, technical and tactical demands of competitive match play, providing a substantial amount of evolving research (Mackenzie & Cushion, 2013). Of particular interest has been the physical demands of match play, due to their importance in assessing match performance and informing training and physical conditioning practices (Sarmento et al., 2014). Importantly, the methods used to collect and analyse this information have evolved over many decades, beginning initially through the use of video and notational analysis, before transitioning to semi-automated camera systems and, more recently, the use of microtechnology such as GPS devices (Buchheit, Allen, et al., 2014; Reilly & Gilbourne, 2003; Sarmento et al., 2014). Employing GPS devices to quantify the physical demands of competitive football match play has proven to be valid and reliable, with such technology demonstrated to be able to accurately quantify the volume, intensity, speed and frequency of match activities undertaken by players (Scott, Scott, & Kelly, 2016). Commonly assed physical performance metrics include total distances (TD) or distances covered around various speed thresholds, acceleration (Acc) profiles, sprint velocities, as well as measures of metabolic power (MP) and high metabolic load distance (HMLD) (Hennessy & Jeffreys, 2018). When used in combination and appropriate interpreted, these metrics provide a holistic overview of the physical demands of football match play.

Commonly, match demands are quantified through the ‘absolute’ running demands, where the data are reported as the total or average demands of competition across the entirety of a match (Dolci et al., 2020). Absolute demands are the summation of physical output for a given metric across a total match, whereas 'relative' demands are expressed relatively to playing duration (per minute basis). Absolute measures provide an understanding of the external loads imposed on a player during competition, with relative loads useful in comparing between individuals/groups that may not play the entirety of a match or have different playing durations (Castagna, Varley, Póvoas, & D'Ottavio, 2017). In summation, players typically cover between 9-13km across a match, with 600-1200m of this covered at high-speed (>19.8 $km \cdot h^{-1}$), while also completing 60-100 Acc (>2 $m \cdot s^{-2}$) (Bradley et al., 2011; Bradley, Di Mascio, Peart, Olsen, & Sheldon, 2010; Dalen, Jørgen, Gertjan, Geir Havard, & Ulrik, 2016; Sarmento et al., 2014). However, further investigations have assessed temporal changes in physical demands, where physical outputs are reduced in the second half of a match (Bradley & Noakes, 2013; Carling & Dupont, 2011; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009; Vieira, Carling, Barbieri, Aquino, & Santiago, 2019). Further, positional differences have been reported in physical demands, with defensive positional groups typically demonstrating lower outputs than both midfielders (MID) and attackers (ATT) (Abbott, Brickley, & Smeeton, 2018; Mallo, Mena, Nevado, & Paredes, 2015; Wehbe, Hartwig, & Duncan, 2014). Lastly, absolute physical demands have been shown to differ across competition levels, although there is equivocal evidence around this notion (Bradley et al., 2013; Di Salvo, Pigozzi, González-Haro, Laughlin, & De Witt, 2013; Sydney, Ball, Chapman, Wollin, & Mara, 2020). Such information regarding the physical demands of competition is useful in preparing players for competition through exposure to the expected physical demands during training. However, the validity of using total match data to inform training practices has been questioned (Delaney, Thornton, et al., 2018).

The physical demands of football are highly intermittent in nature, characterised by periods of intensive actions interspersed with frequent periods of rest or low-intensity activity (e.g. standing, walking or slow jog) (Stølen, Chamari, Castagna, & Wisløff, 2005). As such, reporting total match volumes likely under reports the true match demands of competition during extended periods of intense activity. For example, the relative TD covered during effective game time (i.e. when the ball is in play) is significantly higher than the relative TD covered during total game time (~140-150 $m \cdot min^{-1}$ vs ~78-99 $m \cdot min^{-1}$) (Linke, Link, Weber, & Lames, 2018). Hence, the use of total match data as a reference for training prescription may not expose players to the acute within-match physical demands required during match play. To address this, researchers employed GPS technology to quantify the 'peak' running demands of competition across shorter durations of 1-10 min (Delaney, Thornton, et al., 2018; Fereday et al., 2020; Varley, Elias, & Aughey, 2012). The breakdown of match play into shorter periods allows for the most intense periods of match play to be quantified, with this data aiding coaches to develop and implement training stimuli that better reflects the demands of competition. Amongst current literature, the peak match running demands of competition have been commonly referred to as the "worst-case scenario", however, the use of this descriptor is largely misleading as it disregards other factors associated with football performance, e.g. technical and tactical demands. The multifaceted nature of football requires players to not only have good physical attributes, but also high levels of technical and tactical acuity (Liu, Gómez, Gonçalves, & Sampaio, 2016; Sampaio & Maçãs, 2012). While extreme, a true "worst-case scenario" would be a match situation whereby players are required to perform at peak physical demands, while simultaneously having peak technical involvements in unfavourable environmental conditions while under fatigue. While pedantic, the use of appropriate terminology is crucial, with terms such as “peak match running demands” much more appropriate to represent the metric.

The novel nature of peak match running demands has meant that comprehensive investigations into contextual factors are yet to be undertaken, with temporal, positional and competitional discrepancies not yet fully understood. Addressing these gaps would potentially allow coaches to prescribe training more specifically to positional groups, help prepare youth players to transition into professional teams and/or address temporal changes in physical outputs. Therefore, the overall purpose of this thesis is to further investigate the peak match running demands of professional football, providing crucial context to coaches regarding temporal, positional and competitional discrepancies in outputs, which together will assist coaches in preparing players for the demands of competition.

RESEARCH PROBLEM

Historically, practitioners have utilised information regarding the total physical demands of match play to help inform training practices aimed at preparing players for competition (Morgans, Orme, Anderson, & Drust, 2014). Previously, coaches have used data that’s reflective of the total match demands to assess training session volumes relative to match play volumes (%) or intensities ($m \cdot min^{-1}$ or $accel \cdot min^{-1}$). However, the use of full match data to inform the intensity of training drills, that typically last between 1-10 min, is highly questionable. Football is highly intermittent and characterised by periods of unpredictable exercise interspersed with brief periods of recovery (Stølen et al., 2005), with information regarding total match output encompassing all of physical output. The physical demands of match play when the ball is in play are much higher than when the ball is out of play and as such, use of full match data to inform training practices may underprepare players for the rigors of competition (Linke et al., 2018). To address this, a novel means of quantifying match running demands have emerged aimed at quantifying the peak match running demands of competition over match durations more reflective of typical drill durations (Delaney, Thornton, et al., 2018; Fereday et al., 2020; Varley, Elias, et al., 2012).

It has been suggested that the use of peak match running demands data to inform training practices may better prepare players for the demands of competition than the use of full match data (Oliva-Lozano, Martín-Fuentes, Fortes, & Muyor, 2021). However, while the peak match running demands of football have been quantified and initial investigations into confounding factors that may affect these outputs have begun (Duthie, Thornton, Delaney, Connolly, & Serpiello, 2018; Martín-García, Casamichana, Díaz, Cos, & Gabbett, 2018; Oliva-Lozano, Rojas-Valverde, Gómez-Carmona, Fortes, & Pino-Ortega, 2020). However, a comprehensive review of the contextual factors associated with peak match running demands in football is yet to be completed (Figure 1.1). For example, the variation associated with peak match running demands has yet to be comprehensively determined and consequently, interpreting meaningful changes in peak match running demands is not feasible. Further, while differences in the total physical demands of match play have previously been observed between positional groups (Abbott et al., 2018; Di Salvo, Baron, Tschan, et al., 2007; Mallo et al., 2015; Mohr, Krustrup, & Bangsbo, 2003), competitional levels (Aquino et al., 2017; Di Salvo et al., 2013; Vigh-Larsen, Dalgas, & Andersen, 2018) as well as temporally within matches (Bradley & Noakes, 2013; Dalen et al., 2016; Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009), such differences for peak match running demands of competition require to be explored. This information is crucial when prescribing training stimuli in ensuring that individuals meet appropriate physical targets for their respective match demands, unique to their playing level and position. Overall, this information may assist coaches in better preparing players for the physical demands associated with competition.

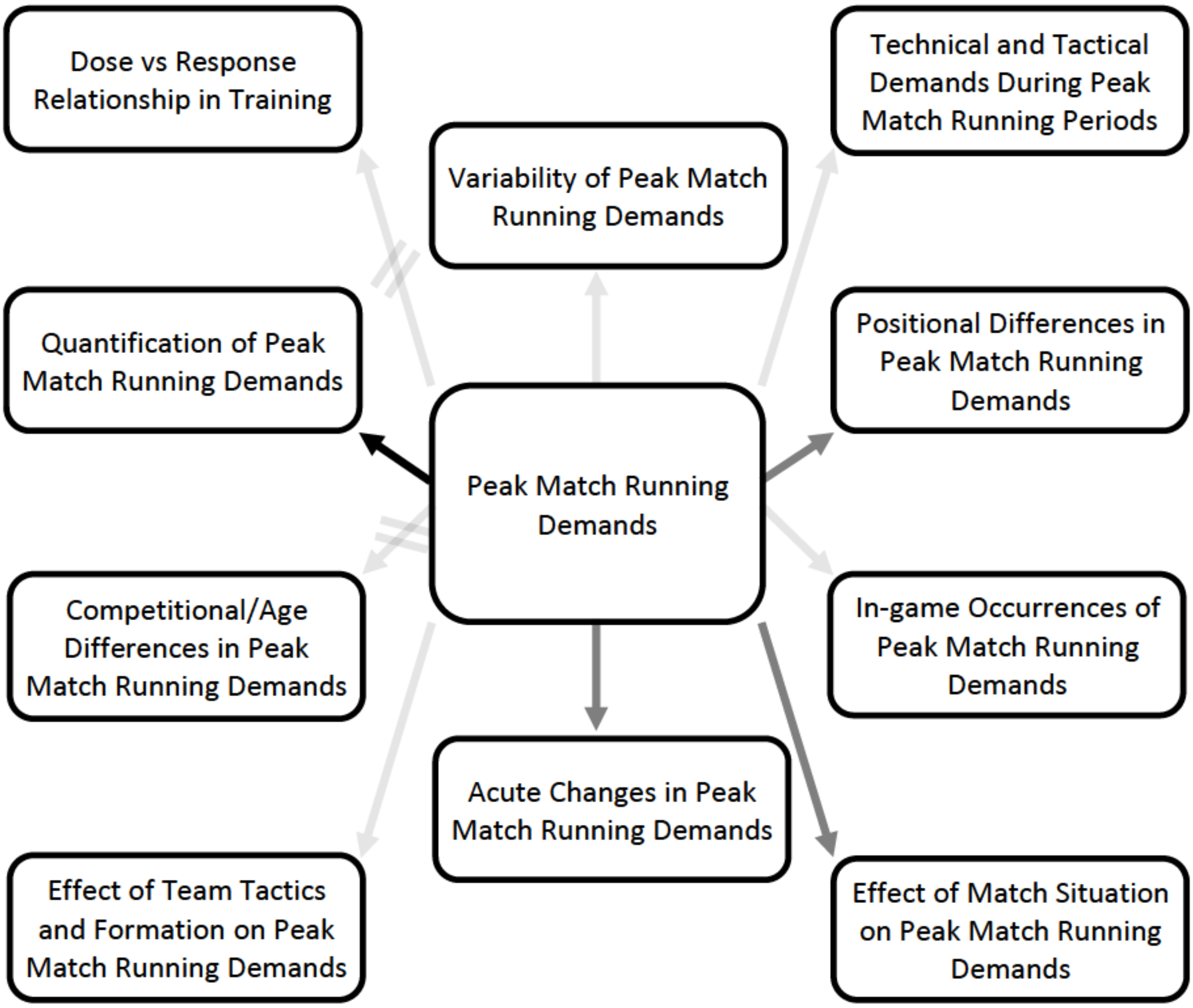

Figure 1.1: Schematic overview of research completed to date on peak match running demands of football. ⇗ = Substantial research conducted, ➔ = Moderate research conducted, ➔ = Minimal research conducted, ≠ = No research conducted.

OBJECTIVES

Peak match running demands have emerged as a novel method of assessing the running demands of competitive football match play that subsequently provide a tool to inform training prescription to replicate match demands. However, contextual information regarding understanding and applying these intensities is currently limited. As such, the overall aims of this thesis are to improve practitioner knowledge surrounding the peak match running demands of football competition to allow coaches to better inform training stimuli prescription. Specifically, the collective studies will help coaches determine meaningful changes in peak match running demands and identify periods of match play where peak physical performance is crucial. Further, the studies will provide a greater understanding of the positional, competitional and temporal variations in peak match running demands. This data will assist coaches in the longitudinal monitoring of match demands, will also helping to inform prescription and periodisation of training drills aimed at replicating the demands of match play.

PURPOSE OF THE STUDIES

The collective purpose of the studies contained within this thesis is to provide greater context surrounding the peak match running demands of professional football. The context which the combined studies in this thesis will provide, will aid practitioners in better preparing players for the demands of professional football competition.

Chapter 3: Between-Match Variation of Peak Match Running Intensities in Elite Football

- This study aimed to quantify the between-match variation in the peak match running demands of elite football players.
- The outcomes provide a reference point for determining meaningful changes in peak match running demands in football across metrics and rolling average durations.

Chapter 4: Positional and Temporal Differences in Peak Match Running Demands of Elite Football

- This study aimed to a) investigate positional differences in peak match running demands across match halves in competitive football, and b) determine between-half differences in the peak match running demands for various positional groups.
- The outcomes of this study will a) provide guidance to coaches in designing position specific training practices to help prepare players for match play demands and b) help guide strategies to mitigate reductions in running performance in the second half of a match.

Chapter 5: Peak Match Acceleration Demands Differentiate Between Elite Youth and Professional Football Players

- This study aimed to quantify and compare the total physical and peak match running demands of elite youth and professional football competitions.
- The outcomes of this study will provide guidance around physically preparing elite youth players for the demands associated with professional football that is typical of football academies.

Chapter 6: Temporal Distribution of Peak Running Demands Relative to Match Minutes in Elite Football.

- This study aimed to identify the periods of match play when footballers are exposed to peak match running demands within the first and second halves of a match.
- The outcomes of this study will help to provide ecological validity to match-simulation training practices employed by coaches.

SIGNIFICANCE OF THE RESEARCH

The primary role of coaching staff in professional football is to holistically prepare players for the demands of competition, for which the use of peak match running demands provide a useful reference for how best to expose players to the peak physical demands of competition in training. The studies undertaken in this thesis will be the first to comprehensively assess positional, competitional and temporal discrepancies in peak match running demands, while also establishing the variability and match periods associated with measures of peak match running demands. The comprehensive assessment of peak match running demands undertaken in this thesis will provide coaches greater context from which to monitor and prescribe training stimuli, assisting in the development of an all-encompassing training regime.

Chapter Two

Review of Literature

INTRODUCTION

Performance analysis in association football (soccer) is widely concerned with assessing the physical, technical and tactical demands of competitive match play (Sarmento et al., 2014). Match performance was initially characterised using notational analysis where practitioners would calculate running demands by assessing time spent in specific locomotor categories (e.g., walking, jogging, running) to calculate distances covered (James, 2006). The absence of modern technology meant that these analyses relied on practitioner's subjective opinion to characterise locomotor patterns, (e.g. the transition from a jog to a run) and while useful at the time, had varying accuracy, validity, and reliability (Dogramac, Watsford, & Murphy, 2011). While inaccurate, notational analysis provided a fundamental base for performance analysis to occur in the 21st century with the advent of video analysis, and more recently, GPS technology (Cummins, Orr, O'Connor, & West, 2013). The permission of GPS use during competitive match play has allowed practitioners to efficiently and non-invasively collect objective data on player locations, and subsequently, speeds and distances covered (Hennessy & Jeffreys, 2018). The increased objectivity achieved with modern technologies such as GPS, compared to notational analysis has allowed for a more accurate quantification of match demands, with GPS technology now universally adopted in field-based team sports (Dolci et al., 2020).

Since the inception of performance analysis, information about the physical demands associated with football match play has guided coaches in how to prepare players for the physical, technical, and tactical demands of match play (Bangsbo, Mohr, & Krustrup, 2006; Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011). Historically, information regarding the total match running demands of competition allowed practitioners to compare relative physical outputs performed during training with those experienced during competitive match play (e.g., m·min^{-1} and/or accel·min^{-1}) to provide further context to the amount of physical work completed by players in both contexts (Baptista, Johansen, Figueiredo, Rebelo, & Pettersen, 2020; Stevens, de Ruiter, Twisk, Savelsbergh, & Beek, 2017).

However, football is comprised of match periods where physical demands are high, interspersed with periods of play in which the ball is not in play and physical demands are low (Carling & Dupont, 2011; Lago-Peñas, Rey, & Lago-Ballesteros, 2012; Linke et al., 2018; Stølen et al., 2005). As such, the use of 90 min match data to inform the prescription of short duration training drills (1-10 min) that are designed to maximise ball-in play time may not be appropriate as this data would likely overestimates the physical demands of when the ball is not in play and underestimates physical demands when the ball is in play. As such, practitioners and researchers have begun to investigate the peak match running demands of competition, by quantifying the most physically demanding periods of match play over shorter (i.e., 1-10 min) periods during match play (Delaney, Thornton, et al., 2018; Fereday et al., 2020; Whitehead, Till, Weaving, & Jones, 2018). Evaluating the physical demands of match play over shorter time periods may more allow practitioners to more accurately design training drills that replicate the physiological demands (i.e., drill duration and intensity) of match play which in turn may allow a better prescription of training load to prepare footballers for physical demands of match play (Riboli, Coratella, Rampichini, Cé, & Esposito, 2020).

Although there is a considerable amount of research on the total match demands of competitive match play, there is comparatively less research examining the peak match running demands of football, as highlighted by Whitehead et al. (2018). Thus, future research (as is contained within this thesis) needs to explore the meaningful changes in peak match running demands during match play and investigate temporal and positional differences in peak match running demands in professional and youth footballers. Such research will provide practitioners with a robust overview of the peak match running demands of football, allowing the appropriate physical preparation of footballers for competition. Further, the analytical approach to quantifying peak match running demands, and their subsequent used to structure training drills will have broader applications across all field-based team sports.

QUANTIFYING THE RUNNING DEMANDS OF FOOTBALL MATCH PLAY

The conventional use of GPS technology in football has resulted in an abundance of research quantifying the physical demands of match play (Bradley et al., 2011; Bradley et al., 2010; Dalen et al., 2016; Di Salvo et al., 2009; Di Salvo et al., 2013; Lord, Blazevich, Abbiss, Drinkwater, & Ma'ayah, 2020; Romagnoli et al., 2016; Sarmento et al., 2014; Sporis, Dujic, Trajkovic, Milanovic, & Madic, 2017). GPS monitoring provides a useful method to understand the volumes of physical work completed during match play and provides practitioners with information to assist training prescription and monitoring of team sport athletes (Akenhead & Nassis, 2016). GPS speeds have been traditionally subdivided into arbitrary speed zones, allowing for a more holistic overview of physical demands through classifying or summating them into low-intensity (<14.4 $km \cdot h^{-1}$), high-speed (14.4-20.0 $km \cdot h^{-1}$) and very high-speed (>18.0-25.2+ $km \cdot h^{-1}$) categories (Rago et al., 2020). Further, practitioners have also been interested in high-intensity sprint efforts over shorter distances, with these efforts commonly referred to as accelerations (Acc) (Murphy, Lockie, & Coutts, 2003). These Acc metrics are typically quantified as either distance covered while accelerating, time spent accelerating or the number of Acc performed within various discrete Acc bands, e.g. 0-1 $m \cdot s^{-2}$, 1-2 $m \cdot s^{-2}$, 2-3 $m \cdot s^{-2}$ (Delaney, Cummins, Thornton, & Duthie, 2018; Thornton, Nelson, Delaney, Serpiello, & Duthie, 2019). While modern GPS devices typically contain a tri-axial accelerometer, data collected from this technology is used to quantify collisions, changes of directions or dives/falls (Cummins et al., 2013). In actuality, Acc metric data are calculated by analysing the velocity/time data collected by GPS devices (Varley, Jaspers, Helsen, & Malone, 2017).

The simple, non-invasive use of GPS technology allows for quantification of the physical demands of match play, both in respects to volumes of physical work completed, but also in relation to higher intensity efforts both over short and long distances. This understanding provides a reference point from which to assess the physical component of match performance, but more importantly, provides a reference point from which coaches can prescribe training stimuli (Akenhead & Nassis, 2016). The constant aspiration to better prepare players for competition has resulted in further investigations into positional (Aquino et al., 2017; Bloomfield, Polman, & O'Donoghue, 2007; Mallo et al., 2015) and competitional (Bradley et al., 2013; Sydney et al., 2020) demands, with an emphasis also placed on temporal changes to running demands within matches (Bradley et al., 2010; Carling, 2013; Di Salvo et al., 2009). The greater understanding from this information may allow for a more tailored approach to athlete preparations. However, while the information attained from GPS is useful, data must be able to quantify activity in both a valid and reliable way so that these data can be used effectively by practitioners to monitor physical loads and prescribe training drills that approximately match desired physical demands (Scott et al., 2016).

GPS RELIABILITY AND VALIDITY

The ability of GPS technology to accurately and reliably quantify both low- and high-speed running demands is crucial (Cummins et al., 2013). The inter- and intra-unit reliability of GPS devices is an important consideration when making comparisons between the physical output of multiple players, within a session, or physical output between sessions for individual players. Intra-unit reliability appears acceptable (Coefficient of Variation [CV] <5%) for TD covered (CV = 0.5-3.5%; Intraclass Correlation Coefficient [ICC] = 0.833) (Castellano, Casamichana, Calleja-González, Román, & Ostojic, 2011; Nikolaidis, Clemente, van der Linden, Rosemann, & Knechtle, 2018), and for velocity measures in a linear direction (CV <2.5%) (Scott et al., 2016). Inter-unit reliability of GPS devices is acceptable for TD covered (CV = 0.7-8.2%; Typical error of measurement [TEM] = 1.3-1.9%), with HSD covered shown to have slightly lower levels of inter-unit reliability (CV = 1.4-17.9%; TEM = 4.8-12.1%) (Buchheit, Al Haddad, et al., 2014; Hoppe, Baumgart, Polglaze, & Freiwald, 2018; R. J. Johnston, Watsford, Kelly, Pine, & Spurrs, 2014; Vickery et al., 2014). Additionally, the inter-unit reliability of GPS devices has shown to be acceptable for assessing low (<14.4 $km{\cdot}h^{-1}$), moderate (14.4-19.8 $km{\cdot}h^{-1}$) and high velocities (>19.8 $km{\cdot}h^{-1}$) (CV = 1.9-6%) (Akenhead, French, Thompson, & Hayes, 2014; Hoppe et al., 2018; R. J. Johnston et al., 2014; Varley, Fairweather, & Aughey, 2012). Finally, Acc counts at low, moderate and high thresholds (1, 2 and 3 m·s^{-2}) have demonstrated moderate to good levels of reliability (CV = 4.4 %, 5.3% and 5.9%, respectively), with average acceleration (AveAcc) average demonstrating acceptable levels of reliability (CV = 1.2-3.6%) (Delaney, Cummins, et al., 2018; Thornton, Nelson, et al., 2019).

When measuring TD covered, GPS devices have shown to be valid compared to criterion measures (known distances measured with a tape measure) (R. J. Johnston et al., 2014; Vickery et al., 2014), with CV's of 1.3-2.2% also reported for straight-line running and team-sport based activities (Nikolaidis et al., 2018; Rampinini et al., 2015). Further, GPS devices have shown moderate (CV =5-10%) to poor (CV >10%) levels of validity for measures of high (>15 km·h^{-1}) and very-high (>20 km·h^{-1}) intensity running (CV = 4.7% and 10.5% respectively) (Rampinini et al., 2015). Shorter sprints over 15-35 m had similar levels of validity (mean SEM = 5.1-10.9%; CV = 10.5%), respectively) (Castellano et al., 2011; Rampinini et al., 2015). More recently, GPS devices with higher sampling frequencies (18 Hz) have shown to possess greater validity than 10 Hz units when quantifying high-intensity efforts both with and without changes of direction over very short (5 m) and short (30 m) distances (Bias = 1.15%, Typical error of estimate [TEE] = 2.3-8%) (Beato, Coratella, Stiff, & Iacono, 2018; Hoppe et al., 2018). Additionally, moderate to good levels of validity have been observed for measures of instantaneous velocity, both during constant and accelerated running, irrespective of starting velocity (CV = 3.6-5.9%) (Varley, Fairweather, et al., 2012). However, GPS devices have been shown to possess poor validity during decelerations (Dec) (CV = 11.3%) (Varley, Fairweather, et al., 2012). While strong correlations have been shown to exist between GPS and criterion measures (r = 0.89-0.98; TEE = 4.5%), GPS devices have been shown to overestimate peak velocities during a team-sport based circuit (Beato et al., 2018; Hoppe et al., 2018; R. J. Johnston et al., 2014). Overall, GPS technology provides a valid and reliable method of quantifying distances covered and peak velocities achieved by team sport athletes, however, with Acc quantified through assessment of velocity/time data collected by GPS devices, and therefore, the validity of Acc measures is dependent on the ability of GPS devices to assess instantaneous velocity accurately and reliably.

The validity and reliability of GPS in assessing instantaneous velocity is crucial in not only assessing and quantifying Acc performance, but in also ensuring accuracy of raw pre-processed GPS data which practitioners may use to perform novel GPS analyses (Delaney, Cummins, et al., 2018; Delaney, Thornton, et al., 2018). Importantly, GPS technology has demonstrated good to moderate levels of validity when assessing instantaneous velocity compared to criterion measures (CV = 3.6-5.9%) (Varley, Fairweather, et al., 2012), there is no criterion measure for quantifying an Acc. GPS providers often use proprietary algorithms to process velocity data, based on arbitrary Acc thresholds, to provide an Acc count. Processing methods have a significant impact on the number of Acc calculated by proprietary software so it is important to for practitioners be aware this limitation when assessing Acc data (Varley et al., 2017). Taken together, GPS technology provides both valid and reliable measures of athlete physical performance and while some limitations exist when quantifying activities performed at higher intensities. Regardless of these limitations, the insights gained from GPS in quantifying the physical demands help to guide training prescription in professional football and other field-based team sports.

TOTAL MATCH RUNNING DEMANDS OF FOOTBALL MATCH PLAY

Football is an intermittent aerobic based team-sport characterised by long periods of low to moderate intensity activities interspersed with periods of high-intensity activity (Stølen et al., 2005). The physical and energetic demands of professional footballers has been well documented across various leagues and competitions throughout the world (Dolci et al., 2020). In professional level European football competitions, its reported that players cover a TD of between 9-13 km, with 600-1200 m covered at high-speed (>19.8 $km{\cdot}h^{-1}$) running, while they perform between 60-100 Acc (>2 $m{\cdot}s^{-2}$) throughout a match (Bradley et al., 2011; Bradley et al., 2010; Dalen et al., 2016; Sarmento et al., 2014). Due the relative infancy of the Australian A-League (AL), and the availability/permittance of technology to analyse match running performance, there is scant data surrounding the match running demands of the AL. From the available data, the AL competition places similar physical demands on players to what has been reported in the European competitions, with AL players covering TD of between 9.5-11 km, with 500-800 m covered through high-speed (>19.8 $km{\cdot}h^{-1}$) running (Varley, Gabbett, & Aughey, 2014; Wehbe et al., 2014). Further, AL footballers have been reported to perform between 80-125 Acc (>2.5 $m{\cdot}s^{-2}$) (Wehbe et al., 2014) or 65 ± 21 Acc (>2.78 $m{\cdot}s^{-2}$) (Varley et al., 2014) throughout a match. Collectively this data demonstrates that football is a very physically demanding sport that requires its players to possess high levels of both aerobic and anaerobic fitness, with a capacity to tolerate and perform frequent Acc efforts.

Although the total physical demands of football competition have been well documented, the between-match variability of these demands is unknown. Understanding of the between-match variability in total match running demands is crucial in separating out the signal from the noise and determining whether any changes in running performance are within the realm of expectedness or are representative of under/over performers (Thornton, Delaney, Duthie, & Dascombe, 2019). While the typical variation for each GPS metric would be calculated in-house at most football clubs, these data are seldom reported in the scientific literature, hence there is limited information about the match-to-match variations in physical performance in elite footballers. Total distance covered has shown to be the most stable (i.e., the lowest between-match CV%) metric (CV: 2.4-4.3%), with HSD (>19.8 km·h^{-1}) and very high-speed distance (VHSD) (>25.2 km·h^{-1}) having demonstrated much greater match-to-match variation (CV: 6.8-22.0% and 30.8-38.9%, respectively) (Carling, Bradley, McCall, & Dupont, 2016; Delaney et al., 2016; Gregson, Drust, Atkinson, & Di Salvo, 2010; Oliva-Lozano, Muyor, Fortes, & McLaren, 2020; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). Recently, the match-to-match variation for Acc count has also been reported (CV: 4.9%), however, the speed threshold for what constituted an Acc was not reported (Oliva-Lozano, Muyor, et al., 2020). While some research exists on the match-to-match variation in the physical demands of football, more research is needed to quantify the variation of Acc requirements between matches. This information is crucial in providing practitioners with information that will help them implement appropriate training practices to prepare players for match demands.

Positional Differences in Total Match Running Demands

Existing data has demonstrated that the physical demands of a match differ between the various football positional groups (Bloomfield et al., 2007; Carling, 2010). While subtle differences in positional demands may reflect an individual team's tactics (Bradley et al., 2011), data from multiple international competitions have identified similar positional differences in match output profiles (Abbott et al., 2018; Di Salvo, Baron, Tschan, et al., 2007; Mallo et al., 2015; Mohr et al., 2003). Using broader positional groups, defenders (DEF) have been shown to cover the lowest TD across match, followed by ATT and MID (9.64 ± 0.66 km, 10.77 ± 1.13 km and 10.17 ± 0.52 km, respectively) (Wehbe et al., 2014). More specifically, other research has reported that central defenders (CD) cover the least amount of distance (9.83-10.6 km) which is followed by strikers (STR) (10.3-11.2 km), with the midfield positional groups required to cover the greatest distance (11.0-12.0 km) (Abbott et al., 2018; Di Salvo, Baron, Tschan, et al., 2007; Mallo et al., 2015; Mohr et al., 2003). Similarly, DEF have been shown to cover the least amount of HSD, irrespective of speed threshold, when compared to the midfield and ATT positional groups (>19.7 km·h^{-1} = 589 ± 279 m vs 717 ± 251 m vs 708 ± 75 m, respectively and >15km·h^{-1} = 1.69 ± 0.10 km vs 2.23 ± 0.15 km vs 2.28 ± 0.14 km, respectively). More specifically, CM are required to cover less, and wide midfielders (WM) more, HSD than all other positional groups using speed thresholds of 19.1-23 km·h^{-1} (397 m vs 738 m vs 627-652 m) and >19.8 km·h^{-1} (681 m vs 1049 m vs 911-968 m) (Di Salvo, Baron, Tschan, et al., 2007; Di Salvo et al., 2009). At very high-speed, CM and central midfielders (CM) cover less distance than ATT, WM and wide defenders (WD) (>23 km·h^{-1}; 215-248 m vs 402-446 m) (Di Salvo, Baron, Tschan, et al., 2007) and >25.1 km·h^{-1} (208-247 m vs 482-505) (Mallo et al., 2015). Taken together, this information suggests that central and defensive based players have different high-speed running demands to those of wider and ATT players and this highlights the need for tailored training programs to ensure specific preparation for the competition demands.

While distances covered at various speeds are of interest, the number of high-intensity efforts performed is also crucial to understanding the overall physical demands of each positional group. When combining positional groupings, central players (i.e., CM, CM and

STR) complete fewer Acc (>2 m·s^{-2}) than wide players (WD and wingers [WIN]) in both the Danish Superliga (186 ± 7 vs 151 ± 5) (Vigh-Larsen et al., 2018) and Norwegian Eliteserien League (98± 21 vs 85 ± 20) (Ingebrigtsen, Dalen, Hjelde, Drust, & Wisløff, 2015). More specifically, CM complete fewer Acc (2 m·s^{-2}) than all other positional groups (129 vs 164-190) (Vigh-Larsen et al., 2018), with WM completing more Acc (2 m·s^{-2}) efforts than STR, CM and CM (102 vs 80-90) (Dalen, Lorås, Hjelde, Kjøsnes, & Wisløff, 2019). Furthermore, employing a higher Acc threshold (3 m·s^{-2}), WM continued to complete more Acc efforts than CM and CM (35 ± 7 vs 27 ± 6 and 27 ± 6, respectively) (Oliva-Lozano, Fortes, Krustrup, & Muyor, 2020), while in the AL, WD complete more Acc (>2.78 m·s^{-2}) than all other positional groups (90 vs 56-69) (Varley & Aughey, 2013). Despite the proposal of the calculation of the AveAcc as a novel method of assessing physical intensity (Delaney et al., 2016), limited research has reported on the metric using match-play data. The varying Acc profiles associated with each positional group provides rationale for the assessment of AveAcc demands by position.

Competitional Differences in Total Match Running Demands

Competition level has been shown to be an influential factor in the running demands of competitive football match play (Aquino et al., 2017). Such information is useful for preparing players in teams that are seeking promotion to higher leagues within a competition structure or separately, in preparing youth players to transition into professional football. Analyses into the top three divisions of football in England (Premier League, Championship, and League 1) observed that League 1 players covered greater distances than those in the Championship and Premier League, both in total (11,607 ± 737 m vs 11,429 ± 816 m vs 10,722 ± 978 m, respectively) and at high- (19.8 km·h^{-1}) (881 ± 200 m vs 803 ± 227 m vs 681 ± 215 m, respectively) and very high-speed (>25.1 km·h^{-1}) (360 ± 123 m vs 308 ± 139 m vs 248 ± 119 m, respectively) distances (Bradley et al., 2013). Conversely, Di Salvo et al. (2013) suggested that there is no difference in the physical demands of the top two English divisions, with Championship level players covering similar total (11,102 ± 916 m vs 10,746 ± 964 m), high-speed (750 ± 222 m vs 693 ± 214 m) and VHSD (273 ± 125 m vs 258 ± 122 m) as Premier League level players. The increased physical demands associated with lower-level competitions may reflect technical and tactical differences whereby teams are unable to maintain ball possession or are inefficient with their movements (Rampinini et al., 2009)

While competitional differences exist in a professional environment, specific interest has also been placed on differences between youth competitions. In Australia, youth footballers regularly transition between playing in elite and sub-elite youth competitions, however, literature in this space is limited due to the majority of footballing nations being limited to solely dedicated elite youth competitions. To the author's knowledge, only one paper currently exists that has compared such data, with greater (effect size [ES] = >0.2) TD and HSD (>19 km·h^{-1}) covered in an elite competition vs a semi-professional competition for all positional groups except for WD (Sydney et al., 2020). Further comparisons in Australia between a professional team and elite youth team (who competed in a semi-professional competition) demonstrated equivocal results when comparing physical outputs (Lord et al., 2020). Both WD and CM covered more TD in the semi-professional competition than in the professional competition (10,814 ± 412 vs 11,307 ± 349 m and 11,838 ± 704 m vs 12,105 ± 695 m, respectively), with the opposite true for CM (10,356 ± 408 m vs 10,113 ± 343 m) (Lord et al., 2020). At higher intensities, no differences were observed between competition levels, with the exception of CM who covered less HSD in the semi-professional competition (Lord et al., 2020). Conversely, a direct comparison of professional, U19 and U17 players at a single Danish club observed high- (>19.8 km·h^{-1}) and very high-speed (>25.2 km·h^{-1}) distances covered were similar between levels. However, U19 players performed more Acc (>2 m·s^{-2}) efforts than both the professional and U17 level players (Vigh-Larsen et al., 2018). While developing youth footballers for transition into professional competition is a primary objective of football academies, there is limited research directly comparing the physical demands between youth and professional competitions within clubs. This information would be extremely useful to inform the long-term development of youth footballers so they can cope with the physical demands associated with training and match play involved in professional competitions.

Intra-Match Variation in Total Match Running Demands

Temporal changes in physical output throughout a match are an area of particular interest to both practitioners and researchers alike. Information regarding temporal changes in performance is useful to practitioners to gauge player performance and help to provide insight into any manifestation of acute physical fatigue. Changes in physical output have traditionally been determined through exploring differences in running demands between match halves, with declines of between 2-7% reported for TD (Bradley & Noakes, 2013; Carling & Dupont, 2011; Rampinini et al., 2009; Vieira et al., 2019). Additionally, high-speed (>18 km•h^{-1}) distances covered also decline by between 3-12% between halves, with a further 2-17% reduction in distance covered at very high-intensities (>25.2 km•h^{-1}) (Di Salvo, Baron, & Cardinale, 2007; Di Salvo et al., 2009; Mohr et al., 2003;

Rampinini et al., 2009). Similarly, the number of Acc efforts performed at high (>3 $m{\cdot}s^{-2}$) and moderate (2 $m{\cdot}s^{-2}$) threshold has been shown to reduce in the second half by between 3-10% (Akenhead, Hayes, Thompson, & French, 2013; Dalen et al., 2016; Vigh-Larsen et al., 2018).

More detailed analysis of temporal changes in running demands have been undertaken through examining smaller discrete periods of a match, such as 15 min epochs e.g., 0-15 min, 15-30 min, etc. (Bradley et al., 2010; Mohr et al., 2003; Vigh-Larsen et al., 2018). Such data has demonstrated that the total and high-speed running demands are greatest during the first 15 minutes of a match and are lowest during the final 15 minutes (Linke et al., 2018; Mohr et al., 2003). In the German Bundesliga, a comparison of physical demands between 1-15 min and 75-90 min resulted in a 21.2% reduction in TD, a 20.8% reduction in HSD and a 27.6% reduction in VHSD covered (Linke et al., 2018). Interestingly, Bradley et al. (2010) reported the inverse, with 5-16% more HSD covered in the final 15 min when compared to all other 15 min periods, however, this data was collected from a different professional league. Interestingly, the league observed by Bradley et al. (2010) (English Premier League) has more goals scored in the final 15 min of a match when compared to any other time period (Zhao & Zhang, 2019), and with goal scoring opportunities linked to high-speed running, this may help explain the conflicting results (Faude, Koch, & Meyer, 2012; Little & Williams, 2005). Additionally, the number of Acc (>2 $m{\cdot}s^{-2}$) efforts performed at 60-75 min and 75-90 min was lower than at 0-15 min and 15-30 min (Vigh-Larsen et al., 2018). However, Bradley et al. (2010) reported no differences in the count of moderate (2.5-4 $m{\cdot}s^{-2}$) or high (>4 $m{\cdot}s^{-2}$) Acc efforts performed across each 15 minute period of a match. Taken together, this information suggests that there is a reduction in various intensity parameters during the second half compared to the first half. While some findings were conflicting, no study showed improvements in the second half and as such, strategies to attenuate reductions would be encouraged.

Future Research Directions

While considerable research has been quantified the physical demands of competitive football match play and subsequently identified the interactions of various factors on these demands, the application of this information to prepare players for competition has so far been limited. Throughout a 90 min football match there are frequent periods of when the ball is in play and physical demands are high, interspersed by periods when the ball is not in play (i.e., throw-ins, goal kicks, substitutions, etc.) and when physical demands are low. Investigations by Riboli, Semeria, Coratella, and Esposito (2021) identified differences in peak match running demands when a team had possession of the ball vs when the opposition had possession and similarly, when the ball was in-play vs out of play. As such, the amalgamation of all this information into 90 min average match intensities would considerably overestimate the demands of match play where the ball is not in play and considerably underestimate the demands of match play where the ball is in play. With training drills typically designed to maximise ball in play time to improve technical, tactical, and physical capabilities, the use of match average data as a guide or target for physical performance likely underestimates players for the demands of match play when the ball is in play. Using alternative methods to quantify match demands where the peak match running demands of competition are quantified over smaller time periods and used to periodise training may better reflect the demands of competition when the ball is in play thus enabling practitioners to better design training drills to prepare footballers for physical intensities involved during match play.

PEAK MATCH RUNNING DEMANDS OF FOOTBALL MATCH PLAY

As highlighted above, typical player GPS monitoring practices involve the quantification of total match demands, with this information subsequently used both to assess match performance and to guide training prescription (Bangsbo et al., 2006; Hill-Haas et al., 2011). However, training drill durations are typically shorter than the 90 min match duration, and as such, using total match data as a reference for training drill intensities may underprepare players for the peak match running demands of competition (Delaney, Thornton, et al., 2018). For example, small-sided games implemented in football training typically last between 1-10 min (Sarmento et al., 2018), with several repetitions prescribed, e.g., 3 x 4 min. Such specific football drills are characterised as having high physical, technical, and tactical demands, with drill constraints often aimed at maximising ball-in-play time and player ball involvements (Morgans et al., 2014). Conversely, competitive match play is characterised by periods of high physical, technical and tactical demands, interspersed with periods of extended down-time due to reductions in ball-in-play time, caused by factors such as free-kicks, throw-in's, goal-kicks, etc. (Lago-Peñas et al., 2012). Across a 90 min match, it has been reported that the ball is typically only in-play for <66% of total time (Carling & Dupont, 2011; Linke et al., 2018). While players may not be stationary when the ball is not in play, the activities performed during these periods are at much lower intensities than when the ball is in play (Wass et al., 2020). Using total match data (inclusive of when the ball is not in-play) as a reference for the prescription and monitoring of training drills, whereby the aim is to maximise ball-in-play time, is questionable and likely not appropriate for informing training practices aimed at preparing players for the rigors of competition.

The recognition of this limitation has led to practitioners to quantify the peak match running demands across durations that are significantly shorter than match play, e.g. 1-10 min (Delaney, Thornton, et al., 2018). Such analysis provides that match data that reflects the greatest physical demands imposed on players during competition, which would better reflect both the duration and constraints associated with football-based conditioning drills (Whitehead et al., 2018). For example, using data that quantifies the physical demands of the most intense 5 minute period of a match as a reference for a 5 minute football based conditioning drill, as opposed to the traditional 90 min match data, may help to better prepare players for match demands (Riboli, Esposito, & Coratella, 2022). To understand peak match running demands as a metric, it is first important to consider how they are calculated. Initial attempts at calculating peak match running demands used fixed time periods to quantify running demands (Bradley & Noakes, 2013; Fereday et al., 2020; Mohr et al., 2003). This process involves calculating physical outputs using a moving average over fixed time periods, for a specified duration. For example, using TD as a metric and a 5-minute duration, distance covered would be calculated between 0-5 min, 1-6 min, 2-7 min, etc., with the maximum observed distance covered then recorded as the peak match running demands. The use of fixed periods likely underestimates running demands due to peak match running periods rarely commencing and culminating “on the minute”. Subsequently, practitioners have begun using moving periods by which physical output is calculated over all sampled data points, rather than fixed time periods. For example, a GPS sampling at 10 Hz across a 90 min match would provide 54,000 data points from which to calculate peak match running demands, e.g., 0-5 min, 0.01-5.01 min, 0.02-5.02 min, etc. The use of fixed durations has shown to underestimate peak match running demands by 4-25% for TD, 7-27% for HSD and 15-69% for VHSD compared to moving average durations (Doncaster, Page, White, Svenson, & Twist, 2020; Fereday et al., 2020; Oliva-Lozano, Martín-Fuentes, et al., 2021; Varley, Elias, et al., 2012). Hence, the moving average approach to calculating peak match outputs should be employed for this reason.

Once the peak match running demands have been quantified, a power law curve can be used to fit the data and provide an individual regression equation to help infer the physical demands for any window duration (Delaney, Thornton, et al., 2018). A power law curve allows for a non-linear relationship between two dependent variables (*x* and *y*) to be described, using constants of *c* and *n* using the equation below (Sylvan Katz & Katz, 1999):

$$y = cx^n$$

A plot of log(*x*) and log(*y*) results in a straight line with a slope of *n* and y-intercept of c^e (Katz & Katz, 1994). Linear regression analyses allow the calculation of *c* and *n* values, with the exponential of *c*, calculated through extrapolation, allowing practitioners to predict running intensity (*i*) as a function of time (*t*) using the formula:

$$i = ct^n$$

For example, using an intercept value (c) of 196 and a slope value (n) of -0.17, as reported by Delaney, Thornton, et al. (2018), for a drill duration (*t*) of 5 min would provide an expected relative drill intensity of:

$$i = 196 \times 5^{-0.17}$$

$$i = \sim 149.1\ m \cdot min^{-1}$$

This method has shown good agreement between actual vs. predicted data in elite football players in Australia (Delaney, Thornton, et al., 2018), providing a valid tool for practitioners when prescribing or monitoring training drills.

Quantifying the Peak Match Running Demands of Football Match play

Although the analysis of peak match running demands is a relatively new concept, a body of literature on these demands has started to develop in football (Whitehead et al., 2018). While many physical output metrics have been reported in the literature, e.g., TD, HSD, various Acc metrics or MP, the reported durations of which they report on are consistent and range from 1-10 min (Casamichana, Castellano, Diaz, Gabbett, & Martin-Garcia, 2019; Hills et al., 2020; Oliva-Lozano, Fortes, & M. Muyor, 2021; Riboli, Semeria, et al., 2021). Due to the high level of practicality associated with peak match running demands, these durations are likely reported on due to their correlation with typically prescribed training drill durations. Consistent across all reported metrics is an observed decline in relative physical output as moving average duration increases, i.e., relative output in the most demanding 1 min of match play is greater than the most demanding 2 min and so on (Delaney, Thornton, et al., 2018). This is likely due to both physiological limitations i.e., limitations of energy systems during maximal efforts, and also match contextual factors, such as ball in play time, where interrupted play is much more likely for 10 min periods when compared to 1 min (Linke et al., 2018). Research has been undertaken on a variety of professional leagues around the world, with the reported peak match running demands largely similar irrespective of league (See Appendix 1). Additionally, the reported peak relative running distances covered, both in totality and at high intensities, are considerably higher than those reported across a 90 min match, with peak relative TD covered ranging between 115-205 $m \cdot min^{-1}$ and relative peak HSD covered ranging between 10-65 $m \cdot min^{-1}$ (See Appendix 1). Such peak physical outputs are far higher than the reported 90 min averages reported in professional competition (TD: ~104 $m \cdot min^{-1}$; HSD: ~6.5 $m \cdot min^{-1}$) (Varley et al., 2014). This discrepancy further highlights that the use of total match physical output data as the basis to structure training drills may underprepare players for the peak physical demands of match play.

While TD and HSD have been the common metrics applied to peak match demand analysis, the reporting of other commonly assessed running performance metrics is seldom done. Of the currently available research, measures of MP and HMLD have been reported on, however, information regarding these measures is limited (Casamichana et al., 2019; Doncaster et al., 2020; Riboli, Semeria, et al., 2021), likely due to the validity and reliability of these metrics previously being questioned (Buchheit, Manouvrier, Cassirame, & Morin, 2015; Buchheit & Simpson, 2017). Interestingly, limited emphasis has been placed on the peak Acc demands of football match-play, with few studies having reported on this data (See Appendix 1). However, of the reported peak Acc metrics, there has been further inconsistencies amongst literature with number of accelerations and decelerations (Acc/Dec) (Oliva-Lozano, Fortes, & M. Muyor, 2021), distance covered while accelerating (Riboli, Semeria, et al., 2021) and AveAcc (Delaney, Thornton, et al., 2018; Hills et al., 2020) all having been reported on. Delaney, Cummins, et al. (2018) suggested that the use of AveAcc, particularly when quantifying peak match running demands, is due to the metric having increased stability when compared to Acc counts, while being sensitive enough to identify differences between player cohorts. Despite this, the current inconsistency in the reported Acc metrics doesn't allow for any major conclusions to be drawn.

While an understanding of the peak match running demands of football is continuing to develop, what constitutes a meaningful change to performance is yet to be fully explored. Currently, two studies have investigated the between-match variation in the peak match running demands of football (Novak, Impellizzeri, Trivedi, Coutts, & McCall, 2021; Riboli, Semeria, et al., 2021). In the study by Novak et al. (2021), peak match running demands of TD varied by 6.5-6.9%, with HSD and VHSD varying by 21.0-30.6% and 35.0-56.1%, respectively. Differing results were reported by Riboli, Semeria, et al. (2021), with match-to-match variation of TD varying by ~11%, with HSD and VHSD varying by ~14% and ~15%, respectively. Such magnitudes of between-match variations are similar to those reported for total match outputs of TD, HSD, and VHSD (Carling et al., 2016; Delaney et al., 2016; Gregson et al., 2010; Oliva-Lozano, Muyor, et al., 2020; Rampinini et al., 2007). It is however important to note that the work of Novak et al. (2021) and Riboli, Semeria, et al. (2021) were limited to assessing the between-match variability over single moving average durations of 3 min and 1 min, respectively, and any generalisability to other moving average durations is currently unknown. Interestingly, a direct comparison of the variability of peak match running demands and total match running demands found the between-match variability of HSD and VHSD were lower for peak match running demands than total match demands (Riboli, Semeria, et al., 2021). Overall, a more robust analysis of the between-match variability of this metric is needed to provide context to fluctuations in peak match running demands, allowing practitioners to determine meaningful changes in performance and guide training prescription practices.

Positional Differences in Peak Match Running Demands

With the total match running demands of football varying by positional group, it may be expected that the peak match running demands of competition also vary by positional group (Abbott et al., 2018; Di Salvo, Baron, Tschan, et al., 2007; Mallo et al., 2015; Mohr et al., 2003). Of the current research, DEF, and more specifically, CM have shown to have lower peak match running demands of TD and HSD when compared to all other positional groups (See Appendix 1) (Delaney, Thornton, et al., 2018; Ju et al., 2021; Oliva-Lozano, Rojas-Valverde, et al., 2020). Additionally, while CM have greater peak TD running demands than both STR and WM (See Appendix 1) (Delaney, Thornton, et al., 2018; Ju et al., 2021; Oliva-Lozano, Rojas-Valverde, et al., 2020), minimal differences have been reported peak HSD running demands (Doncaster et al., 2020; Martín-García et al., 2018; Riboli, Semeria, et al., 2021). It is important to note that Delaney, Thornton, et al. (2018) only assessed positional differences in the components of the power law curve (i.e. intercept and exponent) and not the positional differences of peak match running demands across each epoch. While further investigations into positional differences in peak match running demands have occurred, the quality of performed analyses are questionable. A study by Oliva-Lozano, Fortes, and M. Muyor (2021) only reported a main effect for positional differences with no *post-hoc* analyses conducted, with others only comparing peak match running demands back to a single positional group (Novak et al., 2021). Hence, while research on the positional differences in peak match running demands of TD and HSD exists, the limited nature of this research coupled with inconsistent methods of analyses highlights the need for more investigations in this area.

Additionally, research assessing the peak match Acc demands is limited, with no consistent metric employed across literature (Delaney, Thornton, et al., 2018; Oliva-Lozano, Fortes, & M. Muyor, 2021; Riboli, Semeria, et al., 2021). Initial findings indicating that WD have greater AveAcc demands than all other positional groups (Delaney, Thornton, et al., 2018), however, no positional differences were reported for AveAcc in youth footballers (Duthie et al., 2018). However, inconsistent methods in which AveAcc was calculated mean that definitive conclusions are unable to be drawn (Delaney, Thornton, et al., 2018; Duthie et al., 2018). Further, minimal positional differences have been observed for peak distances covered while accelerating (Riboli, Semeria, et al., 2021). While the body of research on positional differences in peak match running demands is emerging, scant literature and inconsistent analysis of Acc metrics highlights the need for further investigation in positional differences. Taken together, current literature would suggest that positional differences are likely to occur in the peak match running demands. More investigation is needed using clear, consistent and appropriate methods of analysis to definitively assess positional differences in peak match running demands, with special consideration given to the peak match Acc demands. Based on this information, practitioners should assess peak match running demands by positional group and subsequently, may need to tailor drills when designing position specific training drills.

Competitional Differences in Peak Match Running Demands

Understanding of competitional differences in peak match running demands may be useful to coaches in physically preparing players for promotion into higher level competition, or aid in the preparation of youth players transitioning into a professional environment (Williams & Reilly, 2000). While much of the peak match running demands research has been conducted on either youth players (Doncaster et al., 2020; Duthie et al., 2018; Martín-García et al., 2018) or on teams competing in second division competitions (Connor, Mernagh, & Beato, 2021; Oliva-Lozano, Fortes, & M. Muyor, 2021; Oliva-Lozano, Rojas-Valverde, et al., 2020), to the authors knowledge, no study has directly compared the peak match running demands between tiered competitions. While speculative, it appears that the peak match running demands observed for players competing in second divisions are similar to those observed in the first divisions, irrespective of the metric assessed (Delaney, Thornton, et al., 2018; Fereday et al., 2020; Oliva-Lozano, Gómez-Carmona, Rojas-Valverde, Fortes, & Pino-Ortega, 2021; Riboli, Semeria, et al., 2021). When comparing the peak match running demands of youth players to their adult counterparts, mixed findings have been reported. For example, the peak match running demands of the Spanish Segunda División B youth league (Martín-García et al., 2018) appear similar to those observed in the professional Spanish La Liga (Casamichana et al., 2019), while the peak match running demands of the English Premier League 2 youth league (Doncaster et al., 2020) and elite Italian youth competitions (Duthie et al., 2018) appear lower than those of the respective professional competitions (Delaney, Thornton, et al., 2018; Riboli, Semeria, et al., 2021). In Australia, elite youth players compete across an eight game National Youth League (NYL) season, which is followed by participation in a 22-game semi-professional open age competition termed the National Premier League (NPL). The NPL competition acts as the main pre-cursor competition for youth players aiming to transition into the professional A League team. Accurate quantification of the differences between youth and professional competitions is crucial as if the physical demands of youth competitions are far less than those in professional competitions, then training may be the only way for players to be exposed to similar demands before transitioning between from youth to professional competition. This is particularly important in the Australian football system where the transition between youth and professional squads is more substantial than other countries where there are multiple youth teams for players to transition through (e.g., U16, U18, U21, reserves) before being retained in the professional squad.

Intra-Match Variation and Temporal Location of Peak Match Running Demands

Temporal changes in physical performance have been observed for total match outputs, warranting investigation into temporal changes associated with peak match running demands (Bradley & Noakes, 2013; Rampinini et al., 2009; Vigh-Larsen et al., 2018). While substantial research has been published on total match demands, the temporal changes in peak match running demands has not been well quantified, with only two studies assessing changes between halves (Casamichana et al., 2019; Oliva-Lozano, Rojas-Valverde, et al., 2020). Interestingly, when amalgamating all positional groups, the peak TD running demands are reduced in the second half when compared to the first (Oliva-Lozano, Rojas-Valverde, et al., 2020). Conversely, when assessing between-half differences in peak match running demands at a positional level, reductions were observed in the second half for WD at the 10 min epoch, with CM having lower peak match running demands at epochs of 3, 5 and 10 min (Casamichana et al., 2019). Further, only a single study has assessed the between-half differences in peak match running demands of high- and VHSD covered, with the first and second half found to be similar across all epochs (Oliva-Lozano, Rojas-Valverde, et al., 2020). Based on the available literature, no definitive conclusions can be drawn regarding temporal differences in peak match running demands. Additionally, of greater interest to practitioners may be *when* these periods of peak match running demands typically occur, as this may potentially identify periods of match play when players are required to perform maximally, helping to inform match-day strategies. To date, only a single study has assessed the temporal distribution of peak match running demands, attributing the start of a peak match running period to the 15 min period of a match (i.e. 0-15 min, 15-30 min, etc.) in which it commenced, (Oliva-Lozano, Martínez-Puertas, Fortes, & Muyor, 2021). It was identified that the majority of peak match periods, irrespective of running performance metric, occurred in the first 15 minutes of a match. However, as the match was only subdivided into 15 min periods, it isn't apparent whether these occur at the very start of a match or slightly later (Oliva-Lozano, Martínez-Puertas, et al., 2021). This greater granularity may provide greater insights to coaches when designing training sessions to replicate match demands.

CONCLUSIONS

Quantifying the peak match running demands of competitive football match play provides a useful reference for coaches to be able to prescribe and monitor training demands. The reported peak match running demands of football are considerably higher than reported 90 min averages, providing a more appropriate reference for training drill intensities. Quantification of the peak match running demands using a moving average technique has proven superior to fixed time durations, as the fixed-time measures significantly underestimates the peak match running demands. As such, the moving average approach should continue to be employed and more information regarding its variability is needed to quantify meaningful changes in performance. Further, time durations used within the moving average approach should be consistent ranging from 1-10 min, however, some studies have chosen to report on a smaller time range. The smaller moving average window may limit the practicality of this approach since the power law relationship between exercise intensity and the duration that it can be sustained for is not quantified over a time domain relevant to football. While positional, competitional, and contextual changes have been briefly reported on, the research surrounding this is not robust and often inconclusive. While positional differences in match running demands may exist, no paper has explicitly compared these differences across a full spectrum of epochs (i.e., 1-10 min) or between halves. Further, while differences in competition level have been observed for total match physical demands, potential differences in peak match running demands between youth and professional football have not been investigated. Further exploration of the peak match running demands between positions and competition levels will provide crucial information to coaches regarding the preparation of both professional and youth footballers for match play.

Chapter Three

Between-Match Variation of Peak Match Running Intensities in Elite Football

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ABSTRACT

Peak match running demands have recently been employed to quantify the peak match running demands of football competition, across incremental time intervals, to inform training practices. However, their between-match variation is yet to be comprehensively reported, limiting the ability to determine meaningful changes in peak match running demands. The current study aimed to quantify the between-match variability in peak match running demands across discrete moving average durations (1-10 min). GPS data were collected from 44 elite football players across 68 matches (mean ± SD; 13 ± 10 observations per player). For inclusion players must have completed 70 minutes of a match across a minimum of two matches. Performance metrics included total and high-speed (>19.8 km·h^{-1}) running distances and AveAcc (m·s^{-2}), expressed relative to time. For each metric, the CV and SWD were calculated. The peak match running demands data was similar to previously reported from various football competitions. The between-match CV of relative TD ranged between 6.8-7.3%, with the CV for average acceleration and relative high-speed running being 5.4-5.8% and 20.6-29.8%, respectively. The greater variability observed for relative high-speed running is likely reflective of the varying constraints and contextual factors that differ between matches. The reported between-match variability helps to provide context when interpreting match performance and prescribing training drills using peak match running demands data.

INTRODUCTION

While physical performance is a key outcome measures across all sports, quantifying the variance surrounding selected performance metrics is not common, despite such information helping provide crucial context in interpreting the data (Hopkins, Hawley, & Burke, 1999). The available data suggest that athletic performance is highly variable in both endurance and power-based sporting competitions (Malcata & Hopkins, 2014). However, little is known about the inherent variability of team sport performance due to the challenges in measuring running performance and quantifying contextual factors associated with match play (Novak et al., 2021). Changes in performance (i.e. the “signal”) should be interpreted relative to the total variance (i.e. the “noise”) present in the metric to determine whether the observed change in performance is real or an artefact of biological, statistical or measurement error (Hopkins et al., 1999). Furthermore, quantifying the within and between-variation in physical performance measures allows for the effects of contextual factors (e.g., competition travel, level of opposition and time of season), ergogenic strategies and training programs to be thoroughly investigated (Malcata & Hopkins, 2014). To date, the majority of literature has focused on reporting performance variability within individual sports, typically involving time-trials, fixed distance or weightlifting events (Malcata & Hopkins, 2014). However, such individual sports are closed events which are vastly different to team sports such as football, where variability in physical demands is introduced through both technical and tactical elements as well as external opposition. Consequently, the unpredictable nature of football match play provides inherent between-match variation within performance metrics that reflect the various contextual factors.

Additionally, the overall variation of physical performance is also influenced by both extrinsic and intrinsic factors. Intrinsic factors that contribute to the variation around performance metrics may include circadian rhythms, psychological readiness and arousal levels (Craft, Magyar, Becker, & Feltz, 2003; Thun, Bjorvatn, Flo, Harris, & Pallesen, 2015), whereas extrinsic factors may include environmental conditions, quality of opposition, and time between fixtures (Di Salvo et al., 2013; Gregson et al., 2010; Mohr, Nybo, Grantham, & Racinais, 2012). Further, the usefulness of match running performance metrics can be largely influenced by the accuracy, validity and reliability of the relevant technology employed. For example, GPS technology is the primary technology used in field-based team sports to quantify both training and match running demands (Akenhead & Nassis, 2016). However, GPS technology has its own inherent variation, with the CV being heavily affected by running speed (Cummins et al., 2013). For example, when completing straight line shuttle runs using various locomotor speed (walk, jog, run, sprint), GPS devices demonstrated acceptable variation for TD covered (CV [90% confidence interval [CI]: 1.9% [1.6-2.3]) compared to a criterion radar system (Rampinini et al., 2015). However, there was considerable greater variation in the GPS data when the analysis was constrained to only high-speed (>15 km$\cdot$h^{-1}) (CV: 4.7% [4.0-5.8]) and very high-speed running (>20 km$\cdot$h^{-1}) (CV: 10.5% [9.0-12.5]) (Rampinini et al., 2015). Despite these limitations, GPS technology remains a primary tool that is employed to measure the physical performance demands of field-based team sports due to their practicality and ability to collect and record bulk data from multiple sensors (Cummins et al., 2013). Match analysis of football has typically reported on the TD covered either as an average of the entire match duration or at various running speed thresholds (Sarmento et al., 2014). However, more recent analyses has employed the use of moving average analysis across discrete durations (e.g., 1-10 min) to assess the peak match running demands throughout a match in an effort to identify the greatest physical demands placed on field-based team sport athletes (Delaney, Thornton, et al., 2018).

The quantification of the peak match running demands also offers value in the prescription of training stimuli designed to replicate match day requirements (e.g., small-sided games or football-based conditioning drills). Often external training loads are prescribed with the intention of accumulating volume across a variety of GPS based metrics, i.e., TD, high-speed distance (HSD) and Acc, however, the training design used to attain these loads may not reflect the intensity of match play. Consequently, the development and prescription of specific training drills relative to the greatest in-match physical demands may be more appropriate (Delaney, Thornton, et al., 2018). While the data in isolation presents with some contextual limitations, the peak match running demands across a 1-10 minute moving average duration can help inform the prescription of training practices that reflect the intensity of match play. The use of a moving average duration has shown to be superior to fixed durations when quantifying peak match running demands, with fixed durations underestimating peak match running demands by ~7-25% dependent upon metric and epoch duration (Fereday et al., 2020; Oliva-Lozano, Martín-Fuentes, et al., 2021). Though the usefulness of such analysis to inform specific football conditioning has been questioned (Novak et al., 2021), such data helps provide ecological validity to the prescription and assessment of training intensities against match play. As such providing more contextual clarity and relevance than simply applying the total match or discrete period average demands.

Recent literature has questioned the usefulness of peak match running demands to inform training, due to the high variability associated with the metrics (TD: 6.2% CV, HSD [>19.8 km•h^{-1}]: 25.2% CV, VHSD [>25.2 km•h^{-1}]: 46.1% CV) (Novak et al., 2021). However, there was no consideration given to the typical variability of total match derived measures of physical output, previously reported to be 2.4-4.3% CV for TD (Oliva-Lozano, Muyor, et al., 2020; Rampinini et al., 2007), with HSD (>19.8 km·h^{-1}) and VHSD (>25.2 km·h^{-1}) displaying larger variations of 16.2-18.1% and 30.8-38.9% CV, respectively (Carling et al., 2016; Gregson et al., 2010). While Novak et al. (2021) reported that the peak match running demands possessed slightly greater variability, their analysis was limited to a single 3-min period with no exploration of whether the magnitude of variation was affected by peak match running demand duration.

Anecdotally, it could be suggested that the variation of 1-min peak match running demands would demonstrate greater variability due to the temporal changes in HSD and VHSD running demands relative to time than a 10-min epoch, which would incorporate more running and periods of recovery. As such, it's likely that the spectrum of peak match running demand epochs would be affected by temporals shifts in running demands which would be reflected through differing levels of between-match variation. Further, it could be suggested that the variation of peak match running demands at a 1 min epoch would differ to a 10 min epoch due to the differing physical demands associated with these durations of play (Delaney, Thornton, et al., 2018). As such, it is important to consider the broad spectrum of variability across a range of epochs to gain a full insight into the variability of peak match running demands.

Practically, the development of specific player physiological capacities, e.g., anaerobic power or repeat sprint ability occurs through the prescription of small-sided games (Sarmento et al., 2018) and, as such, the use of peak match running demands to guide training prescription can be useful for inform the selection, applied constraints and durations of training drills. While the available data using peak match running demands has grown rapidly, it is acknowledged there is a current gap in the literature quantifying the influence of contextual factors and technical involvements during peak match running periods. In order to interpret longitudinal changes in the peak match running demands and prescribe training stimuli reflective of match play, it's necessary to first understand the between-match variability associated with these metrics. Accurate quantification of the variation in these measures across durations reflective of training drill durations, i.e., 1-10 min, will allow for a more robust analysis of typical match performance and help determine "meaningful changes" in between-match performance, while also allowing for more specific training load prescription. With peak match running demands presenting a physical target for players to hit during specific training drills, understanding the variability of the metric allows practitioners to adjust set targets to encompass a larger proportion of "typical" peak match running demands. Therefore, this study aimed to quantify the between-match variation in the peak match running demands observed for elite football players for durations between 1 to 10 minutes.

METHODS

Experimental Overview

The peak match running demands of elite football players observed across durations of 1-10 min were determined using an observational study design. Durations of 1-10 minutes were selected for analysis as per previously reported (Whitehead et al., 2018). Match data were collected from 44 elite football players across 68 matches that were played across three seasons of the AL (2015-2018). This resulted in a total of 494 individual match observations (mean ± SD; 13 ± 10 observations per player, range; 2-43 observations). To be included in the analyses, players must have played at least two matches where they performed for a minimum of 70 minutes to avoid any data skewing from the impact of substitutions. Past research has demonstrated that substitutes have different peak match running demands during match play to starting players (Fereday et al., 2020), with the largest proportion of substitute introductions occurring after ~70 minutes (Bradley, Lago-Peñas, & Rey, 2014; Rey, Lago-Ballesteros, & Padrón-Cabo, 2015). This resulted in a total of 494 individual match observations (mean ± SD; 13 ± 10 observations per player). All participants played for the same team, with data representative of the entire playing group. Goalkeepers were excluded from analysis due to their vastly different match demands. Informed consent and institutional ethics approval were attained prior to the commencement of the study (HREC#: 18056).

Activity Profile

Players' match activities were recorded using portable 18 Hz GPS units (STATSports, Belfast, Northern Ireland) that were worn in a custom-made harness underneath the playing jersey located between the scapulae. These GPS devices have previously been determined as valid and accurate in tracking player movements, with the bias for distance and velocity measures reported as 1.15-2.02% (Beato et al., 2018). Players consistently wore their own identical GPS device between matches to avoid any inter-unit variability, with satellite availability >10 for all analysed matches. Raw GPS data were downloaded post-match using relevant proprietary software (STATSports, Northern Ireland) and then exported into R Studio statistical programming software (RStudio, v 1.1.453). Running speed data points that exceeded 10 $m{\cdot}s^{-2}$ and Acc speeds above ±6 $m{\cdot}s^{-2}$ were replaced with zero values, which due to the nature of data analysis outlined below had negligible effects on observed values (Delaney, Thornton, et al., 2018).

From the available data, three metrics of match running performance were selected for analysis of their peak match running demands: relative TD covered ($m{\cdot}min^{-1}$); relative HSD covered (>19.8 $km{\cdot}h^{-1}$; $m{\cdot}min^{-1}$) and average acceleration ($m{\cdot}s^{-2}$). Average acceleration was calculated through summing the absolute Acc/Dec values and averaging them over a defined time duration to provide an indication of the total Acc requirements of match play (Delaney et al., 2016). From these metrics, peak match running demands were quantified using a moving average technique, across ten incremental durations (i.e., 1-10 min), using R Studio statistical programming software (RStudio, v 1.1.453), and custom-made code, with the maximum value obtained from each variable at each time period being recorded.

Statistical Analysis

Analyses were conducted in R Studio statistical software (v 1.2.1335) using the *lme4* package (v 1.1-21) (Bates, Mächler, Bolker, & Walker, 2015). Prior to analysis, assessment of data normality and identification of outliers was conducted via the inspection of boxplots and quantile-quantile plots. Data were subset by intensity period (10 levels: 1-10 min), with separate linear mixed models conducted to calculate the CV for each intensity period for each response variable (relative TD, relative HSD, AveAcc), yielding ten models per response variable. Crossed random intercepts for both player ID and match date were included to assess the average between-match variability for each player. Data were log transformed and then back-transformed and converted to a percentage to express the between-match changes in peak match running demands as a CV (%) with imprecision presented as a 95% CI. Additionally, the SWD was calculated for each time point to determine the smallest practically meaningful between-match difference in peak match running demands. The SWD was calculated as 0.3 x within-subject variance and then doubled, to account for the small amount of error associated with GPS technology, with data presented in raw units.

RESULTS

All data were deemed normally distributed by visual inspection of a Quantile-Quantile plot, with no outliers owing to measurement error detected. Data points that were outliers but represented real data (i.e., not due to measurement error) were included in analysis. Peak match running demands for each performance metric are presented in Table 3.1 below. The between-match variability of relative TD was low across all discrete epochs (CV: 6.8-7.3%, Table 3.1), as was the between-match variability of AveAcc across all epochs (CV: 5.4-5.8%, Table 3.1) The between-match variability in relative HSD was higher across all epochs (CV: 20.6-29.8%, Table 3.1), with variability gradually increasing with epoch duration.

Table 3.1. Variability measures of peak match running demands across 1-10 min moving average durations.

Performance Metric		Time Period									
		1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min
Relative Distance ($m{\cdot}min^{-1}$)	Mean ± SD	195 ± 18	165 ± 14	153 ± 13	147 ± 13	142 ± 12	139 ± 12	136 ± 12	134 ± 12	132 ± 12	130 ± 12
	SWD	7.4	5.5	4.7	4.4	4.2	4.1	3.9	3.9	3.9	3.9
	CV %	6.9	6.8	6.8	6.8	6.9	7.0	7.3	7.2	7.2	7.2
	95% CI	5.3 - 8.9	5.2 - 8.7	5.3 - 8.7	5.3 - 8.7	5.4 - 8.9	5.5 - 8.9	5.7 - 9.3	5.7 - 9.3	5.7 - 9.3	5.7 - 9.3
Relative HSD ($m{\cdot}min^{-1}$)	Mean ± SD	60 ± 17	36 ± 11	28 ± 9	23 ± 7	21 ± 7	19 ± 6	17 ± 6	16 ± 5	15 ± 5	14 ± 5
	SWD	8.2	4.9	3.8	3.2	2.8	2.5	2.3	2.2	2.0	1.9
	CV %	20.6	22.4	24.6	26.2	26.9	27.3	27.9	28.9	29.8	29.6
	95% CI	15.4 - 27.4	17.0 - 29.8	18.6 - 32.6	19.9 - 34.8	20.4 - 35.6	20.8 - 36.1	21.2 - 36.9	21.9 - 38.3	22.7 - 39.5	22.5 - 39.3
Average Acceleration ($m{\cdot}s^{-2}$)	Mean ± SD	1.09 ± 0.09	0.92 ± 0.07	0.85 ± 0.07	0.81 ± 0.06	0.79 ± 0.06	0.77 ± 0.06	0.75 ± 0.06	0.74 ± 0.06	0.73 ± 0.06	0.72 ± 0.06
	SWD	0.042	0.031	0.029	0.027	0.025	0.025	0.023	0.023	0.022	0.022
	CV %	5.4	5.5	5.5	5.5	5.6	5.7	5.6	5.7	5.8	5.7
	95% CI	4.1 – 7.0	4.3 - 7.2	4.2 - 7.2	4.2 - 7.1	4.3 - 7.3	4.4 - 7.3	4.4 - 7.3	4.4 - 7.4	4.4 - 7.5	4.4 - 7.4

SD: standard deviation; SWD: smallest worthwhile difference; CV: coefficient of variation; 95% CI: 95% confidence intervals for coefficient of variation; HSD: high-speed distance.

DISCUSSION

The current study quantified the between-match variation in the peak match running demands of elite football players, across moving average durations of 1-10 min, to allow the effect of contextual factors and ergogenic practices on match running performance to be explored. The primary findings demonstrate that the peak match running demands of both relative TD and AveAcc were stable across the 1-10 minute epochs, whereas the relative HSD demonstrated high levels of variability that further increased with epoch length. Importantly, these are the first data to report upon the between-match variability of the Acc demands of football match play. These findings not only provide critical context for the analysis of immediate and longitudinal peak match running demands data, but also provide context for the prescription of training loads during match-specific conditioning sessions.

The between-match variability of the relative TD peak match running demands was demonstrated to be stable across all moving average durations (CV: 6.8-7.3%). This supports past data that has quantified the between-match variability of the absolute TD covered (CV: 2.4-6.1%) across elite football, rugby and Australian football match play (Kempton, Sirotic, & Coutts, 2014; Kempton, Sullivan, Bilsborough, Cordy, & Coutts, 2015; Rampinini et al., 2007). Importantly, it is also similar to that previously reported for a 3-min window peak match running demands (CV: 6.2%) (Novak et al., 2021). However, research has shown that irrespective of contextual factors, such as environmental conditions, level of opposition or match outcome, that the TD covered across a match is largely unchanged (Lago-Peñas, 2012; Nassis, Brito, Dvorak, Chalabi, & Racinais, 2015). More specifically, the main differences in physical performance are likely better reflected in fluctuations in HSD, with the between-match variability of absolute HSD being considerably high (CV: ~16-30%) (Gregson et al., 2010). In the current study, the between-match variability of the relative HSD peak match running demands (CV: 20.6-29.6%) was similar to past data for a sole 3-min window (CV: 25.2%) (Novak et al., 2021). Further, it was also similar to that previously reported for total HSD and VHSD in football (CV: 16.2-38.9%) (Carling et al., 2016; Gregson et al., 2010). The greater variability associated with relative HSD reflects the multi-faceted nature of the collective variability (i.e., that which is introduced through measurement, sampling and biological error). Firstly, GPS devices demonstrate high variability at running speeds >14.4 $km \cdot h^{-1}$ when compared to a criterion radar system (Rampinini et al., 2015). Additionally, due to the relatively low proportion of HSD when compared to TD, small changes in the HSD between matches are reflected through larger changes in variability due to the smaller cluster size. Due to this sensitivity, the tactical strategies of the team will also provide a source of variability, with different oppositions and match play situations likely affecting the playing style of the team.

This current study is the first to assess the between-match variability of AveAcc demands in football, with the AveAcc metric stable across all moving average durations (CV: 5.4-5.8%). The amalgamation of Acc/Dec activities is a novel method in assessing the propulsive and braking requirements of match play, both of which place higher energy demands on the player (Delaney et al., 2016). Due to the relative infancy of the metric, the underlying properties associated with the variability of this metric are not yet fully understood. However, a primary factor associated with the AveAcc variability would be the inconsistencies associated with GPS technology in the quantification of Acc profiles. Despite research showing that the GPS technology possesses good inter-unit reliability for

AveAcc (CV: 3.6 ± 1.5%), this was still three times higher than the inter-unit reliability of other GPS devices (CV: 1.2 ± 1.5%) (Thornton, Nelson, et al., 2019). Despite this, in contrast to the present study, Acc parameters have been identified as the most variable physical output metric (Buchheit, Al Haddad, et al., 2014), across both halves and entire matches (Dalen et al., 2016; Ingebrigtsen et al., 2015; Varley & Aughey, 2013). However, these collective research investigations reported on the quantification of Acc counts, rather than the AveAcc quantified across discrete time points. When quantifying Acc counts, what constitutes an Acc or Dec effort can be largely affected by whether or not the "raw" or "processed" GPS data is used, as well the calculations implemented by proprietary software to clean the data (Thornton, Nelson, et al., 2019; Varley et al., 2017). Therefore, the use of an AveAcc metric may be more representative of match intensity and allow for better comparisons between data sets as well as data obtained across GPS devices.

Importantly, this study presents the most comprehensive analysis of between-match variation of peak match running demands in team sports. When comparing between studies, the present data has presented the between-match variability across ten moving average epochs, i.e., 1-10 min, rather than a singular duration (3 min) as reported upon by Novak et al. (2021). As such, the current is the first to report upon the changes in between-match variability with various window lengths for physical performance metrics. Further, the current study limited its analysis to starting players that completed at least 70 minutes of a match to limit the impact of substitution on maximum physical intensities (Fereday et al., 2020). It is acknowledged, however, that the data set was collected from a single football team and factors such as tactical formation, players' physical capacities, and opposition tactics were not directly accounted for in the present study. Further to this, a wealth of data has reported that the different playing positions possess significantly different match running demands (Di Salvo et al., 2009; Di Salvo et al., 2013; Varley & Aughey, 2013), with additional contextual factors such as time of season, environmental conditions, and time between fixtures shown to alter physical output (Carling et al., 2015; Mohr et al., 2003; Mohr et al., 2012). As such, it is important for future research to account for these factors when comprehensively measuring the between-match variation in peak matching running demands performance metrics.

With practitioners regularly using total match data in the preparation of players for competition, peak match running demands should not be overlooked. While it is acknowledged that the understanding and application of peak match running demands is evolving, dismissal of the metric as a whole is precarious. While it is argued that using peak match running demands data to inform training only prepares players for the average peak match running demands, understanding the variability of the metric can provide a more specific target range from which to prescribe drills. For example, the lower limit of the peak match running demand spectrum could be targeted on lighter days, or conditioning sessions may target the higher limit of peak match running demands (mean ± CV). This may allow for the frequent targeting of peak match running demands without compromising match-day performance. As such, an understanding of the inherent variation of the reported physical output metrics may allow for the better and replication of match demands during training across a wider range of intensities.

CONCLUSIONS

The present study provides important information on the variability of the peak match running demands that are emerging as a common tool in assessing physical match performance. The quantification of variance in the analysis of peak match running demands for these measures is imperative in providing context to the data and maximising the ecological validity and practicality of its use. Such context would allow coaches to distinguish between meaningful and non-meaningful changes in peak match running demands at both an individual and team levels, helping to directly compare between-match physical performance. It has previously been suggested that the variability of peak match running demands limits their use in informing training intensities (Novak et al., 2021). However, the between-match variability reported for peak match running demands in the present study was only slightly higher (TD: ~2-3% and HSD: ~2.5-11.5%) to that previously reported for total match demands which have historically been used in prescribing training volumes and intensities. As such, the use of peak match running demands to inform training practices is encouraged.

Chapter Four

Positional and Temporal Differences in Peak Match Running Demands of Elite Football

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ABSTRACT

Temporal changes in the total running demands of professional football competition have been well documented, with absolute running demands decreasing in the second half. However, it is unclear whether the peak match running demands demonstrate a similar decline. A total of 508 GPS files were collected from 44 players, across 68 matches of the Australian A-League. GPS files were split into the 1st and 2nd half, with the peak match running demands of each half quantified across 10 moving average durations (1-10 min) for three measures of running performance (total distance, high-speed distance [>19.8 km·h^{-1}] and average acceleration). Players were categorised based on positional groups: attacking midfielder (AM), central defender (CD), defensive midfielder (DM), striker (STR), wide defender (WD) and winger (WNG). Linear mixed models and effect sizes were used to identify differences between positional groups and halves. Peak match running demands were lower in the second half for STR across all three reported metrics (ES = 0.60-0.84), with peak average acceleration lower in the second half for DM, WD and WNG (ES = 0.60-0.70). Irrespective of match half, AM covered greater peak total distance than CD, STR, WD and WIN (ES = 0.60-2.08). Peak high-speed distances were greater across both halves for WIN than CD, DM and STR (ES = 0.78-1.61). Finally, STR demonstrated lower peak average acceleration than all positional groups across both halves (ES = 0.60-1.12). These results may help evaluate implemented strategies that attempt to mitigate reductions in second half running performance and inform position specific training practices.

INTRODUCTION

Traditionally the physical demands of professional football match play have been quantified as absolute match running volumes using either video match analysis systems or GPS (Trewin, Meylan, Varley, & Cronin, 2017; Vieira et al., 2019). As such, the physical demands of football and the intra- and inter-match differences in physical match demands (total distance, high-speed distance [>19.8 km•h^{-1}] and acceleration profiles) have become routinely reported (Bradley & Noakes, 2013; Trewin et al., 2017; Varley & Aughey, 2013). Separately, research has explored the effects of acute reductions in physical performance during match play, as represented by temporal changes in physical demands throughout a match (Bradley & Noakes, 2013). Recent methods have quantified changes in physical outputs across discrete periods of match play, such as between halves or distinct 15 min periods within halves e.g., 0-15 min, 15-30 min (Bradley et al., 2010; Carling, 2013; Di Salvo et al., 2009). Collectively, this research has demonstrated that physical output is reduced during the second half , with the greatest reduction occurring in the final 15 minutes of the match (Rampinini et al., 2011). Interestingly, this reduction during the final stages of a match coincides with a reported increase in goal scoring opportunities (Armatas, Yiannakos, & Sileloglou, 2007; Faude et al., 2012; Little & Williams, 2005; Njororai, 2014). Consequently, the ability to perform at higher intensities for shorter periods when fatigued appears crucial to creating or denying goal scoring opportunities (Faude et al., 2012; Little & Williams, 2005). As such, understanding the match demands and how these fluctuate throughout a match can help inform training practices to prepare players for competition.

Quantifying the physical demands of match play provide context for training prescription and preparing players for competition. Recent methods have explored the most physically demanding periods of match play through quantifying the peak match running demands for a range of short epochs rather than absolute running volumes for arbitrary epochs (Delaney, Thornton, et al., 2018; Fereday et al., 2020; Hills et al., 2020) (see Chapter 3). These peak match running demands are calculated using a moving average duration, where the highest observed physical output for selected metrics are calculated at incremental discrete time periods (e.g. 1-10 min), irrespective of match time (Delaney, Thornton, et al., 2018). Through calculating the peak match running demands, the most physically demanding periods of a match can be identified and replicated through training and conditioning drills. For example, the peak distance covered over 5 minutes during a match could be used to inform a training drill of 5 minutes in duration. Importantly, the use of a rolling average (e.g. 0-1, 0.1-1.1, 1.2-2.2 min) has been shown to be more accurate than assessing peak match running demands using predefined 1 minute periods (e.g. 0-1, 1-2, 2-3 min), with the predefined periods underestimating peak match running demands by ~7-25% (Fereday et al., 2020). Such variance between analysis techniques reflects that the peak match running demands often traverse multiple predefined periods, meaning that performance staff may interpret match demands and prescribe training below match intensities (Delaney, Thornton, Burgess, Dascombe, & Duthie, 2017; Varley, Elias, et al., 2012).

With football being stochastic in nature and players frequently performing at near maximal intensities, the mechanisms underlying acute changes to physical performance are multi-factorial and require a holistic approach to quantify (Mohr, Krustrup, & Bangsbo, 2005; Riboli, Esposito, & Coratella, 2021). As such, monitoring physical performance data may not only be used to inform training practices, but also to help assess both individual and team physical performance and acute change to physical demands during match play (Rampinini et al., 2011). One such important consideration for assessing physical match demands is a players position, with position related differences observed for both total match outputs (Mallo et al., 2015) and peak match running demands (Delaney, Thornton, et al., 2018). Additionally, the available research strongly demonstrates that physical output declines between halves in football, with the magnitude of reductions being impacted by multiple factors including fatigue, the use of pacing strategies or differing match situations (Bradley & Noakes, 2013; Di Salvo et al., 2009; Mohr et al., 2003). However, there is limited research on changes in peak match running demands between halves, with only two papers reporting such differences (Casamichana et al., 2019; Oliva-Lozano, Rojas-Valverde, et al., 2020). When all positional groups were pooled, reductions in peak TD across the analysed time periods of 1, 3, 5 and 10 min were observed, with HSD (>19.8 km$\cdot$h^{-1}) and VHSD (>25 km$\cdot$h^{-1}) being maintained between halves (Oliva-Lozano, Rojas-Valverde, et al., 2020). Similarly, when accounting for positional groups, Casamichana et al. (2019) reported moderate reductions in peak TD covered during the second half for CD across 3, 5 and 10 min window durations, with WD and WIN also having moderate reductions for the 10 min duration. Further, minimal differences were observed between halves for HMLD, with average metabolic power (AMP) found to be reduced for all positional groups in the second half (Casamichana et al., 2019).

While position-related differences have been observed for both total match physical outputs (Mallo et al., 2015) and peak match running demands (Delaney, Thornton, et al., 2018), further assessment of between half differences by positional group is warranted. Of the single study that reported on the between half positional differences in peak match running demands (Casamichana et al., 2019), their analysis was constrained to limited windows (1, 3, 5 and 10 min) and reported on TD, HMLD and AMP. Furthermore, despite pooled positional data available in the literature (Oliva-Lozano, Rojas-Valverde, et al., 2020), the between-half positional differences for peak match running demands of HSD and AveAcc are yet to be reported on. As such, this study aimed to report on the within- and between-halves and positional groups differences in peak match running demands across a range of durations (1-10 min) for commonly assessed metrics to help progress match performance analysis and better inform training prescription.

METHODS

An observational design was used to compare the positional differences in peak match running demands across incremental moving average between 1-10 minutes, between halves in elite football players. Data were collected from 44 professional footballers playing in the same team competing within the AL. Data were collected across three seasons of competitive AL matches, consisting of 68 matches, for a total of 508 individual match observations (13 ± 10 matches per player, range 1-43). With majority of peak match running demands occurring prior to the 70th minute (as per Study 3), data were only included if players participated in more than 70 minutes of a match. These observations were representative of the entire playing group, with match files categorised according to position, as Attacking Midfielder (AM; *n* = 6, files = 68), Central Defender (CD; *n* = 10, files = 118), Defensive Midfielder (DM; *n* = 6, files = 91), Striker (STR; *n* = 4, files = 46), Wide Defender (WD; *n* = 9, files = 105) and Winger (WNG; *n* = 9, files = 80); where the team in question typically used a 4-2-1-3 formation. Prior to collection of data, ethical approval was attained from La Trobe University (HREC#: 18056).

Activity Profile

Player activity profiles were recorded during the entirety of match play using 18 Hz (10 Hz GNSS [Global Navigation Satellite System]) portable GPS units (STATSports, Northern Ireland) that were placed between the scapulae in a custom-made harness under the playing jersey. All GPS devices were turned on 30 min prior to match commencement to allow for satellite acquisition. The GPS units employed are valid and reliable in measuring locomotor speeds of team sport athletes (Beato et al., 2018; Beato & de Keijzer, 2019). Following each match, GPS files were downloaded using proprietary software (STATSports, Northern Ireland) with the raw GPS files (inclusive of added time) were exported into statistical software (R Studio, v1.2.5033) for further analysis. The raw exported speed trace was filtered using a 4th order one-way Butterworth filter with a cut-off frequency of 1 Hz. Individual data points, in which running speeds exceeded 10 $m \cdot s^{-1}$ and Acc/Dec values that exceeded 6 $m \cdot s^{-2}$ were classified as technical errors and replaced with zero values.

From the GPS data, three commonly assessed measures of running intensity were chosen for assessment TD, HSD (>19.8 $km \cdot h^{-1}$) and AveAcc, with both TD and HSD made relative to playing time ($m \cdot min^{-1}$). Average acceleration was calculated through the summation of all absolute (Acc/Dec) speeds which were then averaged over a defined time duration (AveAcc) to provide an indication of the total acceleration requirements of match play (Delaney et al., 2016). Although the consolidation of both Acc/Dec into one variable may conceal the underlying mechanisms responsible for the load, it has been suggested that assessing both variables together will better reflect the intensity of the activity (Delaney et al., 2017). To quantify peak match running demands, a moving average technique was applied to all three of the match output variables for ten incremental time epochs (i.e. 1-10 min), with the maximum value from each epoch recorded and then fitted using a power law curve (Delaney, Thornton, et al., 2018; Katz & Katz, 1994).

Statistical Analysis

Statistical analyses were conducted using R Studio statistical programming software (v1.2.5033, R Core Development Team, Vienna) using the *nlme* (Pinheiro, Bates, DebRoy, Sarkar, & Team, 2015) and *lme4* (Bates et al., 2015) packages to conduct linear and non-linear mixed effects analysis. Non-linear mixed models were used to calculate exponent and slope values for the power law model, with differences in peak match running demands of TD, HSD and AveAcc profiles between positions and halves assessed using linear mixed models. In the linear mixed model, fixed effects were included for intensity period, position [six levels: AM, CD, DM, STR, WD and WIN] and match halves (two levels: first half and second half). A random intercept was included for player and an exponential correlation structure, with a nugget effect, to account for temporal correlation between intensity periods. Linear mixed models were also used to assess between position and half measures of absolute TD, HSD and AveAcc, with a fixed effect included for match half (two levels: first half and second half). Raw unit differences between positional groups and halves, at each intensity period or half, were converted to standardised mean differences (SMD) by dividing the mean, raw unit difference by the within-subject SD attained from the random effects (i.e., the square root of the residual variance term). The magnitude of the SMD was quantified using the following qualitative descriptors: trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), very large (2.0-4.0) and extremely large (>4.0) (Hopkins, Marshall, Batterham, & Hanin, 2009). A worthwhile difference was determined as a moderate ES (>0.6), with the imprecision of model regression parameter estimates are expressed using 95% CI.

RESULTS

Absolute measures of total match physical output are presented in Table 4.1, with AM displaying higher absolute and relative TD than CD, WD and STR during the match (ES = 1.63-2.04). Further, WIN performed greater absolute HSD than all other positional groups, except AM (ES = 1.56-2.7). No positional differences were observed for AveAcc across the match. The non-linear relationships of the peak match running demands power law models presented in Table 4.2, with differences between positional groups and halves presented in Figures 4.1-4.3. Attacking midfielders covered more relative TD than all other positional groups across the majority of epochs in the first half (ES = 0.62-1.63). Additionally, AM also had greater TD peak match running demands than all other positional groups except for DM for most epochs in the second half (ES = 0.70-2.08). Further, AM, WD and WIN had greater HSD peak match running demands than CD and DM across first half epochs (ES = 0.61-1.61), with CD, DM and STR all lower than AM, WD and WIN in the second half (ES = 0.60-1.61). Peak match running demands for AveAcc were similar in both halves amongst all positional groups, except for STR which were lower than all positional groups, except for CD in the first (ES = 0.63-1.02) and second (ES = 0.63-1.12) halves. Differences between halves for each positional group at each intensity period are presented in Figures 4.4-4.6. Minimal differences were observed between halves for relative TD and HSD, with the peak relative TD covered by STR reduced in the second half at the 4-10 min windows (ES = 0.60-0.89), and similarly for HSD for the 7-10 min windows (ES = 0.62-0.68). However, several differences were observed for AveAcc, with STR and WD having lower peak AveAcc demands for all peak match running demand periods in the second half (ES = 0.62-0.84), with similar observations made for DM at the 2-10 min windows (ES = 0.61-0.81).

Table 4.1. Absolute and relative match outputs. Data presented as mean ± SD. Data in brackets indicate relative distances covered (m·min^{-1}).

Variable		Attacking Midfielder	Central Defender	Defensive Midfielder	Striker	Wide Defender	Winger
Match Duration (min)	1st Half	47 ± 1	47 ± 1	47 ± 1	47 ± 1	47 ± 1	47 ± 1
	2nd Half	50 ± 1	50 ± 2	50 ± 2	49 ± 2	50 ± 2	50 ± 2
	Match	97 ± 2	97 ± 2	97 ± 2	96 ± 2	97 ± 2	97 ± 2
Total Distance (m)	1st Half	5,645 ± 362^{be} (119 ± 10)^{be}	5,070 ± 469 (107 ± 10)^{1}	5,261 ± 623 (111 ± 13)^{1}	4,742 ± 376 (101 ± 8)^{1}	5,036 ± 410 (106 ± 9)	5,396 ± 549 (114 ± 11)^{1}
	2nd Half	5,624 ± 543^{bde} (114 ± 12)^{bde}	5,078 ± 457 (102 ± 10)	5,308 ± 376 (106 ± 8)	4,627 ± 412 (94 ± 8)	5,087 ± 471 (103 ± 10)	5,362 ± 720 (107 ± 14)
	Match	11,269 ± 689^{bde} (116 ± 8)^{be}	10,149 ± 835 (104 ± 9)	10,569 ± 863 (109 ± 9)	9,369 ± 723 (97 ± 7)	10,123 ± 764 (105 ± 8)	10,758 ± 1142 (110 ± 11)
High-speed Distance (m)	1st Half	354 ± 102^{b} (7 ± 2)	248 ± 101 (5 ± 2)	255 ± 106 (5 ± 2)	270 ± 68 (6 ± 1)	337 ± 124 (7 ± 3)	450 ± 135^{bcde} (9 ± 3)
	2nd Half	347 ± 113 (7 ± 2)	267 ± 118 (5 ± 2)	253 ± 91 (5 ± 2)	254 ± 87 (5 ± 2)	349 ± 127 (7 ± 3)	449 ± 148^{bcde} (9 ± 3)
	Match	701 ± 171^{b} (7 ± 2)	515 ± 195 (5 ± 2)	508 ± 169 (5 ± 2)	524 ± 110 (5 ± 1)	687 ± 222 (7 ± 2)	899 ± 259^{bcde} (9 ± 3)
Average Acceleration (m·s^{-2})	1st Half	0.63 ± 0.06	0.61 ± 0.05	0.65 ± 0.05	0.57 ± 0.02	0.62 ± 0.05	0.64 ± 0.06
	2nd Half	0.59 ± 0.07	0.57 ± 0.07	0.61 ± 0.04	0.53 ± 0.04	0.59 ± 0.06	0.60 ± 0.07
	Match	0.61 ± 0.06	0.59 ± 0.05	0.63 ± 0.04	0.55 ± 0.03	0.60 ± 0.05	0.62 ± 0.06

Differences indicated if standardised mean difference is greater than 0.6. a = greater than AM, b = greater than CD, c = greater than DM, d = greater than STR, e = greater than WD, f = greater than WIN. 1 = greater than second half.

Table 4.2. Non-linear relationships of power law models from the peak match running demands analysis. Data presented as mean ± 90% CI.

	Variable		Attacking Midfielder	Central Defender	Defensive Midfielder	Striker	Wide Defender	Winger
Relative Distance ($m \cdot min^{-1}$)	Intercept	1st Half	199 (188 - 211)	180 (159 - 205)	187 (163 - 214)	182 (157 - 211)	188 (165 - 215)	189 (166 - 216)
		2nd Half	190 (176 - 205)	178 (150 - 210)	185 (155 - 221)	177 (146 - 214)	186 (156 - 221)	188 (158 - 223)
	Slope	1st Half	-0.17 (-0.18 - -0.16)	-0.17 (-0.19 - -0.15)	-0.16 (-0.18 - -0.14)	-0.18 (-0.20 - -0.17)	-0.18 (-0.20 - -0.17)	-0.18 (-0.19 - -0.16)
		2nd Half	-0.16 (-0.19 - -0.14)	-0.18 (-0.23 - -0.13)	-0.17 (-0.22 - -0.12)	-0.20 (-0.25 - -0.14)	-0.19 (-0.24 - -0.14)	-0.19 (-0.24 - -0.14)
Relative High-speed Distance ($m \cdot min^{-1}$)	Intercept	1st Half	53 (44 - 63)	42 (28 - 63)	42 (27 - 65)	45 (28 - 72)	51 (33 - 78)	59 (39 - 90)
		2nd Half	48 (37 - 62)	43 (24 - 76)	41 (23 - 75)	41 (21 - 79)	50 (28 - 91)	58 (32 - 104)
	Slope	1st Half	-0.63 (-0.66 - -0.60)	-0.68 (-0.75 - -0.61)	-0.66 (-0.73 - -0.59)	-0.63 (-0.70 - -0.55)	-0.60 (-0.67 - -0.53)	-0.59 (-0.66 - -0.52)
		2nd Half	-0.60 (-0.69 - -0.52)	-0.64 (-0.84 - -0.45)	-0.63 (-0.83 - -0.43)	-0.68 (-0.89 - -0.47)	-0.59 (-0.79 - -0.40)	-0.61 (-0.81 - -0.41)
Average Acceleration ($m \cdot s^{-2}$)	Intercept	1st Half	1.05 (1.00 - 1.10)	1.02 (0.92 - 1.13)	1.06 (0.95 - 1.18)	1.01 (0.89 - 1.14)	1.07 (0.96 - 1.19)	1.05 (0.94 - 1.17)
		2nd Half	1.01 (0.95 - 1.08)	0.97 (0.83 - 1.13)	1.02 (0.87 - 1.19)	0.94 (0.79 - 1.12)	1.01 (0.86 - 1.17)	1.03 (0.88 - 1.20)
	Slope	1st Half	-0.18 (-0.18 - -0.17)	-0.17 (-0.19 - -0.15)	-0.17 (-0.19 - -0.15)	-0.19 (-0.21 - -0.17)	-0.18 (-0.20 - -0.16)	-0.17 (-0.19 - -0.15)
		2nd Half	-0.18 (-0.20 - -0.15)	-0.17 (-0.23 - -0.12)	-0.19 (-0.24 - -0.13)	-0.19 (-0.25 - -0.13)	-0.18 (-0.24 - -0.13)	-0.19 (-0.25 - -0.13)

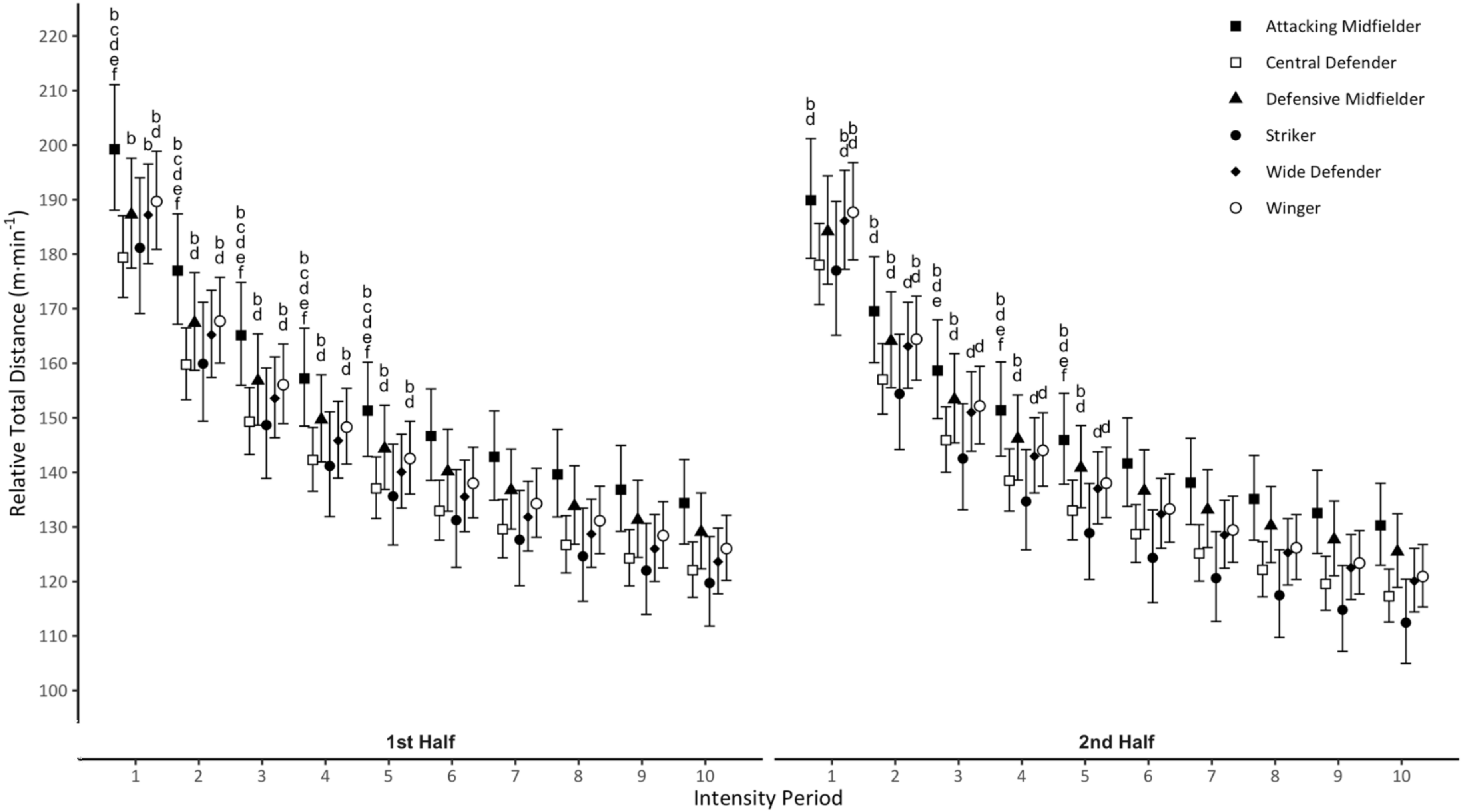

Figure 4.1. A positional comparison of peak match running demands of relative total distance across each match half. Differences indicated if standardised mean difference is greater than 0.6. a = greater than Attacking Midfielder, b = greater than Central Defender, c = greater than Defensive Midfielder, d = greater than Striker, e = greater than Wide Defender, f = greater than Winger.

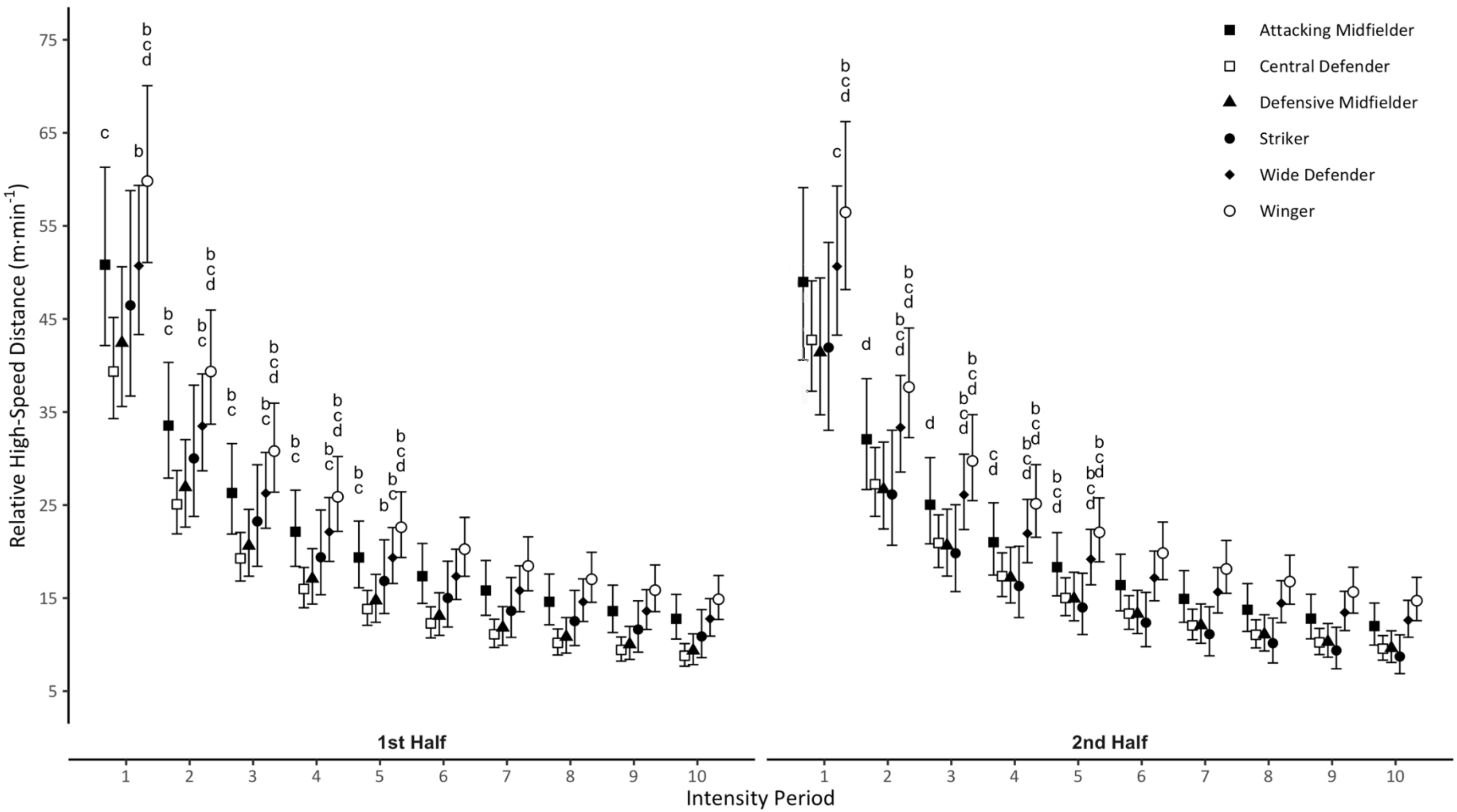

Figure 4.2. A positional comparison of peak match running demands of relative high-speed distance across each match half. Differences indicated if standardised mean difference is greater than 0.6. a = greater than Attacking Midfielder, b = greater than Central Defender, c = greater than Defensive Midfielder, d = greater than Striker, e = greater than Wide Defender, f = greater than Winger.

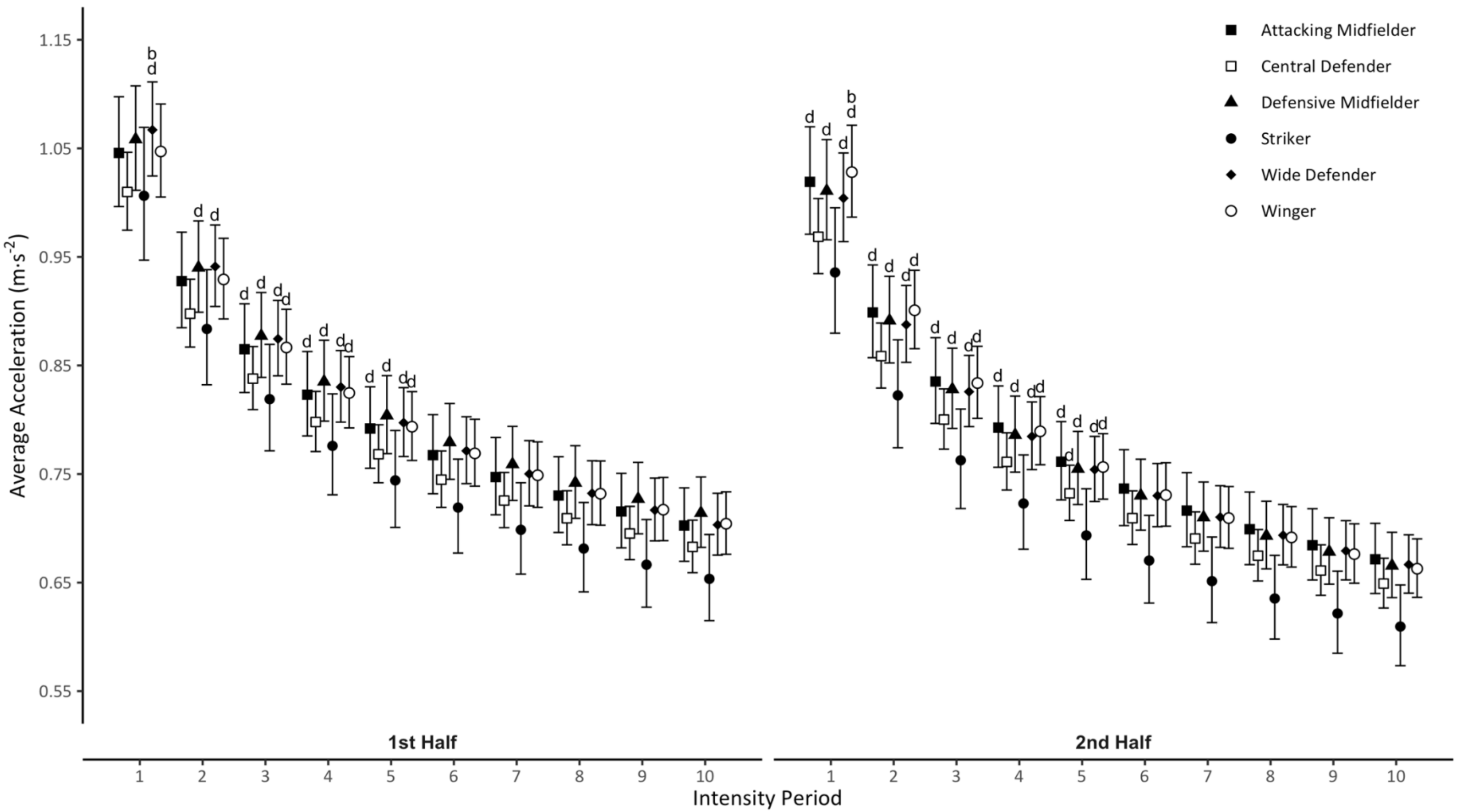

Figure 4.3. A positional comparison of peak match running demands of average acceleration across each match half. Differences indicated if standardised mean difference is greater than 0.6. a = greater than Attacking Midfielder, b = greater than Central Defender, c = greater than Defensive Midfielder, d = greater than Striker, e = greater than Wide Defender, f = greater than Winger.

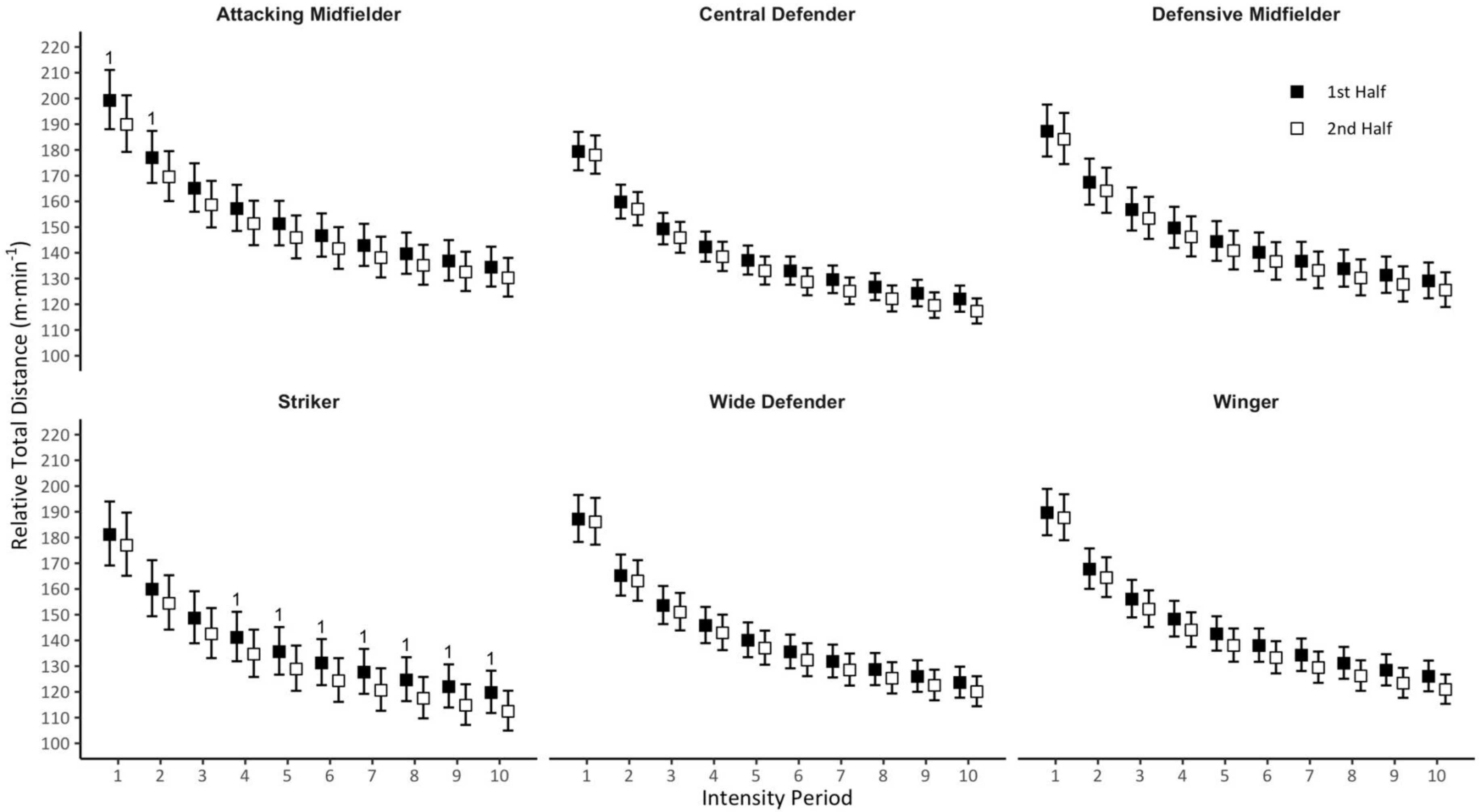

Figure 4.4. A comparison of peak match running demands of relative total distance between halves for each positional group. Differences indicated if standardised mean difference is greater than 0.6. 1 = greater than second half.

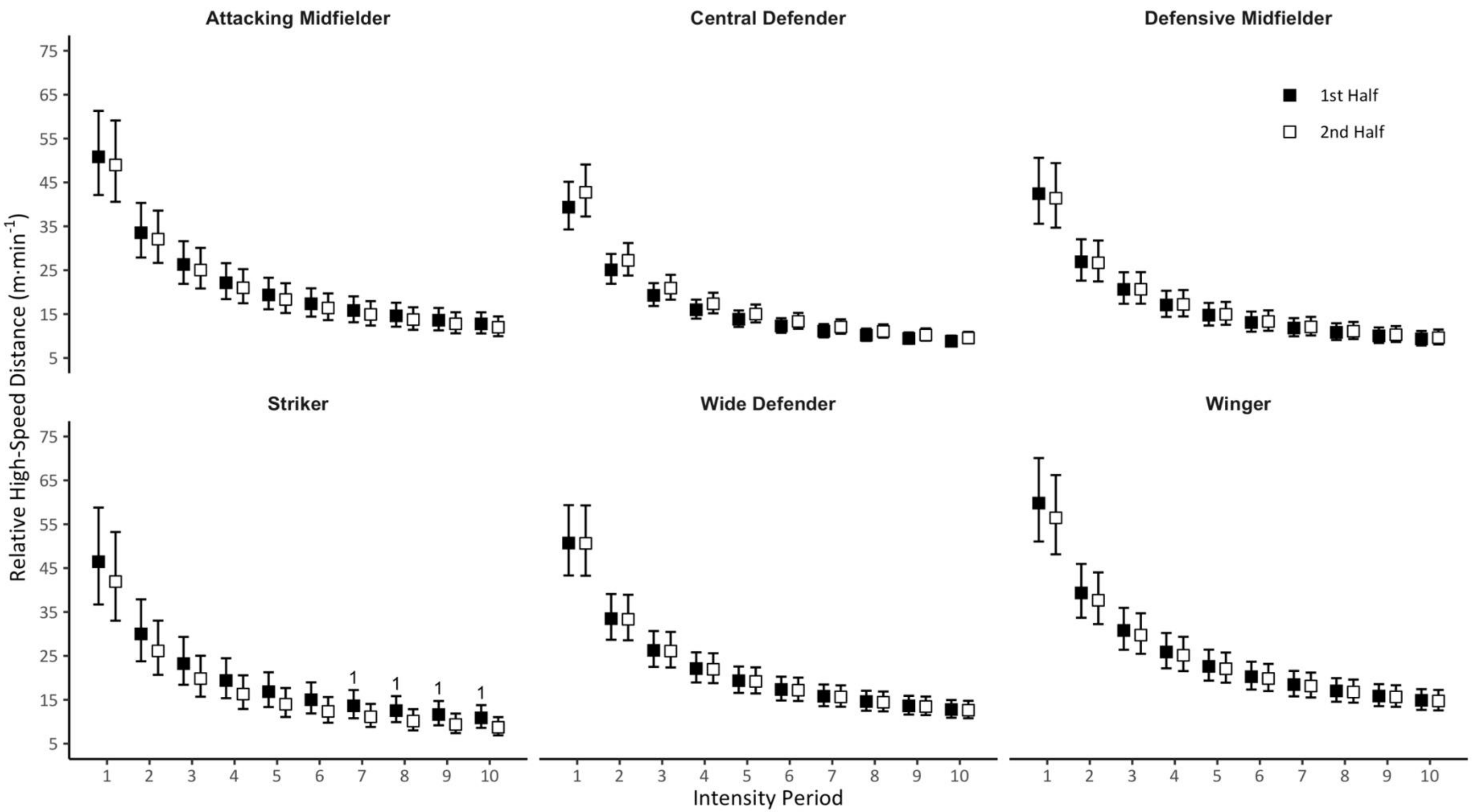

Figure 4.5. A comparison of peak match running demands of relative high-speed distance between halves for each positional group. Differences indicated if standardised mean difference is greater than 0.6. 1 = greater than second half.

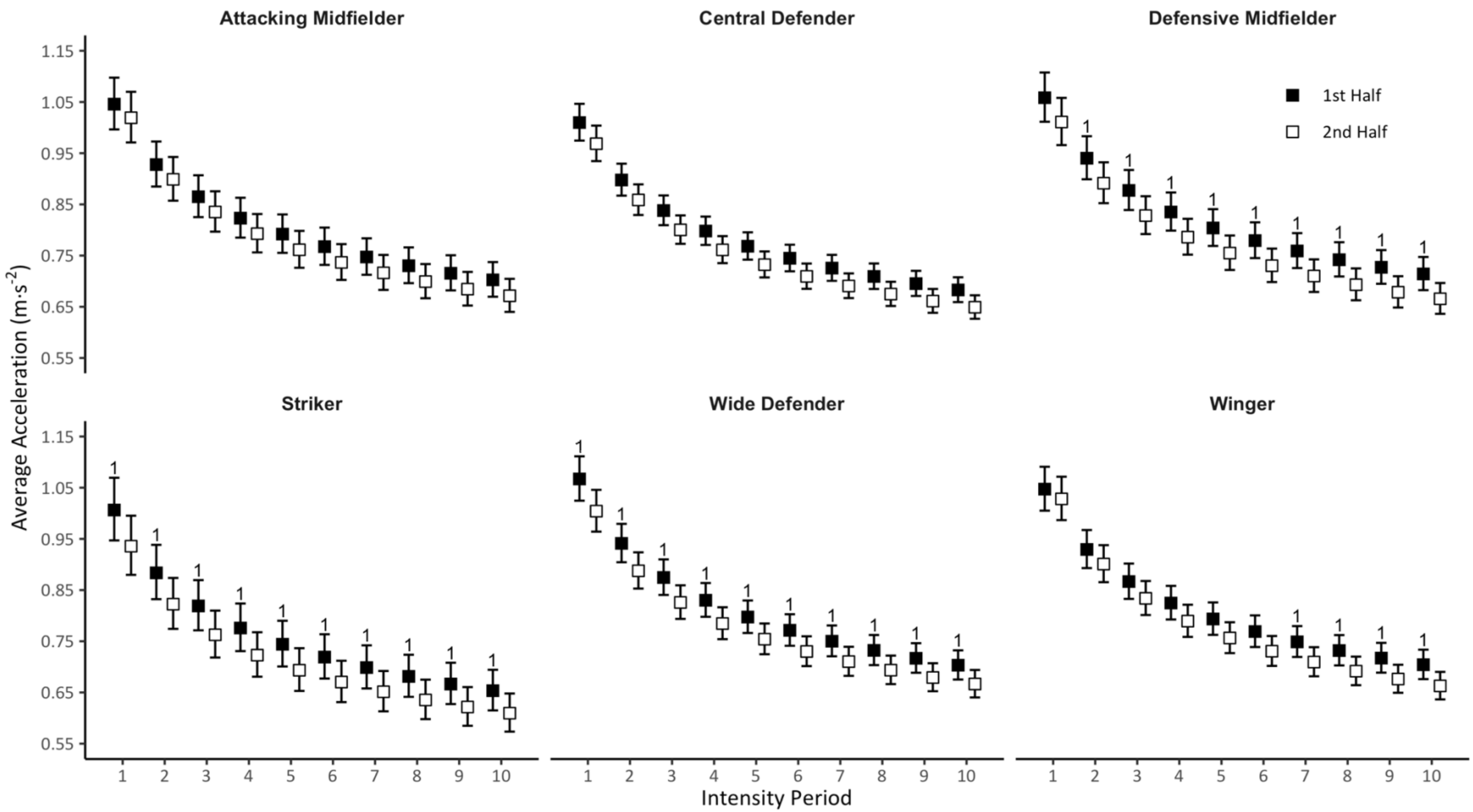

Figure 4.6. A comparison of peak match running demands of average acceleration between halves for each positional group. Differences indicated if standardised mean difference is greater than 0.6. 1 = greater than second half.

DISCUSSION

The current study quantified the within- and between-halves and positional groups differences in peak match running demands for commonly assessed physical performance metrics. To provide further context, absolute measures of physical performance were also assessed. Both the absolute total and high-speed running demands were maintained between halves; however, the second half was on average ~3 min longer, reducing the relative distance covered for CD, DM, STR and WIN (~5-7 m·min^{-1}). Conversely, the peak match running demands of TD and HSD were similar between halves across all positional groups. Interestingly, while the total AveAcc was similar between halves for all positions, the peak AveAcc demands were reduced for DM, STR and WD in the second half. Taken together, the results demonstrate that the total and peak match running demands of TD and HSD differ between positions but are maintained between halves. Separately, the peak AveAcc differed between positions and declined in the second half for some positions, providing direction for the prescription of training drills in conditioning for the high-energy demanding (Acc/Dec) actions.

While the quantification of match running volumes describes the global demands of match play, it offers limited information to help guide conditioning and training drill prescription (Chapter 3). The current peak match running demands ranged between 112-199 m·min^{-1} for relative TD and 8-59 m·min^{-1} for relative HSD, depending on position and epoch duration. These data are similar to those previously reported in the AL (TD: ~115-205 m·min^{-1}, HSD: ~10-65 m·min^{-1}) (Delaney, Thornton, et al., 2018) and English Championship (TD: ~115-197 m·min^{-1} HSD: ~13-61 m·min^{-1}) (Fereday et al., 2020). However, the AveAcc in the present study was considerably higher than that previously reported for the AL (0.60-1.07 m·s^{-2} vs 0.52-0.90 m·s^{-2}) (Delaney, Thornton, et al., 2018). Additional studies have assessed AveAcc in youth football players, however, differences in data filtering processes mean the data are not able to be directly compared (Duthie et al., 2018). As such, establishing a standardised methodology for assessing the AveAcc demands of match play is warranted in future research.

The data demonstrated that AM have the greatest peak match running demands for relative TD covered, with CD and STR having the lowest. This is similar to previous data from the AL that identified CD as having the lowest peak match running demands (Delaney, Thornton, et al., 2018), with MID having the highest and ATT having the lowest peak match running demands (Duthie et al., 2018; Fereday et al., 2020). Conflicting findings have been also reported on the peak relative HSD running demands, with the current study reporting that WD, WIN and AM have the greatest peak match high-speed running demands, whereas past data had reported that STR and WIN had the greatest demands (Delaney, Thornton, et al., 2018) or that there were no positional differences (Fereday et al., 2020). Lastly, there is limited comparable data on the peak AveAcc demands, with previous research reporting that positional groups were similar, except for WD which had the greatest peak match running demands of AveAcc (Delaney, Thornton, et al., 2018). The current data presented similar findings, with the exception for STR, which demonstrated the lowest AveAcc demands of all positions. It is likely that the lack of consensus amongst literature around which positional group has the greatest peak match running demands for HSD and AveAcc is due to the differing demands associated with different playing formations or team tactics (Bradley et al., 2011; Riboli, Semeria, et al., 2021). While this data in the present study may not be reflective of all teams and competitions, it provides rationale for evaluating peak match running demands of competition relative to positional group.

Positional discrepancies in match running demands may reflect several contextual factors related to the performance of high-intensity efforts, which impact on a player's peak match running demands (Chapter 3). High-intensity efforts are closely linked to critical parts of a match, such as scoring or defending goals (Faude et al., 2012; Little & Williams, 2005), and with more goal scoring opportunities in the second half, (Armatas et al., 2007; Njororai, 2014)**,** there are likely more instances where high-intensity efforts are performed to impact upon the match result. As such, while absolute running demands of relative TD are lower, absolute and peak match running demands of HSD are maintained. Furthermore, ball in play time is lower in the second half (Carling & Dupont, 2011) due to the more frequent game interruptions, and as a result the time spent in lower locomotor speed categories increases (Linke et al., 2018). Such a trend would result in a reduction in total physical output, but not impact on the peak match running demands. In comparison, any declines in peak AveAcc demands were position dependent, with AM, CD and WIN maintaining peak match running between halves, with DM, STR and WD declining. Past data has shown that the number of Acc/Dec performed in the second half reduces, with match related fatigue suggested as a contributing factor (Akenhead et al., 2013; Russell et al., 2016). While other factors such as self-imposed pacing strategies (Bradley & Noakes, 2013), or changes to team tactics (Weston et al., 2011) may also contribute. However, the collective data demonstrate that the peak AveAcc match demands are reduced in the second half for some positional groups.

While data is constrained by the limitation that it was only collected from a single professional football team, the assessment of positional peak match running demands is warranted to identify differences within a match, across all three assessed metrics. Hence, the application of such data should be to replicate these demands during training through the designing and implementation of position specific training drills. The methods presented by Delaney, Thornton, et al. (2018) provide scope as to how to mathematically estimate peak match running demands for a given duration using the data presented in Table 4.2. Exposure of players to peak match running demands in the initial phases of training will largely replicate the most difficult physical intensities of match play, with peak match running demands typically greater in the first half. Conversely, structuring a training session to include match simulation drills at the end of a session may help develop the ability of players to perform at higher intensities during key tactical moments in the latter stages of a match. Further, while the underlying mechanistic properties behind differences in running performance between halves are multi-faceted, the understanding that reductions occur may help coaches evaluate implemented strategies aimed at mitigating said differences. Additionally, while not quantified in the present study, the technical and tactical demands of drills replicating match demands drills should also be considered, with drill dimensions, player numbers and drill constraints considerably impacting on both the technical and tactical demands, as well as physical demands (Riboli et al., 2020). Additionally, while peak match running demands differed between halves for some positional groups, it is clear that players are regularly required to perform at or near peak match running demands frequently across a match (Riboli, Esposito, et al., 2021). Hence, frequent performance at or near peak match running demands are suggested within training sessions (Chapter 3). It is however important to note that peak physiological demands were unable to be quantified in the current study, with it possible that there may be a dissociation between peak physical and physiological demands, which would be useful for greater granularity when prescribing conditioning drills. Additionally, while not quantified in the current study, the variability of peak match running demands have previously been reported on, with the inherent variability of the measures worth considering (Chapter 3).

CONCLUSIONS

Peak match running demands have emerged as a detailed method of assessing physical match performance that can aid in the design and prescription of training stimuli. As such, providing context surrounding the acute changes in peak match running demands is crucial in preparing players for competition. Overall, the between half changes to peak match running demands are position dependent, indicating that the assessment of acute changes in peak match running demands should be assessed on a positional basis, as opposed to a team basis. Further, with past data demonstrating that peak match running demands occur at various stages throughout a match (Oliva-Lozano, Martínez-Puertas, et al., 2021)**,** the timing of player exposure to these demands during training should be considered in developing training practices. Overall, the present study provides a framework in which to gauge the physical between half match performance of elite soccer players, in relation to peak match running demands.

Chapter Five

Peak Match Acceleration Demands Differentiate Between Elite Youth and Professional Football Players

As per the peer-reviewed paper **Under Review** with **PLOS One**

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ABSTRACT

Youth footballers need to develop in order to meet the technical, tactical, and physical demands of professional level competitions, ensuring that the transition between competition levels is successful. To quantify the physical demands, peak match running demand have been determined across football competition tiers, with team formations and tactical approaches influencing these physical demands. To date, no research has directly compared the physical demands of elite youth and professional footballers from a single club utilising common formations and tactical approaches. The current study quantified the total match and peak match running demands of youth and professional footballers from a single Australian A-League club. GPS data were collected across a single season from a professional (n=19; total observations=199; mean ± SD; 26.7 ± 4.0 years) and elite youth (n=21; total observations=59; 17.9 ± 1.3 years) team. Total match demands and peak match running demands (1-10 min) were quantified for measures of total distance, high-speed distance [>19.8 km•h^{-1}] and average acceleration. Linear mixed models and effect sizes identified differences between competitions. No differences existed between competition levels for any total match physical performance metric. Peak total distance and high-speed distance demands were similar between competitions for all moving average durations. Interestingly, peak average acceleration demands were lower (SMD = 0.63-0.69) in the youth players across all moving average durations. The data suggests that the development of acceleration and repeat effort capacities is crucial in youth players for them to transition into professional competition.

INTRODUCTION

Football academy systems are an important component of elite football organisations, with their primary aim being to develop youth players for promotion into professional squads (Williams & Reilly, 2000). To foster youth player development, longitudinal training plans are implemented to prepare youth players for the physical, technical and tactical demands of professional football (Morgans et al., 2014). The two primary methods that successful youth development can be achieved is through either participation in high-level competitive matches, or exposure to training sessions that replicate the demands of the competitive match play (Olthof, Frencken, & Lemmink, 2019). As such, there is a strong need to understand the physical demands of match play (Chapters 3 and 4) to proactively prescribe training stimuli that prepare players for the physical demands of competition (Delaney, Thornton, et al., 2018).

Professional football players cover a TD of between 9-13 km across a match, of which between 600-1200 m is covered as HSD (>19.8 km·h^{-1}) with players performing between 60-100 Acc (>2.0 m•s^{-2}) efforts (Bradley et al., 2011; Bradley et al., 2010; Dalen et al., 2016). Similarly, elite youth players cover a TD of between 9-12 km, of which 300-1100 m is completed at high-speeds (Lord et al., 2020; Romagnoli et al., 2016; Sporis et al., 2017; Vieira et al., 2019; Vigh-Larsen et al., 2018). While HSD volume has been shown to distinguish between top- and moderate-class professional football players (based on FIFA rankings) (Mohr et al., 2003), other researchers have reported similar HSD between youth and professional footballers (Vigh-Larsen et al., 2018). However, a recent review has highlighted inconsistencies in the speed thresholds used to quantify HSD covered in youth competitions (Vieira et al., 2019), which limits the direct comparisons to professional competition data. Further, a direct comparison of the Acc profiles of youth and professional players at a single professional Danish club demonstrated that U19 players performed more Acc efforts than both the U17 and open-age professional cohorts (Vigh-Larsen et al., 2018). While total match demands appear similar between youth and professional footballers, it is possible that peak match running demands may differ (Delaney, Thornton, et al., 2018; Varley et al., 2014) (Chapters 3 and 4). As such, research is warranted to explore differences in the peak physical match demands between youth and professional football players. Such information could be used to inform training prescription in programs that aim to develop youth football players into professional players.

With individual training drill durations typically being significantly shorter than match durations (typically 1-10 min in length vs 90 min), quantifying the most physically demanding passages of a match over similar shorter durations ensures that the training stimulus is relevant to the match demands (Chapters 3 and 4) (Delaney, Thornton, et al., 2018). Recently, such peak match running demands have been quantified through the application of a moving average for each physical output metric for pre-determined durations (e.g. 1-10 min), from which the maximum recorded value is then extracted (Delaney, Thornton, et al., 2018). Depending on window length, the peak physical demands have been reported for relative TD (115-205 $m \cdot min^{-1}$), relative HSD (10-65 $m \cdot min^{-1}$) and peak AveAcc (0.52-0.90 $m \cdot s^{-2}$) across professional football competitions based in Australia and England (Delaney, Thornton, et al., 2018; Fereday et al., 2020). Such peak physical outputs are far higher than the reported 90 min averages reported in professional competition (TD ~104 $m \cdot min^{-1}$, HSD ~6.5 $m \cdot min^{-1}$) (Varley et al., 2014). Hence, the use of full match data to inform training practices will provide an insufficient stimulus to prepare players for the peak physical demands of competition.

Within youth academy systems, the application of peak match running data from professional teams offers value in transitioning players into professional competitions. For example, a five-minute football specific conditioning drill prescribed to youth players can be adapted to replicate the most physically demanding five min of a professional competition match (Chapters 3 and 4). Additionally, as youth level competitions often accommodate a quota of overage players, (i.e. as a match opportunity for injured professional players returning to full fitness), such youth competitions can be used as a progression toward professional competition. However, there is limited research that has reported on the peak match running demands of youth footballers (Doncaster et al., 2020; Duthie et al., 2018; Martín-García et al., 2018). From the available data, the peak match TD and HSD running demands of English U23 development league players (Doncaster et al., 2020) appear similar to professional English Championship footballers (Fereday et al., 2020). Conversely, both the elite Italian (U15-U17) (Duthie et al., 2018) and Spanish youth (U20) (Martín-García et al., 2018) have demonstrated lower peak match running demands of TD and HSD than players in the professional Italian and Spanish competitions, respectively (Casamichana et al., 2019; Riboli, Semeria, et al., 2021). However, such comparisons are limited as they do not share a collective philosophy around team formation and tactical approaches. Importantly, past research has observed that peak match running demands differ with team formations and tactical approaches (Bradley et al., 2011; Calder & Gabbett, 2022; Fereday et al., 2020; Riboli, Semeria, et al., 2021), and therefore controlling these factors is crucial in exploring competition differences in peak physical outputs. Therefore, the current study aimed to quantify and compare the peak match running demands (TD, HSD and AveAcc) of elite youth and professional footballers within a single club that employed consistent team formations and tactical approaches.

METHODS

An observational design was employed to compare competition differences in peak match running demands across incremental moving average durations of 1-10 minutes in elite youth and professional football players. Data were collected from 21 elite youth (17.9 ± 1.3 yr, 16.1-20.4 yr) and 19 professional (mean ± SD, range; age: 26.7 ± 4.0 yr, 20.1-32.0 yr) footballers playing for the same professional club in Australia for every available match across one competitive season of fixtures (number of matches: youth = 8, professional = 23). This equated to a total of 59 and 199 individual match observations for the youth and professional competitions, respectively (professional = 10 ± 7 matches per player, range 1-21; youth = 3 ± 2, 1-7). Goalkeepers were excluded from the analysis. Further, only players who played for more than 70 minutes were included in the data analysis due to majority of peak match running demands occurring prior to the 70th minute of match play (Oliva-Lozano, Martínez-Puertas, et al., 2021). While different positional groups have displayed physical demands during match play (Bloomfield et al., 2007; Di Salvo, Baron, Tschan, et al., 2007), players were not sub-divided into positional groups as the small cluster size for each positional group would limit the statistical power. Further, as the primary aim was to determine differences in peak match running demands between youth and professional competitions, the amalgamation of all positional groups was deemed appropriate. The protocols used in the current study were submitted to and approved by the La Trobe University Human Research Ethics Committee, with informed consent obtained from all participants prior to data collection HREC#: 18056.

Activity Profile

Player activity data were collected each match using 18 Hz (10 Hz GNSS) portable GPS units (STATSports, Northern Ireland) positioned under the playing jersey and secured in a custom-made harness between the scapulae. GPS devices were turned on 30 minutes prior to the commencement of a match to allow for satellite acquisition. The GPS units employed are valid and reliable in measuring locomotor speeds of team sport athletes (Beato et al., 2018). GPS data were downloaded post-match using proprietary software (STATSports, Northern Ireland), with raw GPS files (inclusive of added time) exported into statistical software (R Studio, v1.2.5033) for further analysis. As per previous methods, the raw exported speed trace was filtered using a 4th order, one-way Butterworth filter with a cut-off frequency of 1 Hz (Delaney, Thornton, et al., 2018). Individual data points in which running speed exceeded 10 $m{\cdot}s^{-1}$ and instantaneous Acc values exceeded 6 $m{\cdot}s^{-2}$ were classified as technical errors and replaced with zero values.

Based on current player monitoring practices, three GPS metrics of running intensity were assessed: TD, HSD (>19.8 $km{\cdot}h^{-1}$) and AveAcc (Rago et al., 2020). Measures of TD and HSD were made relative to playing time ($m{\cdot}min^{-1}$), with Acc profiles calculated through the summation of the absolute Acc/Dec values before averaging them over a defined duration to calculate AveAcc ($m{\cdot}s^{-2}$) (Delaney et al., 2016). The amalgamation of both Acc/Dec into a singular metric, while concealing the underlying mechanism of load has been suggested to better reflect the overall intensity of match play (Delaney, Thornton, et al., 2018). A moving average technique was applied to all three of the match output variables to calculate the peak match running demands. Ten incremental epochs were used (i.e., 1-10 min), with the maximum value for each epoch, for each variable, recorded and then fitted using a power law curve (Delaney, Thornton, et al., 2018).

Statistical Analysis

R Studio statistical programming software (v1.2.5033, R Core Development Team, Vienna), in conjunction with the *nlme* (Pinheiro et al., 2015) and *lme4* packages (Bates et al., 2015) packages, were used to conduct non-linear and linear mixed effects analysis. Non-linear mixed models were used to calculate exponent and slope values for the power law model. Linear mixed models were used to assess differences in competition levels for TD, HSD, and Acc profiles. In the linear mixed model, fixed effects were included for intensity period [ten levels: 1-10 min] and competition level [two levels: youth and professional]. A random intercept was included for player and an exponential covariance structure, with a nugget effect, to account for temporal autocorrelation between intensity periods.

Raw unit differences between competition level, at each intensity period, were converted to SMD by dividing the mean, raw unit difference by the within-subject SD attained from the random effects (i.e., the square root of the residual variance term). The magnitude of the within-subject SMD was quantified using the following qualitative descriptors: *trivial* (<0.2), *small* (0.2-0.6), *moderate* (0.6–1.2), *large* (1.2–2.0), *very large* (2.0–4.0) and *extremely large* (>4.0) (Hopkins et al., 2009). A worthwhile difference was determined as a moderate ES >0.6, with the imprecision of model regression parameter estimates expressed using 95% CI. Descriptive statistics of the absolute total match outputs were calculated to provide context to peak match running demands.

RESULTS

The total physical outputs were similar between the elite youth and professional competition levels for all metrics of running performance (Table 5.1). Differences in peak TD demands were present between competitions, with epochs of between 2-10 min demonstrating *trivial* (SMD = 0.01-0.15) differences, with the 1 min epoch demonstrating a *small* difference (SMD = 0.25) (see Figure 5.1). Similarly, peak HSD (Figure 5.2) demands showed *trivial* differences (SMD = 0.09-0.18) between competition levels across all epochs. However, the peak AveAcc demands (Figure 5.3) were *moderately* greater (SMD = 0.63-0.69) for the professional than the youth competition for all epoch durations. Intercept and exponent values of the non-linear power law models are presented in Table 5.2.

Table 5.1. Absolute and relative physical output total match averages. Data presented as mean ± SD. Data in brackets indicate relative distances covered ($m \cdot min^{-1}$). Match duration is inclusive of added time.

Competition	Match Duration (min)	Total Distance (m)	High-Speed Distance (m)	Average Acceleration ($m \cdot s^{-2}$)
Professional	97 ± 3	11, 035 ± 698 (114 ± 8)	725 ± 250 (8 ± 3)	0.64 ± 0.05
Youth	97 ± 2	11, 333 ± 1048 (116 ± 11)	713 ± 289 (7 ± 3)	0.64 ± 0.05

No differences observed between competition levels.

Table 5.2. Non-linear relationships of power law models by level of competition. Data presented as mean (90% CI).

Competition	Total Distance		High-Speed Distance		Average Acceleration	
	Intercept	Slope	Intercept	Slope	Intercept	Slope
Professional	200 (195 - 205)	-0.168 (-0.170, -0.166)	57 (51 – 63)	-0.600 (-0.608, -0.592)	1.12 (1.09 – 1.14)	-0.170 (-0.173, -0.168)
Youth	198 (193 - 203)	-0.161 (-0.166, -0.157)	56 (50 – 62)	-0.610 (-0.627, -0.593)	1.08 (1.05 – 1.10)	-0.172 (-0.177, -0.167)

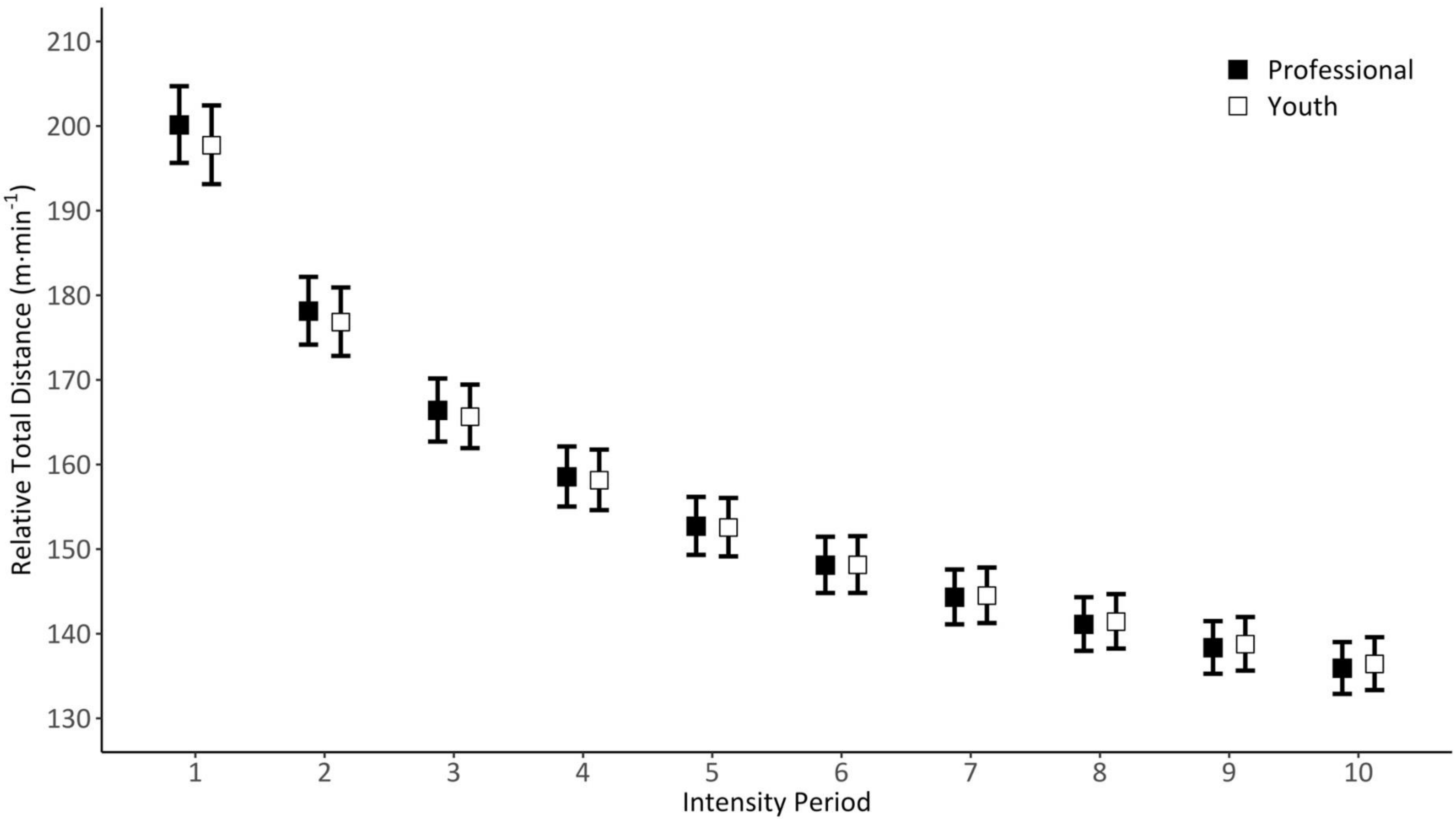

Figure 5.1. A comparison between professional and youth competitions for peak match running demands of relative total distance.

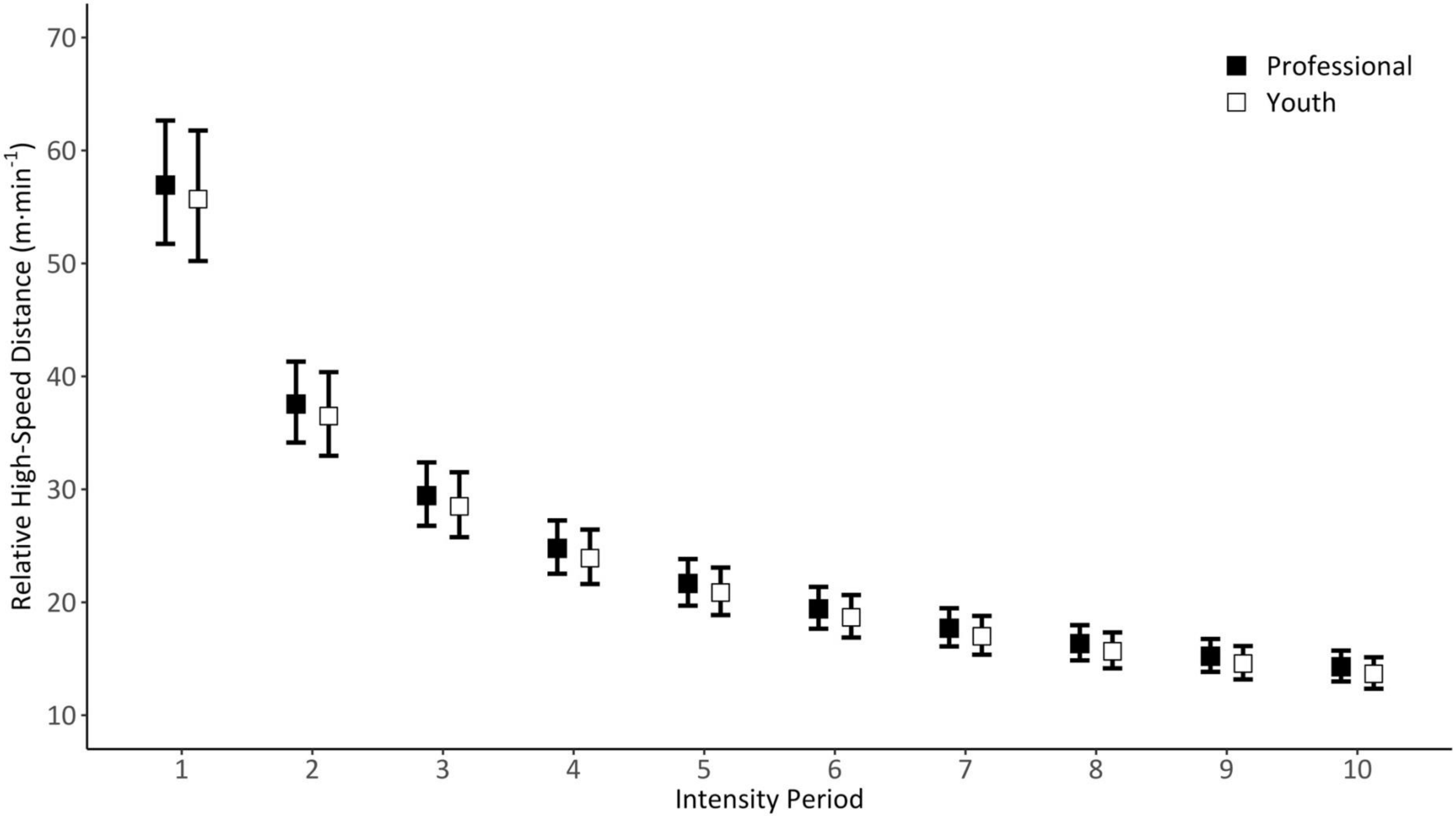

Figure 5.2. A comparison between professional and youth competitions for peak match running demands of relative high-speed distance.

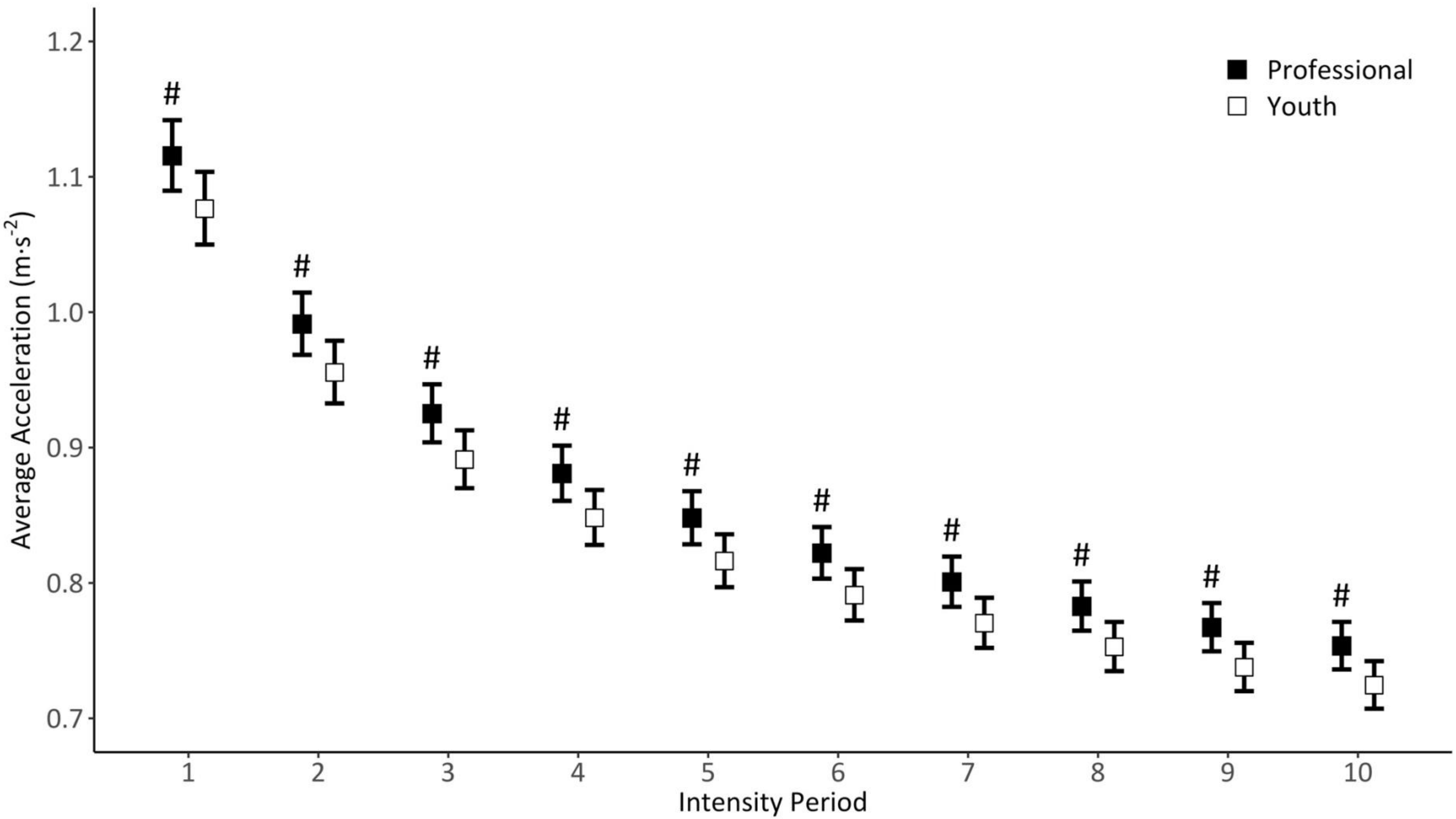

Figure 5.3. A comparison between professional and youth competitions for peak match running demands of average acceleration. [#]= moderate difference to youth (ES = 0.6-1.2).

DISCUSSION

The current study provides insight into the total match demands and peak match running demands between youth and professional football players within a single club that employed similar tactical formations and tactical approaches. Total match running demands were similar between competition levels for all three running demand metrics. Similarly, peak match running demands of TD and HSD were consistent between competition levels, with only the peak AveAcc demands being lower in the youth competition across all epoch durations. While the underlying mechanisms for this discrepancy are likely multi-factorial, it suggests that youth players need more exposure to greater magnitude of Acc demands in training to prepare for professional competition. Further, the power law parameters provided in Table 5.2 can be used to design and implement training drills that develop youth players acceleration and repeat effort capacities in order to expose such players to match intensities reflective of a professional competition (Chapters 3 and 4) (Delaney, Thornton, et al., 2018).

When preparing youth players for the rigors of professional football, a key outcome is to ensure youth players are capable of the physical outputs required of professional competitions. In the present study, players in the youth and professional competitions completed similar TD (11,035 ± 698 m vs 11,333 ± 1048 m, respectively) and HSD (713 ± 289 m vs 725 ± 250 m, respectively) volumes across a match. These total match demands are comparable to those previously reported in professional football across various international leagues (Bradley et al., 2011; Bradley et al., 2010; Dalen et al., 2016; Varley et al., 2014; Wehbe et al., 2014). Furthermore, the observed AveAcc across a match was similar between the youth (0.64 ± 0.05 $m{\cdot}s^{-2}$) and professional (0.64 ± 0.05 $m{\cdot}s^{-2}$) players, which is important as the AveAcc metric provides a good indicator for the overall intensity of the physical stimulus (Delaney, Thornton, et al., 2018). Therefore, while the technical and tactical capacities of youth and professional football players likely differ, the total match demands of youth football competition are similar to those of professional competition. This suggests that the Australian youth football competition investigated provides sufficient physical volumes to replicate the demands of professional match play.

While quantifying the total match outputs allows the comparison of running volume between competition levels, the ability to translate these data into training drills aimed at preparing youth players may be limited due to the different tactical and technical demands. The current peak relative TD and HSD running demands were similar to previously reported data for separate elite youth and professional competitions (Delaney, Thornton, et al., 2018; Doncaster et al., 2020; Duthie et al., 2018). However, in the current study, the peak AveAcc demands were moderately higher in the professional competition compared to the youth competition, suggesting that professional players perform more frequent or higher magnitude changes in velocity. As both Acc/Dec actions impose a higher metabolic cost than constant velocity running (Dalen et al., 2016), youth players may not be physically prepared for the increased AveAcc intensity required of professional football. Moreover, in the Italian Serie A, more successful (league ranking) teams complete more technical involvements with the ball, (e.g. passes, tackles, shots) during match play than less successful teams (Rampinini et al., 2009). Comparatively, as the youth competition is a lower-level competition, it may require players to have fewer technical involvements than professional players. Further, the ability of youth players to recognise match situations and appropriately re-position themselves may also be inferior in comparison to professional players (Evans, Whipp, & Lay, 2012). As such, the physical demands required for players to reposition themselves in both attacking and defensive situations may be greater in the youth competition. Additionally, the lower peak AveAcc demands observed for the youth competition may in part, be explained by the age and maturation status of the players. Age has shown to be a determining factor in a player's ability to accelerate, both maximally and repeatedly, with older youth players (U18) shown to have better Acc capabilities than younger youth players (<U16) (Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010; Mendez-Villanueva et al., 2011). While the underlying mechanism for discrepancies in peak AveAcc demands between competitions is likely multi-faceted, it is inferred that youth players must develop their ability to continually change velocities through tailored training stimuli that progressively replicates the demands of professional match play.

While it is acknowledged that the data in this study has been collected from only one team at each competition level, it is important to recognise that both teams were from the same club which the formation, tactical approaches and playing philosophy of the youth team mirroring that of the professional team. Contrary to previous literature which has been limited to inferring differences between competitions, the current study provides the first direct comparison between the physical demands of youth and professional football competition. The present study was unable to assess any internal measures, with it is possible that, despite physical demands being largely similar between competitional levels, one group may have had a higher physiological cost of performing such demands. A such, investigations into the peak physiological demands of football competition and discrepancies between competition levels is warranted. Further, it is also acknowledged that in the present study, all positional groups were amalgamated, and although this was partially controlled for through the use of the same formation and tactical approaches. While discrepancies in peak physical demands have been reported, the distribution of physical, technical, and tactical demands represented within each discrete time epoch requires further elucidation. For example, as peak match epoch length increases, other team sports have identified an increased frequency of technical involvements, with a resultant decrease in movement demands (R. D. Johnston, Murray, Austin, & Duthie, 2019). Future studies should aim to quantify the technical and tactical demands of these peak match running periods in football to provide a greater insight to the holistic demands of the most physically demanding passages of match play and further identify discrepancies between youth and professional competitions.

Understanding the discrepancy between the physical demands of youth and professional football competitions provides context in developing youth footballers. While coaches of youth teams often implement similar training drills and stimuli to professional teams, the current data suggests that an extra focus may need to be placed on the development of some physical capacities. In the present study, the football players were exposed to similar peak match running demands of TD and HSD as their professional counterparts, with the exception of AveAcc. Hence, as the demands of the youth match play failed to replicate those of professional match play, these capacities must be developed through carefully prescribed and monitored training practices. The initial evaluation of current training practices is crucial in understanding the stimulus which a player receives during training. From this, small adjustments to already implemented drills, i.e. number of players, pitch size, drill constraints, may allow for a more appropriate stimuli that replicates match demands (Lacome, Simpson, Cholley, Lambert, & Buchheit, 2018). With running during match play occurring in tandem with technical and tactical demands, it is important to consider the balance of physical demands with that of technical and tactical demands during training to ensure players are holistically developed (Ju et al., 2021).

CONCLUSIONS

Ensuring that players are capable of the increased physical demands associated with professional football training and competition is crucial in the long-term success of youth footballers. As such, progressively exposing youth players to match demands that replicate those of professional competitions is crucial. Importantly, there were no differences in the absolute and peak relative TD and HSD covered between competitions, although the peak AveAcc demands were moderately lower in the youth football players. As such, the physical demands of youth football competition appear to largely replicate those of professional football competition within Australia, with only AveAcc showing differences between playing levels. While the discrepancy in peak AveAcc demands of youth and professional football competitions is likely to be multi-factorial, it is evident that the youth competition did not fully replicate the physical demands of professional football. As such, training sessions provide the best opportunity to develop this physical stimulus with the evaluation and careful design and implementation of drills replicating peak AveAcc demands of professional competition crucial.

Chapter Six

Temporal Distribution of Peak Running Demands Relative to Match Minutes in Elite Football

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ABSTRACT

The peak match running demands of football have been quantified across time durations of 1-10 min, however, little is known as to when the peak match running demands occur within match play. Data were collected from 44 elite footballers, across 68 fixtures (files = 413, mean ± SD; 11±8 observations per player, range; 1-33), with peak match running demands quantified for each playing half at ten incremental rolling average durations (1 min rolling averages, 2 min rolling averages, etc.). Data were assessed if players completed the full match. Three measures of running performance were assessed [total distance, high-speed distance (>19.8 $km \cdot h^{-1}$) and average acceleration], with the in-game commencement time of the peak match running demands recorded. Descriptive statistics and normality were calculated for each rolling average duration, with the self-containment of shorter rolling average epochs within longer epochs also assessed (e.g. do the 1 min peak match running demands occur within the 10 min peak match running demands). Peak total distance and average acceleration demands occurred early in each half (median time = 7-17 min and 6-16 min, respectively). Conversely, peak high-speed distance covered was uniformly distributed (Skewness = 0-0.5, Kurtosis = 1.7-2.0), demonstrating that it occurred consistently random throughout a match. There were low-moderate levels of self-containment for each peak match running period (10-51%), dependent upon metric. Peak match running demands for total distance and average acceleration occurred at similar stages of a match and aligned with where total distance and acceleration volumes are typically greatest, whereas peak high-speed distance demands appeared more unpredictable. These timings may help inform training prescriptions in preparation of athletes for competition in helping structure the sequence of training drills.

INTRODUCTION

Wearable technology allows for the quantification of the physical match demands of football, aiding in the prescription and monitoring of athlete training loads (Rago et al., 2020). Historically, the physical demands of match-play have been quantified through reporting the absolute distance covered, both overall and within various speed thresholds (Trewin et al., 2017; Vieira et al., 2019). Conventionally, match demands are reported as a function of the entire match or broken down into smaller periods (e.g. between halves or 5-15 minute blocks), in an effort to provide insight into within-match fluctuations in the absolute physical outputs (Bradley et al., 2010; Carling, 2013; Di Salvo et al., 2009; Mohr et al., 2003). Previous researchers have identified that the absolute TD and HSD covered tends to decrease as a match progresses, with physical demands greatest in the first 15 minutes and lowest in the final 15 minutes of a match (Carling, Bloomfield, Nelsen, & Reilly, 2008; Linke et al., 2018; Mohr et al., 2003). Similar findings have also been reported for Acc counts, with the number of Acc (>2 $m{\cdot}s^{-2}$) efforts being significantly ($p<0.05$) higher in the 0-15 and 15-30 minute periods than the 60-75 and 75-90 min periods (Vigh-Larsen et al., 2018). Such information regarding temporal shifts in performance and match demands are useful to practitioners in gauging and monitoring athlete performance, while also helping to provide insight into acute fatigue and potentially guiding pacing strategies. However, while informative, the use of such data to inform training practices may be limited, with the use of absolute or relative total match data likely to under-prepare athletes for shorter periods of higher intensity efforts during different match periods (see Chapters 3-5). As such, alternate methods that quantify the intensity of match play and identify the most physically demanding periods of match play have been developed, providing practitioners additional data that informs training prescription (Fereday et al., 2020; Varley, Elias, et al., 2012).

Practitioners have begun to quantify the peak match running demands of football across durations significantly shorter than previously reported time periods (e.g. 15, 45 or 90-min) (Connor et al., 2021; Delaney, Thornton, et al., 2018; Duthie et al., 2018). The quantification of the peak match running demands involves the identification of the most physically demanding periods of a match across pre-determined window durations of 1-10 minutes (Delaney, Thornton, et al., 2018; Fereday et al., 2020; Hills et al., 2020). The use of a rolling average window (e.g. 0-1 min, 0.1-1.1 min) has demonstrated to be superior in quantifying peak match running demands when compared to discrete time periods (e.g. 0-1 min, 1-2 min, etc.), with discrete periods underestimating both peak total and HSD by ~7-10% and ~12-25%, respectively, across the 1-10 minute window durations (Doncaster et al., 2020; Fereday et al., 2020; Varley, Elias, et al., 2012). However, little is known as to the temporal distribution of peak match running demands, i.e. when the peak match running demands occur during match-play, with there being over 54,000 instances throughout a match where the peak 1 min running demands may occur (if using 10Hz GPS devices) (Cummins et al., 2013; Thornton, Nelson, et al., 2019). Taken together, peak match running demands reflect the greatest physical demands that are required of an athlete throughout match-play. Importantly, the typical window durations associated with peak match running demands (1-10 min) better align with those associated with football-based conditioning drills than the discrete 15, 45 or 90 min windows (Sarmento et al., 2018).

Across recent years, the peak match running demands of football have initially been investigated, with new data exploring the impact of contextual factors, such as competitional (Chapter 5) and positional differences (Chapter 4), beginning to emerge (Duthie et al., 2018; Martín-García et al., 2018; Oliva-Lozano, Rojas-Valverde, et al., 2020). This additional context surrounding peak match running demands has proven useful in ensuring that prescribed training drills simulate the demands typical of match-play and provide an adequate stimulus for preparing athletes for competition (Chapter 3). However, while temporal changes in the absolute running demands of match play have been observed (Bradley & Noakes, 2013; Carling & Dupont, 2011; Rampinini et al., 2009; Vieira et al., 2019; Vigh-Larsen et al., 2018), the temporal distribution of peak match running demands remain to be thoroughly investigated. To date, only a single study has attempted to assess the temporal distribution of peak match running demands, however, the study in question used a categorised the timings of peak match running demands into discrete 15 min epochs, as opposed to using a continuous time scale, from which the temporal distribution of peak match running demands could be more accurately determined (Oliva-Lozano, Martínez-Puertas, et al., 2021). Such information may help to identify the more specific periods of play when peak match running demands occur, helping to inform practitioners around how to structure training sessions accordingly to best replicate matches.

Furthermore, with peak match running demands typically quantified over time durations of varying lengths (1-10 min), it is possible that peak match running demands of shorter durations may occur within longer peak match running durations. For example, the peak match running demands observed for a 5 min duration may self-contain the peak match running demands of the 1-4 min epochs, which would indicate that athletes are infrequently required to perform at peak match intensities. Conversely, if peak match running demands of shorter durations are not self-contained within longer peak match running durations, this would indicate athletes are frequently required to perform at each peak match intensities. Currently, the self-containment of peak match running demands is yet to be reported on, with this information likely proving useful to coaches in ensuring the number of drills replicating match demands within a training session is appropriate in preparing athletes for competition. Therefore, the current study aims to identify the temporal distribution of when peak match running demands occur during competitive football match-play, and to quantify the self-containment levels of peak match running demands.

METHODS

Activity profiles of elite football players were measured during 68 competitive AL matches, spanning three seasons (2015-2018) (2015/16 Season = 25 matches, 2016/17 Season = 15 matches, 2017/18 = 26 matches). Match GPS files were downloaded for 44 elite football players from the one club with a total of 413 individual match observations (mean ± SD; 11 ± 8 observations per player, range; 1-33). As this study aims to identify when peak match demands occur within each half, rather than the magnitude of these demands, all positional groups were combined, with data from players who played less than 90 minutes not included for analysis in order to avoid any artificial skewing of results. Goalkeepers were excluded due to their positional demands not being reflective of the group. Prior to collection of data, ethical approval was attained from La Trobe University (HREC#: 18056).

Activity Profile

Data were collected during match play using 18 Hz portable GPS units (STATSports, Northern Ireland), secured between the shoulder blades of the athlete using a custom-made harness, with data downloaded post-match using proprietary software (STATSports, Northern Ireland). These GPS devices have shown strong validity and reliability in the measurement of locomotor speeds across varying velocities (Bias < 2.11%; CV < 2.91%; ICC = 0.95-0.98) (Beato et al., 2018; Beato & de Keijzer, 2019). Statistical software (R Studio, v1.2.5033) was used to analyse exported raw GPS files (inclusive of added time) using custom functions. The raw exported speed trace was filtered using a 4th order one-way Butterworth filter with a cut-off frequency of 1 Hz. Individual data points exceeding a running speed of 10 $m{\cdot}s^{-1}$ were deemed as erroneous and replaced with zero values. Similarly, any Acc/Dec values greater than ±6 $m{\cdot}s^{-2}$ were classified as technical errors and replaced with zero values. The effect of these replacements was deemed negligible (<0.01% of data points replaced), due to the method used to quantify the peak match running demands.

The measures chosen for the assessment of running intensity were TD covered, HSD covered (>19.8 $km{\cdot}h^{-1}$) and AveAcc. Both TD and HSD covered were expressed relative to unit of time ($m{\cdot}min^{-1}$), with AveAcc calculated as per established methods where the absolute values of all Acc/Dec are summated and averaged over a defined duration ($m{\cdot}s^{-2}$) (Delaney et al., 2016). While it is recognised that the amalgamation of both Acc/Dec into a singular metric may conceal the underlying mechanism of load, the use of this metric provides greater insight into the overall intensity of an activity (Delaney, Thornton, et al., 2018). These values were then mapped to in-game accumulative time, recorded at the commencement of the peak match running duration. For example, a peak 1 min running duration occurring between the 40th and 41st minute would be recorded as commencing at the 40th minute. The mapping of peak match running demands to the minute in which they commenced was used, as opposed to when they finished, to combat the potential artificial skewing of longer duration epochs and allow for direct comparisons between various rolling average durations. As additional time was included in the analyses, it is possible for the commencement of peak match running durations to occur later than the 45th minute.

Statistical Analysis

Statistical analyses were conducted using R Studio statistical programming software (v1.2.5033, R Core Development Team, Vienna). Descriptive statistics of means, SD, median values, and interquartile ranges (IQR) were calculated for each intensity period, with normality at each intensity period calculated using skewness and kurtosis measures. Skewness and kurtosis were calculated using the 'moments' package (Komsta & Novomestky, 2015). The magnitude of skewness was quantified using the following descriptors: approximately symmetric ($-0.5< S_{KP} <0.5$), moderately skewed ($-1< S_{KP} <-0.5$ or $0.5< S_{KP} <1$) or highly skewed ($S_{KP} <-1$ or $1< S_{KP}$). Descriptors for kurtosis were assigned as: mesokurtic ($\beta_2 = 3$), platykurtic ($\beta_2 < 3$) or leptokurtic ($\beta_2 >3$). A larger skewness value (in either direction) demonstrates that peak match running demands predominantly occur at either the start or end of a match half. Subsequently, the kurtosis value would indicate how heavy-tailed or light-tailed the distribution is, with a high value indicating the presence of outliers, i.e. peak match running demands occurring at either the start or end of a match (depending on skewness) are atypical, with a low kurtosis value indicating that there are minimal/no outliers to the distribution. Additionally, the temporal self-containment of shorter peak match intensity windows within longer windows was assessed by determining whether the entirety of a peak match running period occurred within a longer window. The self-containment window is defined as the entirety of a time duration across which peak match running demands occur for a given rolling average duration. For example, if the peak 1 min period was observed between the 40th and 41st minute and the peak 5 min period was observed between the 38th and 43rd minute, then the peak 1 min period would be recorded as being self-contained with the peak 5 min period. The relative proportion of occurrences of a shorter peak match intensity duration within each longer self-containment window is described as a percentage of total occurrences using the following novel qualitative descriptors: *very low* (<30%), *low* (30-40%), *moderate* (40-50%), *high* (50-60%) and *very high* (>60%).

RESULTS

Raw distribution descriptive statistics of when peak match running demands occurred are presented in Table 6.1. Peak match running demands for relative TD (Figure 6.1) and AveAcc (Figure 6.2) were moderately to highly right skewed in both the first and second halves for most intensity periods (Skewness = 0.7-1.2 and 0.6-1, respectively) demonstrating the peak match running demands of TD and AveAcc typical occur early within a half. Conversely, peak match running demands of relative HSD (Figure 6.3) were mostly uniformly distributed across each half for all intensity periods (Skewness = 0-0.5, Kurtosis = 1.7-2.0). The temporal self-containment of peak match intensity periods is presented in Table 6.2, with the TD and AveAcc peak match running demands displaying *low* to *high levels of* relative self-containment (32-47% and 30-51%, respectively). This indicates that peak match running demands of a shorter duration typically coincide with those of longer durations. Further, the self-containment of HSD peak match running demands demonstrated a larger spread, with very *low* to *moderate* (9-49%) levels of self-containment reported which indicates a large proportion of shorter peak match running demands occur irrespective of longer peak match running demands.

Table 6.1. Raw distribution descriptive statistics of when peak match running demands occurred during match play across moving average durations of 1-10 minutes. Data is presented as match minutes of when peak match running demands commenced. Skewness and kurtosis are presented as raw statistical values.

Metric	Variable	Half	Moving Average Duration									
			1 min	**2 min**	**3 min**	**4 min**	**5 min**	**6 min**	**7 min**	**8 min**	**9 min**	**10 min**
Relative Total Distance ($m \cdot min^{-1}$)	Mean ± SD	1st	19 ± 14	16 ± 13	14 ± 13	13 ± 12	12 ± 12	12 ± 11	11 ± 10	11 ± 11	11 ± 10	11 ± 10
		2nd	19 ± 14	18 ± 14	16 ± 14	15 ± 13	14 ± 13	13 ± 12	13 ± 12	12 ± 12	11 ± 11	10 ± 11
	Median	1st	17	12	10	9	9	8	7	9	9	9
		2nd	17	14	12	12	11	10	10	8	7	7
	IQR (Lower-Upper)	1st	23 (7 - 30)	22 (5 - 26)	17 (3 - 20)	16 (3 - 19)	16 (3 - 18)	15 (2 - 17)	14 (2 - 16)	15 (2 - 17)	14 (3 - 16)	14 (2 - 16)
		2nd	23 (7 - 30)	21 (6 - 28)	20 (4 - 25)	19 (4 - 23)	19 (4 - 22)	17 (4 - 20)	18 (3 - 21)	14 (3 - 16)	12 (2 - 14)	12 (1 - 14)
	Skewness	1st	0.4	0.7	0.8	0.8	0.8	0.9	1.1	0.8	0.9	0.9
		2nd	0.5	0.7	0.8	0.8	0.8	0.9	0.9	1.1	1.2	1.2
	Kurtosis	1st	1.9	2.2	2.5	2.4	2.6	2.8	3.3	2.6	2.8	2.7
		2nd	2.1	2.4	2.6	2.6	2.6	2.8	2.7	3.3	3.8	3.7
Relative High Distance ($m \cdot min^{-1}$)	Mean ± SD	1st	22 ± 13	20 ± 14	19 ± 13	18 ± 13	18 ± 13	18 ± 13	17 ± 13	16 ± 12	15 ± 12	15 ± 12
		2nd	22 ± 14	21 ± 14	20 ± 14	19 ± 14	19 ± 15	19 ± 14	18 ± 14	17 ± 14	16 ± 13	16 ± 13
	Median	1st	23	20	18	17	16	16	16	15	13	12
		2nd	19	18	17	16	16	17	16	13	13	13
	IQR (Lower-Upper)	1st	24 (10 - 34)	25 (8 - 33)	22 (7 - 29)	22 (8 - 29)	21 (7 - 28)	22 (6 - 28)	23 (6 - 29)	22 (5 - 27)	22 (4 - 26)	22 (4 - 26)
		2nd	21 (10 - 31)	24 (8 - 32)	24 (8 - 31)	23 (7 - 30)	25 (6 - 31)	24 (6 - 30)	24 (5 - 29)	24 (5 - 28)	23 (4 - 27)	23 (4 - 27)
	Skewness	1st	0.0	0.1	0.2	0.3	0.3	0.2	0.2	0.3	0.3	0.4
		2nd	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.5	0.5	0.4
	Kurtosis	1st	1.8	1.8	1.9	1.9	1.9	1.8	1.7	1.8	1.8	1.8
		2nd	2.1	2.0	2.0	2.0	1.8	1.8	1.9	1.9	1.9	1.9
Average Acceleration ($m \cdot s^{-2}$)	Mean ± SD	1st	18 ± 14	16 ± 14	14 ± 13	13 ± 12	13 ± 12	12 ± 11	11 ± 11	11 ± 11	11 ± 11	11 ± 11
		2nd	18 ± 14	17 ± 14	16 ± 14	15 ± 13	15 ± 14	14 ± 13	13 ± 13	12 ± 13	12 ± 12	11 ± 12
	Median	1st	15	12	10	8	10	9	8	9	8	8
		2nd	16	13	12	10	10	9	9	8	8	8
	IQR (Lower-Upper)	1st	25 (5 - 30)	22 (4 - 26)	18 (3 - 21)	18 (2 - 20)	17 (2 - 19)	15 (2 - 17)	15 (2 - 17)	15 (2 - 17)	14 (2 - 16)	15 (2 - 17)
		2nd	24 (6 - 30)	23 (5 - 27)	22 (3 - 25)	20 (3 - 23)	21 (3 - 24)	17 (3 - 20)	19 (2 - 21)	18 (1 - 19)	17 (1 - 18)	18 (1 - 18)
	Skewness	1st	0.4	0.6	0.8	0.9	0.8	0.9	1.0	0.9	1.0	0.9
		2nd	0.4	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.0
	Kurtosis	1st	1.9	2.1	2.5	2.6	2.6	2.9	3.0	2.7	2.9	2.8
		2nd	2.0	2.3	2.4	2.5	2.3	2.6	2.6	2.8	2.8	2.8

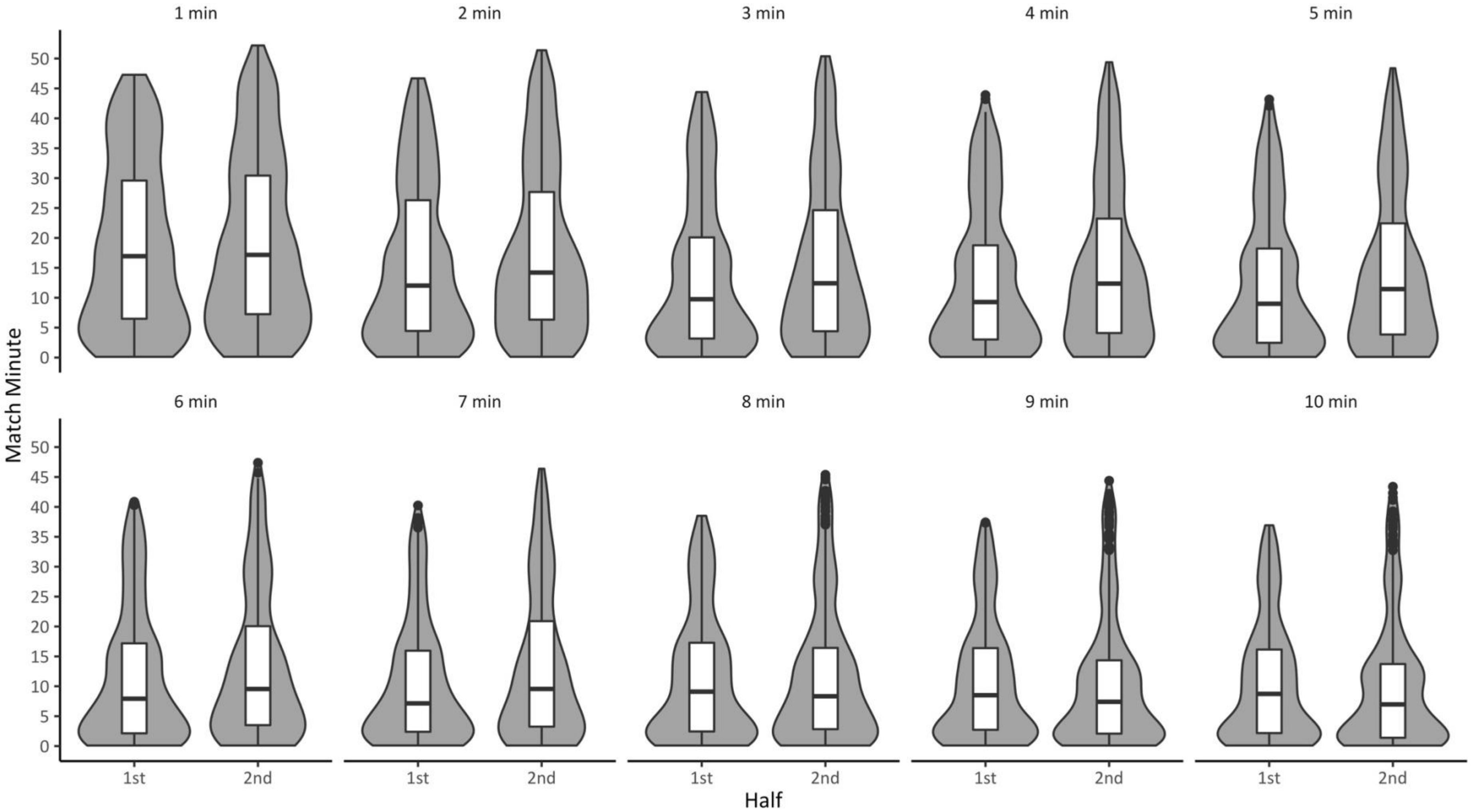

Figure 6.1. Within-half violin and box plots of when peak relative total distance covered commenced for moving average durations of 1-10 minutes.

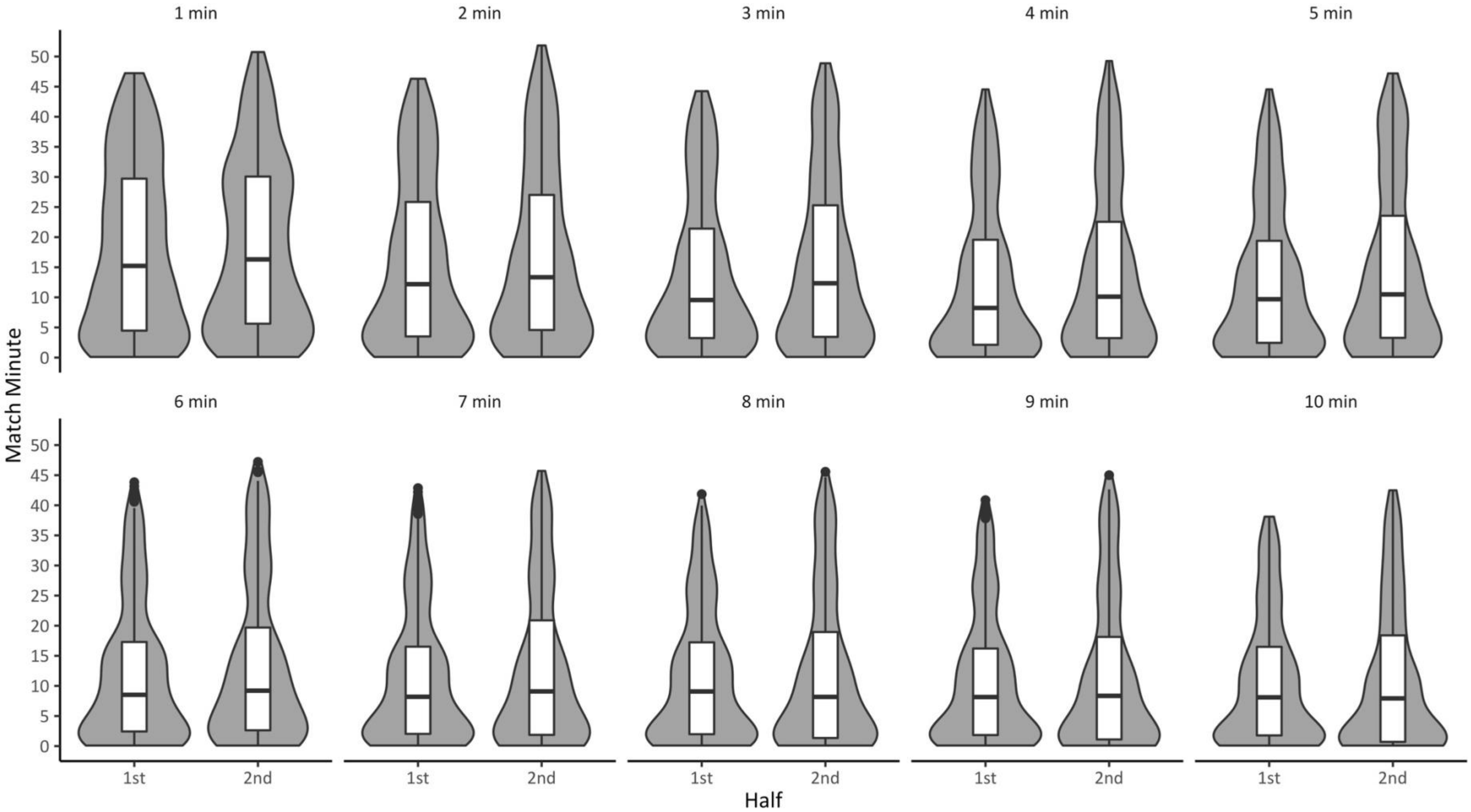

Figure 6.2. Within-half violin and box plots of when peak average acceleration demands commenced for moving average durations of 1-10 minutes.

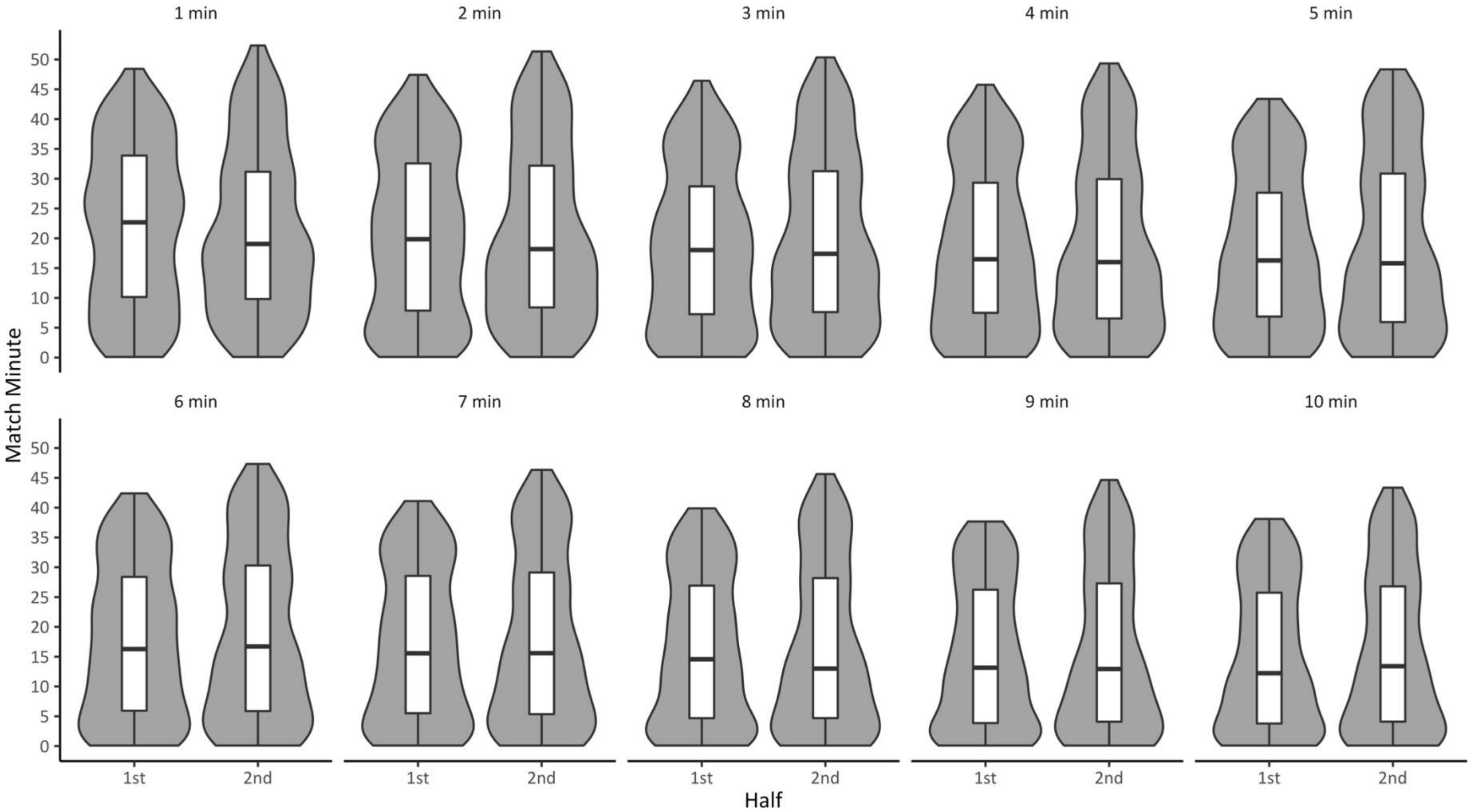

Figure 6.3. Within-half violin and box plots of when peak relative high-speed distance covered commenced for moving average durations of 1-10 minutes.

Table 6.2. Relative (%) level of self-containment of peak match running demands within the self-containment windows.

Metric	Containment Window	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min
Relative Total Distance	1 min										
	2 min	32%									
	3 min	32%	34%								
	4 min	35%	34%	32%							
	5 min	32%	38%	33%	39%						
	6 min	34%	39%	40%	41%	37%					
	7 min	38%	40%	41%	43%	36%	35%				
	8 min	38%	41%	43%	46%	41%	37%	38%			
	9 min	39%	42%	42%	46%	41%	39%	38%	36%		
	10 min	42%	43%	42%	47%	42%	39%	36%	36%	37%	
High-Speed Distance	1 min										
	2 min	10%									
	3 min	23%	10%								
	4 min	30%	17%	12%							
	5 min	35%	29%	19%	11%						
	6 min	39%	35%	26%	20%	11%					
	7 min	41%	37%	31%	27%	20%	10%				
	8 min	46%	42%	35%	31%	26%	21%	13%			
	9 min	46%	46%	40%	35%	31%	25%	21%	14%		
	10 min	48%	46%	43%	40%	31%	29%	25%	21%	13%	
Average Acceleration	1 min										
	2 min	30%									
	3 min	33%	32%								
	4 min	34%	37%	36%							
	5 min	36%	41%	37%	34%						
	6 min	37%	44%	40%	38%	37%					
	7 min	38%	46%	45%	40%	40%	34%				
	8 min	39%	48%	47%	45%	43%	36%	37%			
	9 min	42%	49%	49%	49%	46%	40%	41%	38%		
	10 min	44%	51%	50%	50%	48%	41%	40%	40%	40%	

Key: = very low self-containment (<30%), = low self-containment (30-40%), = moderate self-containment (40-50%), = high self-containment (50-60%).

DISCUSSION

The current study aimed to determine the temporal distribution of when peak match running demands typically occur during elite football matches and secondly, to elucidate the self-containment of match running demands. The primary findings indicated that peak match running demands for relative TD and AveAcc occurred early in each half for all moving average epochs (median time = 7-17 min and 6-16 min, respectively). Separately, the peak relative HSD demands were more evenly distributed across each half (S_{KP} = 0.0-0.5, β_2 = 1.7-2.1). These findings give insight to when peak match running demands typically occur during match halves, while also providing further context for structuring training sessions to appropriately simulate competition demands (Chapters 3-5). Additionally, the current study is the first to assess the temporal self-containment of shorter peak match running periods within longer windows, identifying that less than 55% of shorter peak match intensity periods occur within longer durations. The *very low* to *moderate* levels of self-containment amongst peak match running periods highlights the need for athletes to regularly perform at peak intensities for varying lengths of time. This knowledge may further aid in the design and structure of training drills and sessions through the implementation of numerous drills across a session aimed at replicating peak match demands.

Using discrete time periods (e.g. 0-15 min), temporal reductions in physical output have been observed across both halves and match entirety, with the first 15 minutes of each half requiring the greatest absolute running demands (Bradley et al., 2010; Carling, 2013; Di Salvo et al., 2009; Linke et al., 2018; Mohr et al., 2003). While literature reporting on the AveAcc demands is limited, similar observations have been made for Acc counts (>2 m·s^{-2}), with the number of Acc performed in the final 30 minutes of a match significantly less than in the first half (Vigh-Larsen et al., 2018). The present study observed similar findings, whereby the majority of the peak match running demands of relative TD and AveAcc, irrespective of rolling average window, occurred within the first 17 minutes of each half. These findings are also similar to those previously reported on peak match running demands across a 1 min duration, with peak TD covered and Acc counts found to occur predominantly in the first 15 min of match-play (Oliva-Lozano, Martínez-Puertas, et al., 2021). The mechanistic properties behind the declines in physical output across a match, with regard to both volume and intensity reflect factors such as acute fatigue, team tactics and score line (Trewin et al., 2017), with athletes often implementing pacing strategies in an attempt to attenuate the reduction in physical performance (Aughey, Goodman, & McKenna, 2014; Bradley & Noakes, 2013; Tucker, 2009). The apparent alignment of the highest match running volumes, peak match running demands and Acc counts in the early stages of a half reflects a positive pacing strategy. With coaches aiming to establish superiority in the first 15 minutes of a match (Towlson, Midgley, & Lovell, 2013), the increased physical output observed in this period is likely reflective of players enacting the tactical plans of coaches, with subsequent anticipatory feedback post- this period modulating running performance to ensure successful completion of the match (Tucker, 2009). Additionally, with high-intensity efforts linked to crucial match periods, it is possible that athletes modulate TD covered to ensure they are able to maintain HSD covered when needed, as evidenced by peak match running demands of TD being heavily skewed and peak high-speed demands being more evenly distributed (Faude et al., 2012; Little & Williams, 2005).

External contextual factors may also contribute to the distribution of match activities in players, with changes reported in the effective playing time in football demonstrating an increase in match interruptions and greater dead ball time during the latter stages of a match (Carling & Dupont, 2011). For example, data from the German Bundesliga identified that ball in play time accounted for ~66% of total match time during the first 15 minutes of a match half, but only ~56% in the final 15 minutes (Linke et al., 2018). This reduction corresponded to a significant increase in distance covered while walking and a subsequent decrease in physical intensities in the latter stages of a match. Therefore, it appears that the opportunity for uninterrupted match-play decreases in the latter stages of a half, across extended window durations, which may help explain a converse increase in low-intensity activity. Taken together, this may explain why the majority of TD and AveAcc peak match running demands occurred across the longer window durations in the early stages of each half. As such, both the TD and AveAcc peak match running demands were likely to coincide with longer periods of uninterrupted match-play, which practitioners should consider when structuring the constraints of game-based training drills targeting physical conditioning in order to maximise the ball in time.

Furthermore, the current data demonstrated that the HSD peak match running demands were uniformly distributed across each half (S_{KP} = 0.0-0.5, β_2 = 1.7-2.1). These results are similar to past research that has assessed temporal trends in total HSD where reductions were present only in the final 15 minutes of a match, with the preceding 15 minute periods requiring similar demands (Mohr et al., 2003). Additionally, the requirements sprint requirements of football players have previously been shown to be evenly distributed across a match, with slightly higher sprint demands in the first 15 min of each half and in the second half when compared to the first (Oliva-Lozano, Fortes, & Muyor, 2021). High-intensity efforts have been closely linked to crucial match events, such as creating or defending goal scoring opportunities (Faude et al., 2012; Little & Williams, 2005), which may be the case in the shorter window lengths reported in the current study. Analyses of goal timing during international level football matches demonstrates that most goals are scored in the final 15 minutes of a match, with goals scored in all preceding 15 minute periods being equally distributed (Armatas et al., 2007) (Zhao & Zhang, 2019). With goal scoring opportunities occurring frequently and randomly across a match, athletes must continue to perform at higher intensities to maximise offence and defensive success which likely explains the uniform distribution of peak match demands of HSD. It is important to note that the peak match running demands of competition have shown to differ based on factors such as micro-cycle length and positional group (Chapter 4) (Martín-Fuentes, Oliva-Lozano, Fortes, & Muyor, 2021; Oliva-Lozano, Gómez-Carmona, et al., 2021), however, due to cluster size constraints, the impact of these factors on the temporal distribution of peak match running demands were unable to be conducted in the current study and should be further investigated.

Understanding the self-containment of peak match running demands during match-play may help inform the design of training sessions and variety of drills aimed at simulating match-play. For each physical performance metric, there was increasing levels of self-containment observed for shorter peak match intensity windows as the self-containment window duration lengthened. However, differing levels of self-containment were observed at each self-containment window as peak match intensity window increased. Self-containment increased for HSD peak match periods as the self-containment window duration increased and peak match running duration decreased. Separately for TD and AveAcc, self-containment increased as window duration increased and peak match running duration increased, until 2-4 minutes, before then decreasing. Overall, there were *very low* to *moderate* levels of self-containment (<55%), which likely represents that peak periods occur frequently across a match. Further, with the decreasing margin of containment possible as peak match intensity window increases, i.e. there are more time points for which a 1 minute period can be fully contained within a 10 minute window compared to a 9 minute period, there is the possibility of increasing overlap, as opposed to containment as peak match intensity duration increases. Additionally, for HSD it appears that shorter peak match running durations may dictate when longer peak match running periods occur, while for TD and AveAcc it appears that shorter durations (1-4 min) occur more frequently in isolation during match-play. Hence, athletes are regular required to perform at peak intensities for varying lengths of time, with the *very low* to *moderate* levels of self-containment suggesting athletes should be exposed to match simulation drills of varying durations within a single session

The current study provides new insight into the temporal distribution of peak match running demands in elite football, which can help provide greater insight how to appropriately structure training sessions to prepare athletes for the most physically demanding phases of match-play (Chapters 3-5). Exposing athletes to peak match running demands in the initial stages of training will largely replicate what is experienced during match-play and may help coaches to improve athlete's ability to perform under fatigue after performing at peak match intensities. Conversely, through prescribing match simulation drills at the end of a session, may help develop the capacity of athletes to continue to perform at peak intensities while under fatigue. Further, the unpredictable nature of peak HSD demands requires athletes to perform at such intensities across all stages of a match, which should also be reflected in training. With coaches possibly aiming to expose athletes to peak match running demands across a spectrum of durations, information surrounding self-containment may aid coaches in the prescription of drills aimed at replicating the peak match running demands for various length epochs within a single drill. Alternatively, understanding that <55% of the time peak match running periods do not overlap may warrant athlete exposure to match simulation drills across various durations. As such, tailoring of drills throughout a session to promote HSD efforts may be a more conducive way to replicate match demands, rather than targeting this metric in isolation.

CONCLUSION

This study is the first to report on the temporal distribution of peak match running demands during competitive football match-play. This information provides further important context to coaches regarding when the most physically demanding periods of match-play occur, helping to provide ecological validity to match-simulation training practices. While it has previously been reported that greater running volume (TD) and Acc demands occurs in the first 15 minutes, this is the first data to show that the greatest peak demands also occur during this period. Conversely, while high-speed running demands have also shown to be greatest in the first 15 minutes before reducing across the match, the peak match running demands for HSD appear uniformly distributed across each half. With practitioners aiming to prepare athletes for the rigors of competition, the present study provides insight on when peak match running demands typically occur which may prove useful in the planning and structure of training sessions.

Chapter Seven

Summary and Conclusions

Overview

The four studies presented in this thesis have advanced the available literature on the contextual factors that affect peak match running demands in football. Together, the data provided from these studies inform practitioners of how to identify and apply peak match running demands in preparing football players for the demands of match play (see Figure 7.1). Specific to its aims, this thesis provides guidance on determining meaningful changes in peak match running demands through quantifying the between-match variation across various metrics and range of window lengths (Chapter 3). Further, the thesis identified the periods of match play where peak match running demands typically occur, providing useful information to coaches regarding when players are typically required to perform at their highest intensities (Chapter 6). Additionally, the thesis also aimed to investigate the positional, competitional and temporal variations in peak match running demands of football competition (Chapters 4 and 5). The collective studies provide rationale for the quantification of peak match running demands by positional group (Chapter 4), while also identifying the limitations of relying on youth competitions to physically prepare youth players for senior professional competitions (Chapter 5). Lastly, as coaches regularly implement training drills aimed at replicating the demands of match play, the positional and competitional demands of the current thesis help prepared players for the peak match running demands of their respective positions, while also allowing youth coaches to address competitional discrepancies during training sessions (Chapters 4 and 5). Overall, the outcomes of this thesis have expanded on the current body of literature available on peak match running demands in football. The results presented in this thesis provide a more robust framework for coaches from which to interpret peak match running demands and better inform training stimuli prescription.

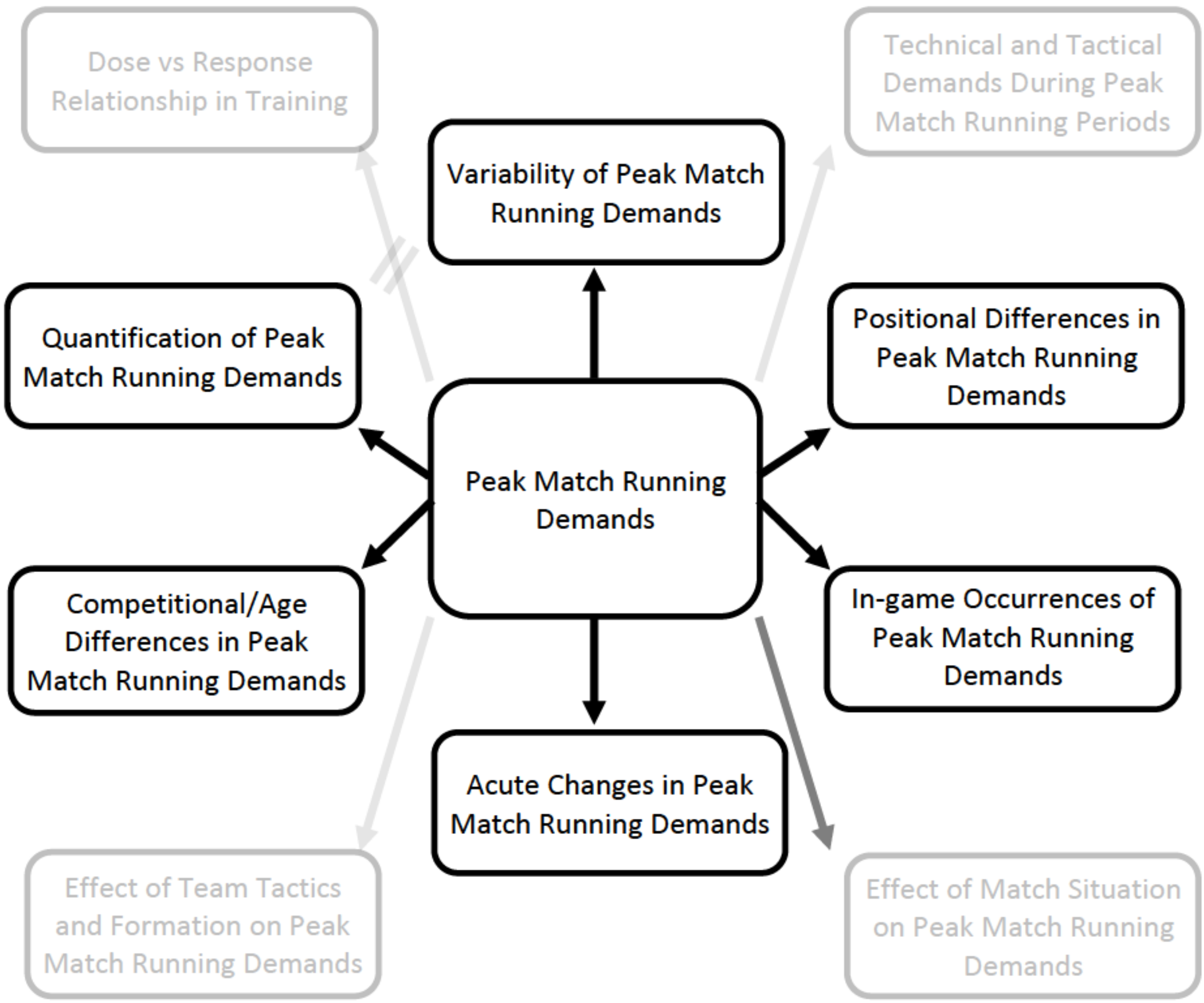

Figure 7.1: Updated schematic overview of research completed to date on peak match running demands of football. ➔ = Substantial research conducted, ➔ = Moderate research conducted, ➔ = Minimal research conducted, ≠ = No research conducted

Research Progression

The series of studies contained within this thesis provide a robust overview of peak match running demands that inform the prescription of training stimuli that are aimed at replicating the physical demands of match play. The collective understanding provided by these studies provides crucial context to coaches in both the design and implementation of the prescribed training stimuli (Figure 7.2). Firstly, the understanding of variability associated with peak match running demands (Chapter 3) provides context to interpreting the peak match running demands of different positional groups (Chapter 4), as well as different levels of competition (Chapter 5), which collectively will help coaches to tailor training demands to suit the micro-cycle and training outcomes. Further, the positional differences in peak match running demands reported in this thesis (Chapter 4) provides an understanding of how training drills should be altered to replicate the specific match running demands associated with each positional group. While positional differences were not able to be directly quantified for different levels of competition due to cluster sizes (Chapter 5), the available data demonstrated that some peak match running demands metrics differ between elite junior and senior professional level competitions. Such data helps to provide a broad picture of the prescription and monitoring of training stimuli prescribed to youth players of different positional groups. Finally, while three of the studies provide understanding and context pertaining to the magnitude of peak match running demands, the final study (Chapter 6) provides context pertaining to when peak match running demands typically occur in match play. This context allows coaches to not only prescribe training stimuli representative of match demands (Chapters 3-5), but to also prescribe the timing of this stimulus within a training session to best align with the time periods at which peak match running demands commonly occur within a match.

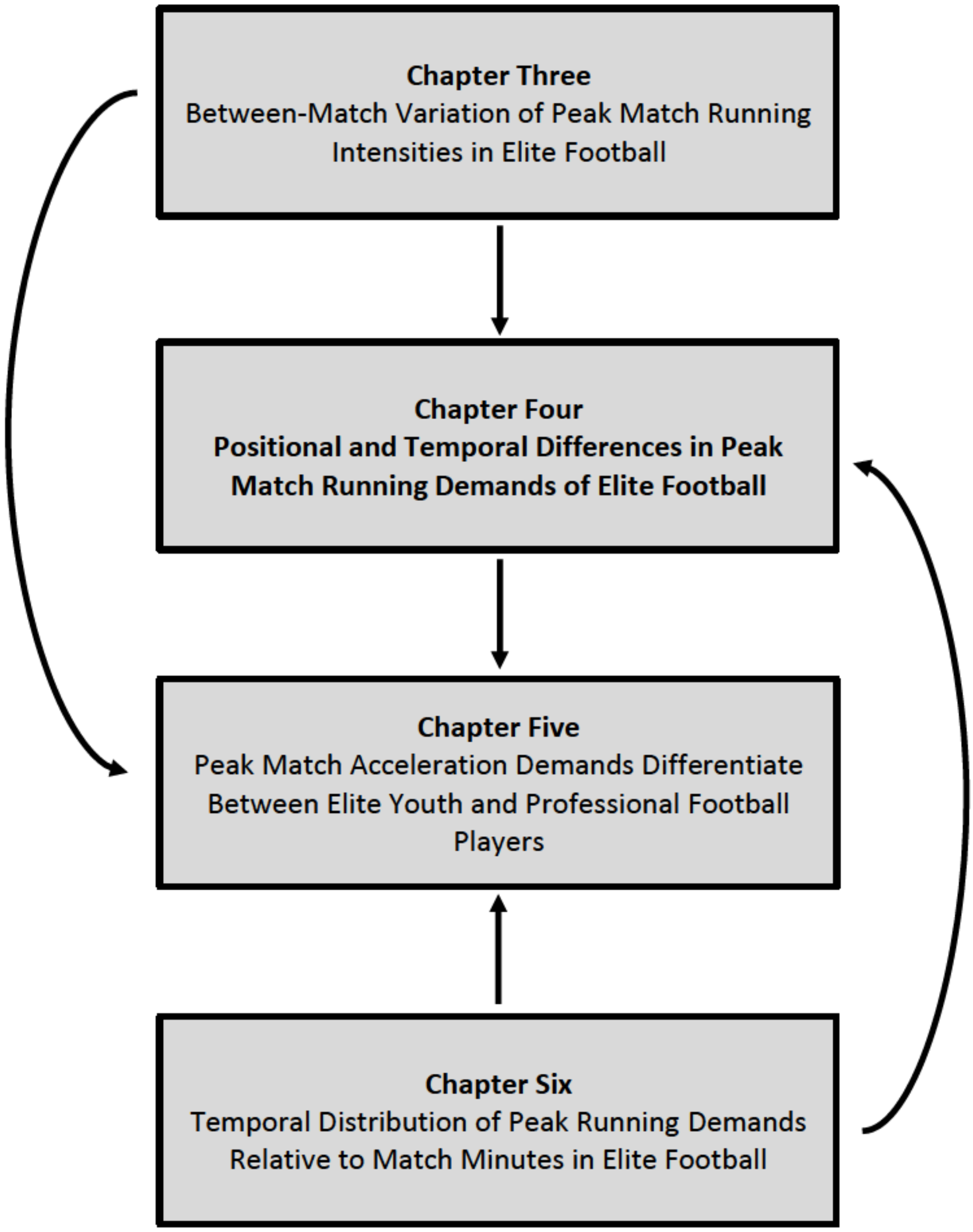

Figure 7.2. Outline of the research progress linking the major studies of this thesis.

Summary

Between-Match Variation of Peak Running Intensities in Elite Football

Peak match running demands have been employed as a novel means of quantifying match running demands of football competitions across incremental rolling average durations (1-10 min) (Delaney, Thornton, et al., 2018; Duthie et al., 2018; Fereday et al., 2020). An understanding of the match-to-match variation in peak match running demands is crucial to identify meaningful changes in performance, helping to provide context to training drills that replicate peak match running demands. While two studies have previously reported on the between-match variability of a single rolling average duration (Novak et al., 2021; Riboli, Semeria, et al., 2021), the present study was the first to comprehensively assess the between-match variation in peak match running demands across a spectrum of 1-10 min rolling average durations. Of particular interest, the between-match variation of peak match running demands were similar to that previously reported for total match volumes of TD and HSD (CV: 6.8-7.3% vs 2.4-4.3% and CV: 20.6-29.8% vs 16.2-18.1%, respectively) (Carling et al., 2016; Gregson et al., 2010; Oliva-Lozano, Muyor, et al., 2020; Rampinini et al., 2007). However, this study is the first to report on the between-match variability of the AveAcc demands across the 1-10 min rolling average durations (CV: 5.4-5.8%). These data not only provide critical context for the immediate and longitudinal analysis of peak match running demands but provide context to coaches when designing and prescribing training stimuli to replicate peak match running demands.

Positional and Temporal Differences in Peak Match Running Demands of Elite Football

Positional differences in total match running demands have previously been reported within literature, with reductions in total running volumes observed in the second half of a match (Bradley et al., 2010; Carling, 2013; Di Salvo et al., 2009; Mohr et al., 2003). However, the positional and between-half differences in the peak match running demands of football are yet to be fully investigated. This study is the first to report on the within-half between-position and between-half within-position differences in peak match running demands. In this study, reductions in the peak match running demands of TD and HSD were observed for STR in the second half (ES = 0.60-0.89 and 0.60-0.68, respectively). Further, AveAcc was lower in the second half for DM, STR, WD and WIN in the second half (ES = 0.60-0.84). Positional differences existed within each half, with STR displaying the lowest peak match running demands for both TD and AveAcc across the first and second halves. Further, centrally based positional groups (CM, DM and STR) possessed the lowest peak match running demands for HSD in both halves. This study provides rationale for the quantification of peak match running demands at a positional level. Additionally, while total match volumes of TD and HSD covered are reduced between halves, peak match running demands appear largely maintained, which indicating that the peak match running demands required of players aren't affected by the temporal fatigue that manifests in the second half of the match.

Peak Match Acceleration Demands Differentiate Between Elite Youth and Professional Football Players

Preparation of elite youth players for the transition into professional squads is a primary objective of professional football academies, and while running volumes can be developed, match running intensities are likely to be a difference between competitions due to the physical development of the professional players. Understanding the discrepancies in physical demands between youth and professional squads provides a reference point for academy coaches for which to develop the physical capacities of youth players. In this study, the total and peak match running demands of an elite youth competition were compared to the demands of a professional competition. Importantly, in this study, both teams were recruited from the same professional club and utilised the same team tactics, which is unique in such research studies. The total physical volume demands were similar between competitional levels, with the peak match running demands of TD and HSD similar across all rolling average durations (1-10 min). Importantly, it was the peak AveAcc demands that were identified to be lower in the youth competition across all rolling average durations. This suggests that elite youth players are not exposed to the peak Acc demands that are typical of professional competition. As such, for youth players to adequate prepare and transition to professional competitions, it is important that they are exposed to training sessions that facilitate higher Acc demands.

Temporal Distribution of Peak Running Demands Relative to Match Minutes in Elite Football

Temporal changes in match running performance have previously been assessed for measures of total match running demands, identifying the first and final 15 minutes of a match as to when the greatest and lowest running volumes occur, respectively (Bradley et al., 2010; Carling, 2013; Di Salvo et al., 2009; Linke et al., 2018; Mohr et al., 2003). Further, high-intensity efforts have been linked to the creation or defending of goal scoring opportunities, with the reduction in running output during the final 15 minutes of a match coinciding with an increased amount of goal scoring opportunities (Faude et al., 2012; Little & Williams, 2005; Zhao & Zhang, 2019). This would suggest that while total running volumes are reduced, the ability to perform at maximal intensities is still crucial given the capacity for such pivotal moments to influence match results. As such, this study assessed periods of a match when peak match running demands typically occur. Peak match running demands of TD and AveAcc demonstrated similar trends, with their peak match running demands occurring in the early stages of each half (median match half time = 7-17 min and 6-16 min, respectively). However, the peak match running demands of HSD covered were much more uniformly distributed across each half (Skewness = 0-0.5, Kurtosis = 1.7-2.0). Importantly, this suggests that even under fatigue, football players are required to perform at peak match running demands of high-speed running and, as such, exposure to these demands under fatigue during training would likely be beneficial in preparing for matches.

Practical Applications

Through employing peak match running demands analysis, the pitfalls of solely using total match running volumes to inform training prescription can be overcome. While it is well established that football matches are comprised of moderate to high-intensity activity that is regularly interspersed with periods of low to very-low intensity, the relative 90 min match data likely underestimates the physical demands of match-play (Chapter 4). More so, such global measures of physical demands are directly affected by the time that the ball is in play and match stoppages (Linke et al., 2018). With football conditioning drills typically designed to maximise ball in play time, the use of 90 min match average data to guide training prescription would likely be inadequate for replicating the physical demands of competition. To address this, the quantification of peak match running demands across smaller time durations, i.e. 1-10 min, allows data to be plotted using a power law curve, providing an intercept (*c*) and exponent (*n*) term, which can be used to estimate peak physical demands for a given exercise duration (*t*) using the following equation:

$$i = ct^{n}$$

For example, using an intercept value (c) of 196 and a slope value (n) of -0.17, as reported by Delaney, Thornton, et al. (2018), for a drill duration (*t*) of 5 min would provide an expected relative drill intensity of:

$$i = 196 \times 5^{-0.17}$$

$$i = {\sim}149.1\ m \cdot min^{-1}$$

While the use of the power law model to prescribe and monitor training drills is useful, the context of how this is then implemented in practice is crucial.

Collectively, the studies presented in this thesis are the first to comprehensively assess the variability and distribution of peak match running demands in football (Chapter 3), while also been the first to assess competitional, positional and temporal changes in peak match running demands (Chapters 4-6). While it is not recommended that every drill of every training session is performed at match intensities, the ability to expose players to match demands in preparation for competition are hypothesised to be beneficial. As such, careful periodisation of exposure should be considered, with the variability of peak match running demands reported in this thesis allowing coaches to tailor exposure dependent upon training priorities and outcomes (Morgans et al., 2014). For example, on a main conditioning day, coaches plan expose players to the upper range of peak match running demands, while coaches may schedule players to the lower range of intensities on a lighter session (Oliveira et al., 2019). In conjunction with this, consideration on the timing in a session when exposure to these intensities occur is also warranted (Fanchini, Ghielmetti, Coutts, Schena, & Impellizzeri, 2015). Exposure of players to peak match running demands at the early stages of a session better replicates what is experienced during match play and may help facilitate the improvement of player physical output post-maximal performance. Conversely, structuring a session to expose players to peak match running demands at the end of a session may help develop an player’s ability to perform maximally while under fatigue, which appears reflective of the match demands (Turner & Stewart, 2014). The latter is of specific consideration, with exposure to intensive small area small-sided games at the end of a session possibly aiding in the mitigation of decrements in the peak AveAcc demands observed in the second half of a match (Sanchez-Sanchez et al., 2018).

Further to these considerations, training drill design when attempting to replicate the peak match running demands of competition during training is of upmost importance (Riboli et al., 2022). Primarily, the number of players and dimensions of the pitch (area per player) used for a training drill have shown to be a determining factor in whether peak match running demands are able to be replicated (Riboli et al., 2022). A positive correlation between area per player and distance covered indicates that a larger playing area relative to player numbers would be advantageous in replicating peak match running demands of TD, HSD and VHSD, while area per player did not appear to be relevant in replicating peak Acc/Dec demands (Riboli et al., 2022). Additionally, the inclusion of a goalkeeper has shown to have a significant impact on the area needed per player in order to replicate match demands, with the minimum area per player needing to increase by ~1.5-3 times (depending on metric), when a goalkeeper is included, in order to replicate match demand (Riboli et al., 2022).

Depending on coaching philosophies, as to how players will be exposed to these demands is also important to consider due to the observed differences in positional groups. Amongst drill restrictions such as pitch size, number of players and rules, it is also important to consider the constraints placed on players relating to tactical responsibilities (Sarmento et al., 2018). The use of small-sided games without established positional roles may provide all players with the opportunity to perform at peak match running demands. However, depending on drill design, the inverse may also be true by which due to the lack of positional roles, players are either under- or over- exposed to their peak positional demands (Lacome et al., 2018). Further, the use of football drills with specific positional roles may provide greater opportunity for each positional group to perform as they would on match-day. However, these constraints may also limit a player's ability to perform at match intensities due to tactical requirements limiting their movements (Castelão, Garganta, Santos, & Teoldo, 2014).

Finally, the technical, tactical and physical balance of training drills must be taken into consideration to ensure that the objective of a session is achieved (Dellal et al., 2012). For example, in a professional environment, players are likely to be able to perform at peak match running demands without a lesser reduction in the quantity and quality of technical actions, while in a youth environment, such physical demands may be highly detrimental to their technical proficiency (Sarmento et al., 2018). As such, consideration should be given as to whether it is better to target increased physical demands and improve technical ability in these drills over time, or the inverse, and target quality and quantity of actions while increasing physical demands over time. While peak match running demands are a simple concept, its implementation in practice is much more complex, due to the multitude of factors to consider. This thesis provides information to coaches on several important considerations when physically preparing players for the peak physical demands of competition. As there is no standardised approach, it is important that coaches assess the current needs of a team when designing and periodisation training programs to appropriately prepare players for competition.

Limitations

Limitations in the present studies are primarily as a result of both constraints associated with conducting research in applied settings and the broad spectrum of player monitoring processes implemented within football. While the reported metrics in the current studies were consistent, due to the volume of available metrics from the GPS technology employed, not all commonly reported physical performance metrics were assessed. Measures of TD, HSD (>19.8 $km{\cdot}h^{-1}$) and AveAcc were reported on with the intention of providing a holistic view of a player's movement profile. Further, a standardised method of data analysis for the quantification of peak match running demands has yet to be established. As such, although the data processing techniques utilised in the current studies were consistent and methodically sound, they may not be identical to those utilised in previous research. Another limitation associated with this thesis is the limited sample size. However, this is a common limitation of research conducted in professional football and is unavoidable due to limited number of players and matches available within a team to collect data from whilst maintaining homogeneity. However, sample size was maximised through collection of data from all available players at each available match, with the statistical analyses implemented in this thesis accounting for repeated measures on each player. These analyses address a common limitation of applied research which do not account for repeated measures from the same player.

Additionally, in the collection of studies reported within this thesis, internal measures of physical performance were unable to be assessed. As such, while differences may have been reported on by positional group, match half and competition level, it is possible that the physiological cost of performing at said intensities in each of these splits may have also differed. For example, while central defenders were found to have lower peak match running demands than other positional groups, the physiological demands required to perform at such intensities may be similar across positional groups.

Conclusions

Quantification of peak match running demands has emerged as an analysis method through which the peak physical demands of competition can be determined and, from which training drills can programmed to maximise ecological validity against competition demands. The novel nature of this analysis technique has seen the need for expanded research on the topic to better inform player monitoring practices and coaches decision making when designing and implementing training drills aimed at players physical development. Therefore, the collective aim of the studies included within this thesis was to provide greater context to the peak match running demands of football competition, to better inform training practices. Specifically, the between-match variation in peak match running demands was quantified (Chapter 3), while also identifying periods of match play where peak match running demands typically occur (Chapter 6). Further, various contextual factors pertaining to positional, competitional and temporal differences in peak match running demands were also investigated (Chapters 4 and 5). Practitioners in elite football periodise training programs systematically to prepare players for the demands of match play and, as such, understanding of what is typically required both at an individual and team level is crucial to make sure players are not underprepared.

Practically, training drills are often prescribed at a team or positional level, rather than individual, with the findings of this thesis rationalising the need for peak match running demands to be quantified by positional grouping as well as by level of competition (Chapters 4 and 5). This is important as the use of team average peak match running demands will likely under-prepare some positional groups for the peak match running demands of competition (Chapter 4). Further, with the peak match running demands of youth are similar to that reported for professional competition, with the exception of AveAcc demands. Such data highlights the need for youth players to be exposed to professional peak match running demands through structured and prescribed training, in particular for higher Acc demands, (Chapter 5). Finally, the understanding of the match-to-match fluctuations in peak match running demands provides context for the identification of meaningful changes in peak match running demands, while also providing a reference point from which to prescribe and monitor training intensities (Chapter 3). The fluctuated targeting of training drill intensities at the lower, middle and upper end of the peak match running demand spectrum may allow coaches to frequently target peak match running demands across a training micro-cycle, without negatively affecting match-day performance.

Future Research Directions

Following on from this collection of studies, future areas of research that would further the understanding and application of peak match running demands are:

1. Establishment of standardised data processing techniques when quantifying peak match running demands to ensure consistency and transferability of data.

2. Quantification of the peak physiological demands of match-play and the physiological demands associated with the peak match running demands of match-play
3. Quantification of the technical demands associated with peak match running demands of competitive football match play, as this will provide more context to the balance of physical and technical requirements during peak match running periods.
4. Quantification of peak technical involvements during match play, as this understanding may allow for the preparation of worst-case scenarios through prescription of training drills that elicit peak physical and technical demands.
5. Investigations into the dose-response relationship associated with the implementation of training drills/sessions aimed at replicating the peak match running demands of competition, as this would provide useful information to coaches when periodising training plans.

Appendix A

Peak Match Running Demands Data Table

Appendix 1: Peak match running demands data taken from studies contained in this thesis.

Reference	Competition, Level of Competition and Subjects	Analysis	Metric	Position	1 min	2 min	3 min	4 min	5 min	6 min	7 min	8 min	9 min	10 min	Results
(Varley, Elias, et al., 2012)	Australian A-League Professional n = 19 Matches = 11	ROLL	TD	Team	-	-	-	-	177 ± 91	-	-	-	-	-	Roll > Fixed
		FIXED	TD	Team	-	-	-	-	142 ± 24	-	-	-	-	-	
(Delaney, Thornton, et al., 2018)	Australian A-League Professional n = 24 Matches = 40	Match Analysis	TD	CM	202 ± 13	172 ± 9	161 ± 11	152 ± 15	148 ± 14	145 ± 14	143 ± 14	139 ± 13	137 ± 13	136 ± 14	CM > CD and WIN (Based on Intercept Term)
		Match Analysis	TD	CD	178 ± 15	152 ± 13	140 ± 12	133 ± 10	129 ± 11	126 ± 10	123 ± 10	121 ± 10	120 ± 10	118 ± 10	
		Match Analysis	TD	STR	201 ± 15	169 ± 12	155 ± 13	148 ± 12	144 ± 13	140 ± 13	138 ± 12	135 ± 12	134 ± 13	132 ± 12	STR > CD and WIN (Based on Intercept Term)
		Match Analysis	TD	WD	200 ± 20	169 ± 13	156 ± 10	148 ± 10	143 ± 10	139 ± 10	136 ± 10	134 ± 10	132 ± 11	131 ± 10	WD > CD and WIN (Based on Intercept Term)
		Match Analysis	TD	WM	198 ± 17	171 ± 12	160 ± 11	152 ± 11	147 ± 12	144 ± 11	140 ± 11	138 ± 11	136 ± 12	134 ± 12	WM > CD and WIN (Based on Intercept Term)
		Match Analysis	TD	WIN	191 ± 16	160 ± 14	149 ± 13	142 ± 12	137 ± 12	133 ± 11	130 ± 11	128 ± 11	126 ± 11	124 ± 10	WIN > CD (Based on Intercept Term)
		Match Analysis	HSD (>19.8 $km{\cdot}h^{-1}$)	CM	53 ± 14	32 ± 8	24 ± 6	20 ± 7	19 ± 7	17 ± 6	16 ± 5	14 ± 5	14 ± 5	13 ± 5	CM > CD (Based on Intercept Term)
		Match Analysis	HSD (>19.8 $km{\cdot}h^{-1}$)	CD	48 ± 15	28 ± 8	22 ± 6	18 ± 5	15 ± 4	14 ± 4	13 ± 4	12 ± 3	11 ± 3	10 ± 3	
		Match Analysis	HSD (>19.8 $km{\cdot}h^{-1}$)	STR	65 ± 16	40 ± 10	31 ± 7	26 ± 6	24 ± 6	22 ± 6	20 ± 5	19 ± 6	18 ± 5	17 ± 5	STR > CM (Based on Intercept Term)
		Match Analysis	HSD (>19.8 $km{\cdot}h^{-1}$)	WD	66 ± 18	40 ± 11	31 ± 8	27 ± 7	23 ± 6	21 ± 6	20 ± 5	19 ± 5	17 ± 5	17 ± 4	WD > CD and CM (Based on Intercept Term)
		Match Analysis	HSD (>19.8 $km{\cdot}h^{-1}$)	WM	51 ± 18	30 ± 10	23 ± 8	20 ± 7	17 ± 6	16 ± 6	14 ± 5	13 ± 4	12 ± 4	11 ± 4	

		Match Analysis	HSD (>19.8 km·h^{-1})	WIN	59 ± 17	37 ± 11	29 ± 9	25 ± 7	22 ± 7	21 ± 6	19 ± 6	18 ± 5	17 ± 5	17 ± 4	WIN > CD (Based on Intercept Term)
		Match Analysis	AveAcc	CM	0.82 ± 0.06	0.68 ± 0.05	0.64 ± 0.05	0.61 ± 0.04	0.59 ± 0.04	0.58 ± 0.04	0.56 ± 0.04	0.55 ± 0.04	0.55 ± 0.04	0.54 ± 0.04	
		Match Analysis	AveAcc	CD	0.80 ± 0.06	0.68 ± 0.06	0.63 ± 0.06	0.60 ± 0.05	0.58 ± 0.06	0.57 ± 0.06	0.56 ± 0.06	0.55 ± 0.06	0.54 ± 0.05	0.53 ± 0.06	
		Match Analysis	AveAcc	STR	0.81 ± 0.06	0.67 ± 0.05	0.62 ± 0.05	0.59 ± 0.05	0.57 ± 0.05	0.56 ± 0.04	0.55 ± 0.04	0.54 ± 0.04	0.53 ± 0.04	0.52 ± 0.04	
		Match Analysis	AveAcc	WD	0.89 ± 0.07	0.75 ± 0.05	0.69 ± 0.04	0.66 ± 0.04	0.64 ± 0.03	0.63 ± 0.04	0.61 ± 0.04	0.60 ± 0.04	0.60 ± 0.04	0.59 ± 0.04	WD > All (Based on Intercept Term)
		Match Analysis	AveAcc	WM	0.82 ± 0.06	0.69 ± 0.05	0.65 ± 0.05	0.62 ± 0.05	0.60 ± 0.05	0.58 ± 0.04	0.57 ± 0.04	0.56 ± 0.04	0.55 ± 0.04	0.55 ± 0.04	
		Match Analysis	AveAcc	WIN	0.85 ± 0.07	0.71 ± 0.05	0.66 ± 0.05	0.62 ± 0.05	0.60 ± 0.05	0.58 ± 0.04	0.57 ± 0.04	0.56 ± 0.04	0.56 ± 0.04	0.55 ± 0.04	WIN > CD and STR (Based on Intercept Term)
(Fereday et al., 2020)	English Championship Professional n = 25 Matches = 28	ROLL	TD	Team	190 ± 20	157 ± 17	145 ± 15	138 ± 14	133 ± 14	130 ± 14	127 ± 13	125 ± 13	123 ± 13	121 ± 13	Roll > Fixed at All
		FIXED	TD	Team	173 ± 20	144 ± 16	135 ± 15	127 ± 14	124 ± 14	120 ± 14	119 ± 14	117 ± 14	115 ± 14	114 ± 14	
		ROLL	TD	DEF	188 ± 19	155 ± 14	143 ± 12	136 ± 11	131 ± 11	128 ± 10	125 ± 10	122 ± 10	120 ± 10	119 ± 10	Defenders > Attackers at All
		FIXED	TD	DEF	171 ± 18	143 ± 14	133 ± 12	126 ± 11	122 ± 10	119 ± 10	117 ± 11	116 ± 9	114 ± 10	112 ± 10	Defenders > Attackers at All
		ROLL	TD	MID	197 ± 20	163 ± 17	150 ± 15	143 ± 14	138 ± 14	134 ± 14	131 ± 14	129 ± 13	127 ± 13	125 ± 13	Midfielders > Attackers at All
		FIXED	TD	MID	179 ± 19	149 ± 15	139 ± 15	132 ± 14	129 ± 14	124 ± 14	122 ± 14	121 ± 14	118 ± 15	118 ± 14	Midfielders > Attackers at All
		ROLL	TD	ATT	180 ± 19	149 ± 15	139 ± 15	131 ± 15	127 ± 15	124 ± 15	122 ± 15	119 ± 14	117 ± 15	116 ± 14	
		FIXED	TD	ATT	166 ± 20	136 ± 16	128 ± 16	120 ± 14	118 ± 14	115 ± 16	114 ± 15	111 ± 15	110 ± 15	108 ± 17	

ROLL	HSD (>19.8 km·h^{-1})	Team	60 ± 23	36 ± 18	28 ± 14	24 ± 12	21 ± 12	19 ± 10	17 ± 9	16 ± 8	15 ± 7	14 ± 7	Roll > Fixed at All
FIXED	HSD (>19.8 km·h^{-1})	Team	54 ± 20	31 ± 14	24 ± 12	20 ± 10	17 ± 9	16 ± 9	14 ± 7	13 ± 7	13 ± 6	12 ± 6	
ROLL	HSD (>19.8 km·h^{-1})	DEF	60 ± 21	34 ± 16	27 ± 13	23 ± 12	20 ± 10	18 ± 9	16 ± 8	15 ± 7	14 ± 7	14 ± 6	
FIXED	HSD (>19.8 km·h^{-1})	DEF	54 ± 18	31 ± 13	23 ± 11	19 ± 9	17 ± 9	15 ± 8	14 ± 7	13 ± 6	12 ± 6	11 ± 6	
ROLL	HSD (>19.8 km·h^{-1})	MID	61 ± 26	38 ± 21	30 ± 16	25 ± 14	22 ± 13	20 ± 11	18 ± 10	17 ± 9	16 ± 8	15 ± 7	
FIXED	HSD (>19.8 km·h^{-1})	MID	55 ± 22	32 ± 16	25 ± 14	21 ± 12	18 ± 10	16 ± 10	15 ± 7	14 ± 9	13 ± 7	12 ± 6	
ROLL	HSD (>19.8 km·h^{-1})	ATT	56 ± 19	34 ± 13	27 ± 11	22 ± 10	20 ± 8	18 ± 7	16 ± 6	15 ± 6	15 ± 5	14 ± 5	
FIXED	HSD (>19.8 km·h^{-1})	ATT	51 ± 17	28 ± 10	22 ± 9	18 ± 7	17 ± 8	15 ± 6	14 ± 5	12 ± 5	12 ± 4	11 ± 5	
Match Analysis	TD	WD	195 ± 18	159 ± 15	147 ± 13	139 ± 15	134 ± 13	131 ± 13	128 ± 12	124 ± 14	122 ± 12	120 ± 12	WD > CD at 1-7'
Match Analysis	TD	CD	181 ± 17	151 ± 11	140 ± 9	133 ± 8	129 ± 7	125 ± 7	123 ± 7	121 ± 7	119 ± 6	117 ± 6	
Match Analysis	TD	CDM	194 ± 15	162 ± 13	150 ± 10	143 ± 9	139 ± 10	136 ± 10	133 ± 10	131 ± 10	129 ± 10	127 ± 10	CDM > CD at All
Match Analysis	TD	WM	192 ± 24	158 ± 20	144 ± 19	137 ± 17	132 ± 18	128 ± 17	126 ± 16	123 ± 16	121 ± 16	119 ± 16	WM > CD at 1-2'
Match Analysis	TD	CM	200 ± 17	166 ± 14	155 ± 11	147 ± 12	142 ± 11	138 ± 11	135 ± 11	132 ± 11	130 ± 11	128 ± 11	CM > CD at All
Match Analysis	TD	WIN	182 ± 21	147 ± 16	138 ± 16	130 ± 16	126 ± 17	122 ± 17	120 ± 17	117 ± 17	115 ± 17	113 ± 16	
Match Analysis	TD	STR	179 ± 18	149 ± 15	139 ± 15	132 ± 14	128 ± 13	125 ± 13	123 ± 13	120 ± 13	119 ± 13	117 ± 13	

Match Analysis	HSD (>19.8 km·h^{-1})	WD	69 ± 19	41 ± 15	32 ± 13	28 ± 13	25 ± 11	22 ± 9	20 ± 8	19 ± 7	18 ± 6	17 ± 6	WD > CD at All
Match Analysis	HSD (>19.8 km·h^{-1})	CD	51 ± 17	28 ± 10	21 ± 7	18 ± 6	16 ± 6	14 ± 5	13 ± 5	12 ± 4	11 ± 4	10 ± 4	
Match Analysis	HSD (>19.8 km·h^{-1})	CDM	52 ± 12	30 ± 8	23 ± 6	20 ± 6	17 ± 5	15 ± 4	14 ± 4	13 ± 4	12 ± 4	11 ± 3	
Match Analysis	HSD (>19.8 km·h^{-1})	WM	66 ± 26	41 ± 21	32 ± 15	27 ± 13	25 ± 14	22 ± 12	20 ± 11	19 ± 10	18 ± 9	17 ± 8	WM > CD at All
Match Analysis	HSD (>19.8 km·h^{-1})	CM	60 ± 27	38 ± 22	30 ± 18	25 ± 15	22 ± 14	20 ± 12	18 ± 10	17 ± 9	16 ± 8	15 ± 7	CM > CD at All
Match Analysis	HSD (>19.8 km·h^{-1})	WIN	59 ± 17	35 ± 9	28 ± 10	23 ± 7	20 ± 6	18 ± 5	17 ± 5	16 ± 5	15 ± 4	14 ± 4	WIN > CD at 8-10'
Match Analysis	HSD (>19.8 km·h^{-1})	STR	53 ± 17	33 ± 11	25 ± 9	21 ± 7	19 ± 6	17 ± 6	16 ± 5	15 ± 5	14 ± 5	13 ± 5	STR > CD at 8-10'
Starters	TD	Team	191 ± 19	158 ± 16	146 ± 14	139 ± 14	135 ± 13	131 ± 13	129 ± 13	126 ± 13	124 ± 13	123 ± 13	Starters > Subs at 3-10'
Substitutes	TD	Team	187 ± 24	154 ± 18	141 ± 17	133 ± 16	129 ± 15	124 ± 15	121 ± 15	119 ± 13	117 ± 13	114 ± 12	
Starters	HSD (>19.8 km·h^{-1})	Team	59 ± 19	35 ± 14	28 ± 11	23 ± 9	20 ± 9	18 ± 8	17 ± 7	16 ± 6	15 ± 6	14 ± 6	Starters > Subs at 5'
Substitutes	HSD (>19.8 km·h^{-1})	Team	61 ± 33	38 ± 26	30 ± 23	26 ± 20	23 ± 18	20 ± 15	18 ± 13	17 ± 12	15 ± 10	14 ± 9	Win > Draw at All
Win	TD	Team	195 ± 21	161 ± 18	149 ± 14	141 ± 13	137 ± 13	133 ± 12	130 ± 12	128 ± 12	126 ± 12	124 ± 12	Loss > Draw at 5-10'
Loss	TD	Team	189 ± 19	156 ± 14	145 ± 14	138 ± 13	133 ± 12	130 ± 12	127 ± 12	125 ± 12	122 ± 12	121 ± 12	Win > Draw at 1' and 7-10'
Draw	TD	Team	184 ± 19	153 ± 17	140 ± 16	134 ± 16	128 ± 16	124 ± 16	122 ± 16	119 ± 15	118 ± 15	116 ± 14	
Win	HSD (>19.8 km·h^{-1})	Team	64 ± 23	39 ± 20	30 ± 15	25 ± 14	23 ± 13	20 ± 11	19 ± 10	17 ± 8	16 ± 8	15 ± 7	

		Loss	HSD (>19.8 $km \cdot h^{-1}$)	Team	58 ± 23	35 ± 16	28 ± 14	23 ± 12	21 ± 12	19 ± 10	17 ± 9	16 ± 8	15 ± 7	14 ± 7	
		Draw	HSD (>19.8 $km \cdot h^{-1}$)	Team	56 ± 21	33 ± 15	26 ± 13	22 ± 11	19 ± 9	17 ± 8	15 ± 7	14 ± 6	13 ± 6	13 ± 5	
(Oliva-Lozano, Gómez-Carmona, et al., 2021)	Spanish La Liga 2 Professional n = 23 Matches = 13	Micro-cycle Analysis	TD	Short	198 ± 23	-	156 ± 20	-	145 ± 17	-	-	-	-	133 ± 16	
		Micro-cycle Analysis	TD	Moderate	217 ± 65	-	157 ± 26	-	141 ± 16	-	-	-	-	130 ± 12	Descriptive only
		Micro-cycle Analysis	TD	Long	201 ± 15	-	157 ± 13	-	146 ± 12	-	-	-	-	132 ± 9	
		Micro-cycle Analysis	HSD (>19.8 $km \cdot h^{-1}$)	Short	61 ± 16	-	29 ± 8	-	25 ± 7	-	-	-	-	16 ± 5	
		Micro-cycle Analysis	HSD (>19.8 $km \cdot h^{-1}$)	Moderate	61 ± 19	-	28 ± 8	-	23 ± 6	-	-	-	-	15 ± 5	Descriptive only
		Micro-cycle Analysis	HSD (>19.8 $km \cdot h^{-1}$)	Long	63 ± 14	-	32 ± 8	-	25 ± 6	-	-	-	-	17 ± 4	
		Micro-cycle Analysis	VHSD (>25.2 $km \cdot h^{-1}$)	Short	32 ± 13	-	12 ± 6	-	8 ± 4	-	-	-	-	5 ± 3	
		Micro-cycle Analysis	VHSD (>25.2 $km \cdot h^{-1}$)	Moderate	28 ± 14	-	12 ± 7	-	8 ± 5	-	-	-	-	5 ± 3	Descriptive only
		Micro-cycle Analysis	VHSD (>25.2 $km \cdot h^{-1}$)	Long	33 ± 12	-	13 ± 5	-	9 ± 4	-	-	-	-	5 ± 2	
(Casamichana et al., 2019)	Spanish La Liga Professional n = 23 Matches = 37	1st Half	TD	CD	177 ± 14	-	142 ± 9	-	131 ± 8	-	-	-	-	122 ± 7	1st > 2nd at 3'¬ 5'¬ 10' and 90'
		2nd Half	TD	CD	176 ± 12	-	135 ± 9	-	124 ± 8	-	-	-	-	114 ± 7	
		1st Half	TD	WD	190 ± 16	-	149 ± 11	-	137 ± 9	-	-	-	-	127 ± 10	1st > 2nd at 10' and 90'
		2nd Half	TD	WD	186 ± 21	-	143 ± 10	-	132 ± 9	-	-	-	-	119 ± 8	

1st Half	TD	CM	196 ± 22	-	156 ± 17	-	145 ± 15	-	-	-	-	135 ± 15	1st > 2nd at 90'
2nd Half	TD	CM	190 ± 20	-	150 ± 15	-	140 ± 14	-	-	-	-	127 ± 14	
1st Half	TD	WM	195 ± 26	-	157 ± 13	-	146 ± 12	-	-	-	-	137 ± 12	1st > 2nd at 10' and 90'
2nd Half	TD	WM	192 ± 23	-	151 ± 14	-	141 ± 12	-	-	-	-	127 ± 11	
1st Half	TD	STR	175 ± 23	-	136 ± 17	-	126 ± 15	-	-	-	-	116 ± 14	1st > 2nd at 90'
2nd Half	TD	STR	171 ± 25	-	132 ± 17	-	122 ± 14	-	-	-	-	110 ± 14	
1st Half	TD	Team	186 ± 22	-	147 ± 16	-	136 ± 11	-	-	-	-	126 ± 14	1st > 2nd at 90'
2nd Half	TD	Team	182 ± 23	-	141 ± 15	-	131 ± 14	-	-	-	-	119 ± 13	
1st Half	HMLD	CD	62 ± 12	-	36 ± 7	-	29 ± 4	-	-	-	-	24 ± 3	1st > 2nd at 90'
2nd Half	HMLD	CD	65 ± 12	-	34 ± 6	-	28 ± 4	-	-	-	-	22 ± 3	
1st Half	HMLD	WD	74 ± 17	-	42 ± 7	-	35 ± 6	-	-	-	-	29 ± 5	
2nd Half	HMLD	WD	73 ± 16	-	40 ± 8	-	33 ± 6	-	-	-	-	27 ± 5	
1st Half	HMLD	CM	70 ± 15	-	39 ± 8	-	33 ± 7	-	-	-	-	27 ± 6	
2nd Half	HMLD	CM	66 ± 15	-	37 ± 8	-	31 ± 6	-	-	-	-	25 ± 5	
1st Half	HMLD	WM	74 ± 15	-	45 ± 9	-	37 ± 8	-	-	-	-	32 ± 7	

2nd Half	HMLD	WM	74 ± 14	-	42 ± 7	-	35 ± 7	-	-	-	-	28 ± 5	
1st Half	HMLD	STR	67 ± 17	-	39 ± 8	-	32 ± 7	-	-	-	-	26 ± 6	
2nd Half	HMLD	STR	65 ± 15	-	36 ± 9	-	30 ± 7	-	-	-	-	24 ± 6	
1st Half	HMLD	Team	70 ± 16	-	40 ± 8	-	33 ± 7	-	-	-	-	27 ± 5	
2nd Half	HMLD	Team	68 ± 15	-	38 ± 8	-	31 ± 7	-	-	-	-	25 ± 5	
1st Half	AMP	CD	18 ± 1	-	13 ± 1	-	12 ± 1	-	-	-	-	11 ± 1	1st > 2nd at 3'¬ 5'¬ 10' and 90'
2nd Half	AMP	CD	17 ± 1	-	13 ± 1	-	12 ± 1	-	-	-	-	11 ± 1	
1st Half	AMP	WD	19 ± 2	-	14 ± 1	-	13 ± 1	-	-	-	-	12 ± 1	1st > 2nd at 3'¬ 5'¬ 10' and 90'
2nd Half	AMP	WD	19 ± 2	-	14 ± 1	-	13 ± 1	-	-	-	-	11 ± 1	
1st Half	AMP	CM	19 ± 2	-	15 ± 2	-	14 ± 1	-	-	-	-	13 ± 1	1st > 2nd at 90'
2nd Half	AMP	CM	18 ± 2	-	14 ± 2	-	13 ± 1	-	-	-	-	12 ± 1	
1st Half	AMP	WM	19 ± 2	-	15 ± 1	-	14 ± 1	-	-	-	-	13 ± 1	1st > 2nd at 10' and 90'
2nd Half	AMP	WM	19 ± 2	-	14 ± 1	-	13 ± 1	-	-	-	-	12 ± 1	
1st Half	AMP	STR	18 ± 2	-	13 ± 2	-	12 ± 2	-	-	-	-	11 ± 1	1st > 2nd at 90'
2nd Half	AMP	STR	17 ± 2	-	13 ± 2	-	12 ± 2	-	-	-	-	10 ± 1	

		1st Half	AMP	Team	18 ± 2	-	14 ± 2	-	13 ± 1	-	-	-	-	12 ± 1	1st > 2nd at 10' and 90'
		2nd Half	AMP	Team	18 ± 2	-	13 ± 2	-	12 ± 1	-	-	-	-	11 ± 1	
(Novak et al., 2021)	English Premier League Professional n = 26 Matches = 38	Match Analysis	TD	CM	-	-	500 ± 33	-	-	-	-	-	-	-	
		Match Analysis	TD	CD	-	-	439 ± 29	-	-	-	-	-	-	-	
		Match Analysis	TD	WD	-	-	479 ± 31	-	-	-	-	-	-	-	Positional differences only made in reference to CM; No in depth positional analysis conducted.
		Match Analysis	TD	STR	-	-	444 ± 29	-	-	-	-	-	-	-	
		Match Analysis	TD	WM	-	-	475 ± 33	-	-	-	-	-	-	-	
		Match Analysis	HSD (>19.8 km·h^{-1})	CM	-	-	91 ± 26	-	-	-	-	-	-	-	
		Match Analysis	HSD (>19.8 km·h^{-1})	CD	-	-	66 ± 20	-	-	-	-	-	-	-	
		Match Analysis	HSD (>19.8 km·h^{-1})	WD	-	-	103 ± 23	-	-	-	-	-	-	-	Positional differences only made in reference to CM; No in depth positional analysis conducted.
		Match Analysis	HSD (>19.8 km·h^{-1})	STR	-	-	97 ± 21	-	-	-	-	-	-	-	
		Match Analysis	HSD (>19.8 km·h^{-1})	WM	-	-	107 ± 25	-	-	-	-	-	-	-	
		Match Analysis	VHSD (>25.2 km·h^{-1})	CM	-	-	33 ± 18	-	-	-	-	-	-	-	
		Match Analysis	VHSD (>25.2 km·h^{-1})	CD	-	-	30 ± 15	-	-	-	-	-	-	-	Positional differences only made in reference to CM; No in depth positional analysis conducted.
		Match Analysis	VHSD (>25.2 km·h^{-1})	WD	-	-	45 ± 16	-	-	-	-	-	-	-	

		Match Analysis	VHSD (>25.2 km·h⁻¹)	STR	-	-	44 ± 18	-	-	-	-	-	-	-	
		Match Analysis	VHSD (>25.2 km·h⁻¹)	WM	-	-	47 ± 19	-	-	-	-	-	-	-	
(Riboli, Semeria, et al., 2021)	Italian Serie A Professional n = 223 Matches = 18	Match Analysis	TD	STR	177 ± 38	148 ± 34	139 ± 30	132 ± 31	129 ± 30	-	-	-	-	108 ± 43	
		Match Analysis	TD	WIN	191 ± 19	160 ± 13	150 ± 12	143 ± 12	138 ± 10	-	-	-	-	126 ± 15	
		Match Analysis	TD	CM	198 ± 27	168 ± 28	156 ± 24	150 ± 26	145 ± 24	-	-	-	-	130 ± 33	CM > STR at All; CM > CD at 1-5'; CM > WD at 2'; CM > WIN at 90'
		Match Analysis	TD	WM	198 ± 19	167 ± 18	157 ± 14	148 ± 23	143 ± 19	-	-	-	-	126 ± 37	WM > STR and WIN at 90'
		Match Analysis	TD	CD	181 ± 30	151 ± 28	141 ± 23	136 ± 26	133 ± 23	-	-	-	-	121 ± 28	
		Match Analysis	TD	WD	187 ± 27	157 ± 27	144 ± 21	140 ± 23	136 ± 21	-	-	-	-	121 ± 30	
		Match Analysis	TD	Team	188 ± 26	159 ± 24	148 ± 20	142 ± 23	138 ± 43	-	-	-	-	122 ± 29	
		Match Analysis	MSD (15-20 km·h⁻¹)	STR	48 ± 21	23 ± 13	18 ± 17	20 ± 13	13 ± 6	-	-	-	-	13 ± 3	
		Match Analysis	MSD (15-20 km·h⁻¹)	WIN	58 ± 19	29 ± 10	26 ± 14	24 ± 11	21 ± 5	-	-	-	-	15 ± 3	WIN > STR at 1'; WIN > CD at 1-4'
		Match Analysis	MSD (15-20 km·h⁻¹)	CM	68 ± 19	36 ± 12	36 ± 16	32 ± 12	27 ± 5	-	-	-	-	21 ± 4	CM > STR and CD at All; CM > WIN at 10' and 90'; CM > WD at 1-4'¬ 10' and 90'
		Match Analysis	MSD (15-20 km·h⁻¹)	WM	68 ± 20	35 ± 13	34 ± 17	32 ± 14	26 ± 6	-	-	-	-	23 ± 5	WM > STR at 1'¬ 10' and 90'; WM > CD at 1-4'¬ 10' and 90'; WM > WD at 10' and 90'
		Match Analysis	MSD (15-20 km·h⁻¹)	CD	50 ± 22	23 ± 11	18 ± 14	18 ± 12	17 ± 7	-	-	-	-	12 ± 3	
		Match Analysis	MSD (15-20 km·h⁻¹)	WD	56 ± 19	26 ± 14	24 ± 19	21 ± 14	19 ± 6	-	-	-	-	13 ± 3	

Match Analysis	MSD (15-20 km·h^{-1})	Team	58 ± 18	29 ± 12	26 ± 17	25 ± 13	21 ± 6	-	-	-	-	16 ± 3	
Match Analysis	HSD (20-24 km·h^{-1})	STR	34 ± 13	22 ± 8	16 ± 6	14 ± 5	12 ± 5	-	-	-	-	9 ± 4	
Match Analysis	HSD (20-24 km·h^{-1})	WIN	39 ± 8	22 ± 6	18 ± 4	14 ± 4	13 ± 3	-	-	-	-	10 ± 3	
Match Analysis	HSD (20-24 km·h^{-1})	CM	39 ± 12	24 ± 8	19 ± 5	16 ± 5	14 ± 4	-	-	-	-	10 ± 3	CM > STR at 2' and 90'; CM > CD at 1-4'; CM > WD at 2'
Match Analysis	HSD (20-24 km·h^{-1})	WM	41 ± 14	25 ± 9	20 ± 6	17 ± 6	15 ± 5	-	-	-	-	11 ± 4	WM > STR at 90'; WM > CD at 1-4'
Match Analysis	HSD (20-24 km·h^{-1})	CD	34 ± 11	19 ± 7	15 ± 5	13 ± 4	11 ± 4	-	-	-	-	8 ± 3	
Match Analysis	HSD (20-24 km·h^{-1})	WD	37 ± 13	22 ± 8	17 ± 6	14 ± 5	12 ± 4	-	-	-	-	9 ± 4	
Match Analysis	HSD (20-24 km·h^{-1})	Team	37 ± 12	22 ± 7	17 ± 5	15 ± 5	13 ± 5	-	-	-	-	9 ± 3	
Match Analysis	VHSD (24+ km·h^{-1})	STR	38 ± 19	21 ± 11	16 ± 8	13 ± 8	11 ± 6	-	-	-	-	7 ± 4	
Match Analysis	VHSD (24+ km·h^{-1})	WIN	46 ± 14	27 ± 9	19 ± 7	16 ± 6	13 ± 5	-	-	-	-	8 ± 3	
Match Analysis	VHSD (24+ km·h^{-1})	CM	40 ± 17	23 ± 10	16 ± 7	13 ± 6	11 ± 5	-	-	-	-	7 ± 3	CM > STR at 90'
Match Analysis	VHSD (24+ km·h^{-1})	WM	49 ± 17	27 ± 10	20 ± 8	16 ± 6	15 ± 6	-	-	-	-	9 ± 4	WM > STR at 1' and 90'; WM > CD at 1'
Match Analysis	VHSD (24+ km·h^{-1})	CD	36 ± 15	19 ± 9	14 ± 6	11 ± 5	10 ± 4	-	-	-	-	6 ± 3	
Match Analysis	VHSD (24+ km·h^{-1})	WD	44 ± 15	23 ± 9	18 ± 7	14 ± 6	11 ± 5	-	-	-	-	7 ± 3	WD > CD at 1'
Match Analysis	VHSD (24+ km·h^{-1})	Team	42 ± 16	23 ± 9	17 ± 7	14 ± 6	12 ± 6	-	-	-	-	7 ± 3	

Match Analysis	Acc/Dec Distance.	STR	29 ± 5	17 ± 3	14 ± 2	12 ± 2	11 ± 2	-	-	-	-	7 ± 2	
Match Analysis	Acc/Dec Distance.	WIN	33 ± 4	21 ± 2	16 ± 2	14 ± 1	12 ± 1	-	-	-	-	8 ± 1	
Match Analysis	Acc/Dec Distance.	CM	31 ± 4	18 ± 2	15 ± 2	12 ± 2	11 ± 2	-	-	-	-	8 ± 1	CM > STR at 1'
Match Analysis	Acc/Dec Distance.	WM	35 ± 4	21 ± 3	17 ± 2	14 ± 2	13 ± 1	-	-	-	-	9 ± 2	WM > STR and WIN at 90'
Match Analysis	Acc/Dec Distance.	CD	31 ± 4	18 ± 3	15 ± 2	12 ± 2	11 ± 2	-	-	-	-	7 ± 1	CD > CM at 1'
Match Analysis	Acc/Dec Distance.	WD	33 ± 5	20 ± 3	15 ± 2	13 ± 2	11 ± 2	-	-	-	-	8 ± 1	WD > CD at 1'
Match Analysis	Acc/Dec Distance.	Team	32 ± 7	19 ± 4	15 ± 3	13 ± 2	12 ± 3	-	-	-	-	8 ± 2	
Match Analysis	MP	STR	19 ± 4	16 ± 3	14 ± 3	13 ± 3	11 ± 6	-	-	-	-	11 ± 3	
Match Analysis	MP	WIN	20 ± 2	16 ± 2	15 ± 1	14 ± 1	13 ± 3	-	-	-	-	12 ± 2	WIN > STR at 5'; WIN > CD at 1'
Match Analysis	MP	CM	21 ± 4	17 ± 2	16 ± 2	15 ± 2	13 ± 5	-	-	-	-	13 ± 3	CM > STR at 2'¬ 4-5'¬ 10' and 90'; CM > WIN at 90'; CM > CD at 1-4'; CM > WD at 2-4' and 10'
Match Analysis	MP	WM	22 ± 8	17 ± 5	16 ± 3	15 ± 3	13 ± 4	-	-	-	-	13 ± 3	WM > STR at 5' and 90'; WM > WIN at 90'; WM > CD at 1'
Match Analysis	MP	CD	19 ± 4	16 ± 3	14 ± 2	14 ± 2	13 ± 3	-	-	-	-	12 ± 2	CD > STR at 5'
Match Analysis	MP	WD	20 ± 3	16 ± 3	14 ± 2	14 ± 3	12 ± 4	-	-	-	-	12 ± 3	
Match Analysis	MP	Team	20 ± 4	16 ± 3	15 ± 2	14 ± 2	13 ± 4	-	-	-	-	12 ± 3	
Match Analysis	HMLD	STR	86 ± 23	60 ± 17	52 ± 13	46 ± 13	36 ± 20	-	-	-	-	35 ± 13	

		Match Analysis	HMLD	WIN	94 ± 17	66 ± 12	56 ± 9	51 ± 9	44 ± 13	-	-	-	-	39 ± 8	WIN > STR at 5'; WIN > CD at 1-3'
		Match Analysis	HMLD	CM	103 ± 17	75 ± 14	64 ± 10	59 ± 11	50 ± 18	-	-	-	-	46 ± 11	CM > STR and CD at All; CM > WD at 1-4'¬ 10' and 90'; CM > WIN at 90'
		Match Analysis	HMLD	WM	103 ± 21	75 ± 16	64 ± 13	57 ± 13	50 ± 18	-	-	-	-	45 ± 12	WM > STR at 1-2'¬ 5' and 90'; WM > WIN at 90'; WM > CD at 1-2' and 90'; WM > WD at 90'
		Match Analysis	HMLD	CD	88 ± 20	60 ± 13	52 ± 11	46 ± 10	42 ± 12	-	-	-	-	36 ± 9	
		Match Analysis	HMLD	WD	92 ± 24	65 ± 17	54 ± 13	49 ± 13	43 ± 16	-	-	-	-	38 ± 13	WD > CD at 1'
		Match Analysis	HMLD	Team	94 ± 20	67 ± 15	57 ± 12	51 ± 11	44 ± 16	-	-	-	-	40 ± 11	
(Hills et al., 2020)	English Championship Professional n = 33 Matches = 44	Substitute Match Analysis	TD	Team	188 ± 22	158 ± 18	145 ± 16	137 ± 15	132 ± 14	128 ± 14	125 ± 13	122 ± 13	120 ± 13	119 ± 13	
		Substitute Match Analysis	HSD (>19.8 km·h^{-1})	Team	50 ± 20	30 ± 12	23 ± 9	20 ± 8	18 ± 7	16 ± 6	14 ± 6	14 ± 5	13 ± 5	12 ± 5	Descriptive only
		Substitute Match Analysis	AveAcc	Team	0.89 ± 0.29	0.72 ± 0.2	0.65 ± 0.19	0.61 ± 0.19	0.58 ± 0.19	0.55 ± 0.20	0.53 ± 0.20	0.51 ± 0.21	0.49 ± 0.23	0.47 ± 0.24	
(Martín-García et al., 2018)	Spanish Liga 2 B Youth n = 23 Matches = 37	Match Analysis	TD	CD	182 ± 16	-	143 ± 10	-	133 ± 8	-	-	-	-	123 ± 7	
		Match Analysis	TD	WD	195 ± 16	-	152 ± 9	-	139 ± 8	-	-	-	-	128 ± 8	WD > CD and STR at All
		Match Analysis	TD	CM	204 ± 15	-	161 ± 9	-	150 ± 7	-	-	-	-	140 ± 8	CM > CD and STR at All; CM > WD at 3 , 5' and 10'
		Match Analysis	TD	WM	201 ± 19	-	157 ± 16	-	146 ± 16	-	-	-	-	135 ± 16	WM > CD and STR at All; WM > WD at 10'
		Match Analysis	TD	STR	181 ± 20	-	138 ± 16	-	128 ± 14	-	-	-	-	117 ± 13	
		Match Analysis	TD	Team	192 ± 20	-	149 ± 15	-	138 ± 14	-	-	-	-	127 ± 13	

		Match Analysis	HMLD	CD	68 ± 13	-	37 ± 7	-	29 ± 5	-	-	-	-	23 ± 4	
		Match Analysis	HMLD	WD	80 ± 6	-	45 ± 7	-	37 ± 6	-	-	-	-	30 ± 5	WD > CD and STR at All
		Match Analysis	HMLD	CM	77 ± 3	-	42 ± 6	-	36 ± 5	-	-	-	-	29 ± 4	CM > CD at All
		Match Analysis	HMLD	WM	80 ± 1	-	45 ± 8	-	38 ± 8	-	-	-	-	32 ± 7	WM > CD at All; WM > STR at 3-10'
		Match Analysis	HMLD	STR	72 ± 5	-	41 ± 8	-	33 ± 7	-	-	-	-	27 ± 6	STR > CD at 5-10'
		Match Analysis	HMLD	Team	75 ± 5	-	42 ± 8	-	35 ± 7	-	-	-	-	28 ± 6	
		Match Analysis	AMP	CD	18 ± 1	-	13 ± 1	-	12 ± 1	-	-	-	-	11 ± 1	
		Match Analysis	AMP	WD	19 ± 2	-	15 ± 1	-	13 ± 1	-	-	-	-	12 ± 1	WD > CD and STR at All
		Match Analysis	AMP	CM	20 ± 1	-	15 ± 1	-	14 ± 1	-	-	-	-	13 ± 1	CM > CD and STR at All; CM > WD at 5-10'
		Match Analysis	AMP	WM	20 ± 2	-	15 ± 1	-	14 ± 1	-	-	-	-	13 ± 1	WM > CD and STR at All; CM > WD at 10'
		Match Analysis	AMP	STR	18 ± 2	-	14 ± 2	-	12 ± 2	-	-	-	-	11 ± 1	
		Match Analysis	AMP	Team	19 ± 2	-	14 ± 1	-	13 ± 1	-	-	-	-	12 ± 1	
(Duthie et al., 2018)	Australian National Premier League Youth n = 96 Matches = 61	Match Analysis	TD	WIN	200 ± 17	169 ± 14	158 ± 12	151 ± 12	147 ± 12	143 ± 11	140 ± 11	138 ± 11	136 ± 11	135 ± 10	WIN > DEF (Based on Intercept Term)
		Match Analysis	TD	MID	199 ± 15	173 ± 12	162 ± 11	156 ± 10	152 ± 10	148 ± 10	146 ± 10	144 ± 10	142 ± 10	141 ± 10	MID > ATT and DEF (Based on Intercept Term); MID > ATT and WIN (Based on Slope Term)
		Match Analysis	TD	DEF	188 ± 13	162 ± 11	151 ± 11	145 ± 10	141 ± 10	137 ± 10	135 ± 10	134 ± 9	132 ± 9	130 ± 10	

		Match Analysis	TD	ATT	195 ± 20	166 ± 15	155 ± 14	149 ± 13	145 ± 13	141 ± 13	139 ± 12	137 ± 12	135 ± 12	134 ± 12	
		Match Analysis	AveAcc	WIN	1.84 ± 0.25	1.68 ± 0.22	1.61 ± 0.22	1.56 ± 0.21	1.53 ± 0.21	1.51 ± 0.21	1.49 ± 0.21	1.48 ± 0.21	1.46 ± 0.2	1.45 ± 0.2	
		Match Analysis	AveAcc	MID	1.86 ± 0.25	1.69 ± 0.23	1.61 ± 0.22	1.57 ± 0.22	1.54 ± 0.21	1.51 ± 0.21	1.49 ± 0.21	1.48 ± 0.2	1.46 ± 0.2	1.45 ± 0.2	
		Match Analysis	AveAcc	DEF	1.81 ± 0.23	1.63 ± 0.22	1.55 ± 0.21	1.51 ± 0.2	1.48 ± 0.2	1.45 ± 0.2	1.44 ± 0.19	1.42 ± 0.2	1.41 ± 0.19	1.4 ± 0.19	
		Match Analysis	AveAcc	ATT	1.81 ± 0.23	1.65 ± 0.22	1.57 ± 0.21	1.53 ± 0.21	1.5 ± 0.21	1.47 ± 0.2	1.45 ± 0.2	1.44 ± 0.2	1.43 ± 0.19	1.41 ± 0.19	
		Match Analysis	MP	WIN	27.2 ± 3.6	22.4 ± 2.9	20.7 ± 2.6	19.6 ± 2.5	18.9 ± 2.4	18.3 ± 2.3	17.9 ± 2.2	17.6 ± 2.2	17.4 ± 2.1	17.1 ± 2	WIN > DEF (Based on Intercept Term)
		Match Analysis	MP	MID	26.9 ± 3.4	22.7 ± 2.6	20.9 ± 2.3	20.1 ± 2.2	19.4 ± 2.2	18.9 ± 2.1	18.5 ± 2.1	18.2 ± 2	17.9 ± 1.9	17.7 ± 2	MID > DEF (Based on Intercept Term); MID > WIN (Based on Slope Term)
		Match Analysis	MP	DEF	25.1 ± 2.7	21 ± 2.2	19.2 ± 2.1	18.4 ± 2.1	17.7 ± 2	17.2 ± 1.9	16.9 ± 1.9	16.6 ± 1.8	16.4 ± 1.8	16.2 ± 1.8	
		Match Analysis	MP	ATT	26 ± 3.7	21.7 ± 3.1	20 ± 2.9	19 ± 2.6	18.4 ± 2.5	17.9 ± 2.5	17.5 ± 2.4	17.2 ± 2.4	16.9 ± 2.4	16.7 ± 2.4	
(Doncaster et al., 2020)	English U23 Professional Development League Youth n = 29 Matches = 17	FIXED	TD	Team	-	-	142 (140 - 144)	-	134 (131 - 136)	-	-	-	-	-	Fixed > Roll at All
		ROLL	TD	Team	-	-	148 (146 - 151)	-	139 (137 - 141)	-	-	-	-	-	
		FIXED	HSD (>19.8 km·h^{-1})	Team	-	-	26 (24 - 28)	-	19 (18 - 21)	-	-	-	-	-	Fixed > Roll at All
		ROLL	HSD (>19.8 km·h^{-1})	Team	-	-	29 (27 - 31)	-	22 (20 - 24)	-	-	-	-	-	
		FIXED	MP	Team	-	-	25 (24 - 26)	-	22 (21 - 23)	-	-	-	-	-	Fixed > Roll at All
		ROLL	MP	Team	-	-	27 (26 - 28)	-	24 (23 - 25)	-	-	-	-	-	

		Match Analysis	TD	ATT	163 (157 - 169)	-	133 (127 - 140)	-	125 (119 - 131)	-	-	-	-	-	
		Match Analysis	TD	CD	175 (172 - 178)	-	141 (137 - 144)	-	131 (127 - 134)	-	-	-	-	-	CD > ATT at 1'
		Match Analysis	TD	CM	193 (190 - 197)	-	162 (159 - 165)	-	151 (148 - 154)	-	-	-	-	-	CM > ATT and CD at All; CM > WD at 3'
		Match Analysis	TD	WD	183 (176 - 189)	-	148 (141 - 154)	-	140 (134 - 146)	-	-	-	-	-	WD > ATT at 1'
		Match Analysis	TD	WD	193 (188 - 197)	-	155 (150 - 160)	-	145 (141 - 150)	-	-	-	-	-	WD > ATT at All; WD > CD at 1' and 3'
		Match Analysis	TD	WM	183 (176 - 190)	-	153 (146 - 160)	-	144 (138 - 151)	-	-	-	-	-	WM > ATT at All; WM > CD at 3' and 5'
		Match Analysis	HSD (>19.8 km·h^{-1})	ATT	49 (44 - 54)	-	26 (21 - 32)	-	19 (14 - 24)	-	-	-	-	-	
		Match Analysis	HSD (>19.8 km·h^{-1})	CD	53 (50 - 55)	-	23 (20 - 25)	-	16 (13 - 19)	-	-	-	-	-	
		Match Analysis	HSD (>19.8 km·h^{-1})	CM	55 (52 - 57)	-	28 (25 - 31)	-	22 (19 - 24)	-	-	-	-	-	
		Match Analysis	HSD (>19.8 km·h^{-1})	WD	57 (52 - 63)	-	31 (25 - 37)	-	27 (22 - 32)	-	-	-	-	-	WD > CD at 5'
		Match Analysis	HSD (>19.8 km·h^{-1})	WD	65 (61 - 69)	-	31 (27 - 35)	-	25 (21 - 29)	-	-	-	-	-	WD > CD at All; WD > ATT and CM at 1'
		Match Analysis	HSD (>19.8 km·h^{-1})	WM	65 (59 - 70)	-	35 (29 - 41)	-	24 (19 - 30)	-	-	-	-	-	WM > CD at 1' and 3'; WM > ATT and CM and 1'
(Connor et al., 2021)	English Championship Professional n = 28 Matches = 23	Match Analysis	TD	CD	178	151	139	132	128	125	122	120	118	117	
		Match Analysis	TD	Str	194	164	154	146	141	137	133	130	128	126	
		Match Analysis	TD	CM	202	169	158	151	146	143	140	138	134	133	CM > WM

		Match Analysis	TD	WD	200	163	151	144	139	134	131	129	128	126	
		Match Analysis	TD	WM	188	150	138	131	126	123	119	116	115	113	
		Match Analysis	TD	Team	193 (174 - 212)	159 (144 - 173)	147 (133 - 161)	140 (127 - 154)	136 (123 - 148)	132 (119 - 144)	129 (116 - 141)	126 (114 - 139)	124 (112 - 135)	122 (111 - 134)	
(Oliva-Lozano, Fortes, & M. Muyor, 2021).	Spanish La Liga 2 Professional n = 20 Matches = 13	Match Analysis	TD	CD	187 ± 34	-	142 ± 28	-	131 ± 18	-	-	-	-	119 ± 10	
		Match Analysis	TD	STR	206 ± 37	-	156 ± 17	-	144 ± 13	-	-	-	-	132 ± 13	
		Match Analysis	TD	WM	203 ± 13	-	156 ± 11	-	145 ± 8	-	-	-	-	132 ± 7	Descriptive only
		Match Analysis	TD	WD	207 ± 21	-	159 ± 13	-	143 ± 9	-	-	-	-	131 ± 7	
		Match Analysis	TD	CM	202 ± 23	-	158 ± 17	-	147 ± 13	-	-	-	-	132 ± 8	
		Match Analysis	TD	Team	201 ± 27	-	155 ± 18	-	142 ± 13	-	-	-	-	130 ± 10	
		Match Analysis	HSD (>19.8 $km \cdot h^{-1}$)	CD	52 ± 14	-	25 ± 7	-	18 ± 5	-	-	-	-	12 ± 3	
		Match Analysis	HSD (>19.8 $km \cdot h^{-1}$)	STR	62 ± 16	-	29 ± 7	-	22 ± 6	-	-	-	-	16 ± 4	
		Match Analysis	HSD (>19.8 $km \cdot h^{-1}$)	WM	71 ± 13	-	35 ± 7	-	27 ± 6	-	-	-	-	19 ± 4	Descriptive only
		Match Analysis	HSD (>19.8 $km \cdot h^{-1}$)	WD	69 ± 14	-	34 ± 8	-	25 ± 6	-	-	-	-	18 ± 3	
		Match Analysis	HSD (>19.8 $km \cdot h^{-1}$)	CM	53 ± 16	-	25 ± 7	-	19 ± 5	-	-	-	-	13 ± 4	
		Match Analysis	HSD (>19.8 $km \cdot h^{-1}$)	Team	62 ± 16	-	30 ± 8	-	22 ± 6	-	-	-	-	16 ± 5	

Match Analysis	SD (>25.2 km·h^{-1})	CD	27 ± 8	-	10 ± 4	-	7 ± 3	-	-	-	-	4 ± 2	
Match Analysis	SD (>25.2 km·h^{-1})	STR	30 ± 13	-	12 ± 5	-	8 ± 3	-	-	-	-	4 ± 2	
Match Analysis	SD (>25.2 km·h^{-1})	WM	39 ± 14	-	17 ± 7	-	11 ± 5	-	-	-	-	8 ± 3	Descriptive only
Match Analysis	SD (>25.2 km·h^{-1})	WD	34 ± 10	-	14 ± 5	-	10 ± 3	-	-	-	-	6 ± 2	
Match Analysis	SD (>25.2 km·h^{-1})	CM	21 ± 13	-	7 ± 4	-	5 ± 3	-	-	-	-	3 ± 2	
Match Analysis	SD (>25.2 km·h^{-1})	Team	30 ± 14	-	12 ± 6	-	8 ± 4	-	-	-	-	5 ± 3	
Match Analysis	Acc	CD	3.4 ± 0.6	-	1.8 ± 0.4	-	1.4 ± 0.3	-	-	-	-	1 ± 0.2	
Match Analysis	Acc	STR	3.3 ± 0.9	-	1.8 ± 0.5	-	1.4 ± 0.3	-	-	-	-	1.1 ± 0.3	
Match Analysis	Acc	WM	4.2 ± 0.9	-	2.3 ± 0.4	-	1.7 ± 0.3	-	-	-	-	1.3 ± 0.2	Descriptive only
Match Analysis	Acc	WD	4 ± 1	-	2.1 ± 0.6	-	1.6 ± 0.4	-	-	-	-	1.2 ± 0.3	
Match Analysis	Acc	CM	3.8 ± 0.8	-	2.1 ± 0.4	-	1.6 ± 0.3	-	-	-	-	1.2 ± 0.2	
Match Analysis	Acc	Team	3.8 ± 0.9	-	2.0 ± 0.5	-	1.6 ± 0.4	-	-	-	-	1.2 ± 0.3	
Match Analysis	Dec	CD	4.1 ± 1.1	-	2.3 ± 0.5	-	1.8 ± 0.3	-	-	-	-	1.4 ± 0.2	
Match Analysis	Dec	STR	4.2 ± 1	-	2.4 ± 0.5	-	1.9 ± 0.4	-	-	-	-	1.4 ± 0.3	Descriptive only
Match Analysis	Dec	WM	5 ± 0.9	-	2.7 ± 0.5	-	2.1 ± 0.4	-	-	-	-	1.7 ± 0.3	

		Match Analysis	Dec	WD	4.5 ± 1.2	-	2.5 ± 0.5	-	2 ± 0.3	-	-	-	-	1.5 ± 0.2	
		Match Analysis	Dec	CM	4.4 ± 1.1	-	2.5 ± 0.6	-	2 ± 0.5	-	-	-	-	1.5 ± 0.4	
		Match Analysis	Dec	Team	4.5 ± 1.1	-	2.5 ± 0.5	-	2 ± 0.4	-	-	-	-	1.5 ± 0.3	
(Oliva-Lozano, Rojas-Valverde, et al., 2020)	Spanish La Liga 2 Professional n = 23 Matches = 13	Match Analysis	TD	CD	168 ± 32	-	132 ± 22	-	120 ± 18	-	-	-	-	108 ± 14	
		Match Analysis	TD	WD	188 ± 31	-	148 ± 22	-	134 ± 18	-	-	-	-	117 ± 16	WD > CD at 3-10'
		Match Analysis	TD	STR	186 ± 61	-	145 ± 27	-	132 ± 19	-	-	-	-	117 ± 17	STR > CD at 3-10'
		Match Analysis	TD	CM	201 ± 142	-	153 ± 60	-	140 ± 38	-	-	-	-	124 ± 24	CM > CD at All; CM > WM at 3-10'; WM > STR at 5' and 10'
		Match Analysis	TD	WM	187 ± 43	-	144 ± 21	-	131 ± 18	-	-	-	-	116 ± 17	WM > CD at 3-10'
		Match Analysis	HSD (>19.8 km·h^{-1})	CD	53 ± 133	-	17 ± 11	-	13 ± 8	-	-	-	-	8 ± 7	
		Match Analysis	HSD (>19.8 km·h^{-1})	WD	67 ± 136	-	25 ± 11	-	18 ± 9	-	-	-	-	13 ± 6	WD > CD at 3-10'; WD > CM at 5' and 10'
		Match Analysis	HSD (>19.8 km·h^{-1})	STR	60 ± 126	-	21 ± 10	-	16 ± 8	-	-	-	-	11 ± 6	
		Match Analysis	HSD (>19.8 km·h^{-1})	CM	65 ± 159	-	22 ± 44	-	16 ± 27	-	-	-	-	10 ± 14	CM > CD at 5'
		Match Analysis	HSD (>19.8 km·h^{-1})	WM	60 ± 97	-	25 ± 11	-	19 ± 9	-	-	-	-	13 ± 7	WM > CD at 3-10'; WM > CM at 5' and 10'; WM > STR at 10'
		Match Analysis	VHSD (>25.2 km·h^{-1})	CD	17 ± 11	-	6 ± 6	-	4 ± 4	-	-	-	-	2 ± 2	
		Match Analysis	VHSD (>25.2 km·h^{-1})	WD	22 ± 13	-	9 ± 7	-	6 ± 5	-	-	-	-	4 ± 3	

Match Analysis	VHSD (>25.2 km·h^{-1})	STR	19 ± 13	-	7 ± 6	-	5 ± 4	-	-	-	-	3 ± 2	STR > CD at 10'
Match Analysis	VHSD (>25.2 km·h^{-1})	CM	29 ± 14	-	10 ± 5	-	7 ± 2	-	-	-	-	3 ± 2	
Match Analysis	VHSD (>25.2 km·h^{-1})	WM	26 ± 16	-	11 ± 7	-	7 ± 6	-	-	-	-	4 ± 4	WM > CD and STR at 10'
1st Half	TD	Team	217 ± 157	-	159 ± 58	-	144 ± 36	-	-	-	-	132 ± 20	1st > 2nd at All
2nd Half	TD	Team	191 ± 23	-	147 ± 17	-	136 ± 14	-	-	-	-	124 ± 11	
1st Half	HSD (>19.8 km·h^{-1})	Team	66 ± 125	-	30 ± 42	-	22 ± 25	-	-	-	-	14 ± 13	
2nd Half	HSD (>19.8 km·h^{-1})	Team	53 ± 18	-	25 ± 9	-	18 ± 7	-	-	-	-	12 ± 5	
1st Half	VHSD (>25.2 km·h^{-1})	Team	37 ± 120	-	14 ± 39	-	9 ± 24	-	-	-	-	5 ± 12	
2nd Half	VHSD (>25.2 km·h^{-1})	Team	26 ± 14	-	10 ± 6	-	7 ± 4	-	-	-	-	4 ± 3	
Win	TD	Team	227 ± 20	-	157 ± 31	-	139 ± 14	-	-	-	-	124 ± 14	Win > Draw and Loss at 1'; Win > Loss at 3'
Draw	TD	Team	197 ± 29	-	152 ± 12	-	137 ± 17	-	-	-	-	122 ± 13	Draw > Loss at 3'
Loss	TD	Team	193 ± 16	-	138 ± 17	-	138 ± 12	-	-	-	-	125 ± 10	
Win	HSD (>19.8 km·h^{-1})	Team	73 ± 15	-	31 ± 55	-	23 ± 3	-	-	-	-	15 ± 1	Win > Draw and Loss at 1'
Draw	HSD (>19.8 km·h^{-1})	Team	57 ± 18	-	27 ± 9	-	20 ± 7	-	-	-	-	14 ± 4	
Loss	HSD (>19.8 km·h^{-1})	Team	63 ± 13	-	29 ± 8	-	22 ± 7	-	-	-	-	16 ± 5	

		Win	VHSD (>25.2 km·h^{-1})	Team	42 ± 15	-	16 ± 5	-	11 ± 3	-	-	-	-	7 ± 1	Win > Draw and Loss at 1 and 3'
		Draw	VHSD (>25.2 km·h^{-1})	Team	28 ± 14	-	11 ± 6	-	8 ± 4	-	-	-	-	6 ± 2	
		Loss	VHSD (>25.2 km·h^{-1})	Team	31 ± 13	-	12 ± 6	-	9 ± 5	-	-	-	-	6 ± 3	
		Home	TD	Team	288 ± 49	-	200 ± 36	-	178 ± 27	-	-	-	-	154 ± 20	Away > Home at All
		Away	TD	Team	335 ± 49	-	216 ± 122	-	186 ± 75	-	-	-	-	161 ± 42	
		Home	HSD (>19.8 km·h^{-1})	Team	66 ± 25	-	30 ± 42	-	22 ± 25	-	-	-	-	14 ± 13	Away > Home at 3-10'
		Away	HSD (>19.8 km·h^{-1})	Team	53 ± 144	-	25 ± 9	-	18 ± 7	-	-	-	-	12 ± 5	
		Home	VHSD (>25.2 km·h^{-1})	Team	28 ± 14	-	11 ± 5	-	7 ± 4	-	-	-	-	4 ± 3	Away > Home at All
		Away	VHSD (>25.2 km·h^{-1})	Team	39 ± 13	-	15 ± 4	-	10 ± 2	-	-	-	-	5 ± 2	
(Oliva-Lozano, Martín-Fuentes, et al., 2021)	Spanish La Liga 2 Professional n = 19 Matches = 12	FIXED	TD	CD	174 ± 31	-	135 ± 29	-	122 ± 15	-	-	-	-	113 ± 9	Roll > Fixed at All
		ROLL	TD	CD	187 ± 36	-	143 ± 30	-	130 ± 18	-	-	-	-	118 ± 10	
		FIXED	TD	WD	186 ± 18	-	145 ± 8	-	133 ± 9	-	-	-	-	123 ± 8	Roll > Fixed at All
		ROLL	TD	WD	215 ± 50	-	164 ± 29	-	144 ± 15	-	-	-	-	130 ± 8	
		FIXED	TD	STR	188 ± 21	-	145 ± 15	-	133 ± 14	-	-	-	-	119 ± 21	Roll > Fixed at All
		ROLL	TD	STR	209 ± 38	-	157 ± 19	-	143 ± 14	-	-	-	-	132 ± 13	

FIXED	TD	CM	190 ± 30	-	145 ± 14	-	135 ± 14	-	-	-	-	122 ± 15	Roll > Fixed at All
ROLL	TD	CM	208 ± 34	-	159 ± 18	-	147 ± 14	-	-	-	-	132 ± 9	
FIXED	TD	WM	194 ± 35	-	146 ± 9	-	134 ± 8	-	-	-	-	124 ± 11	Roll > Fixed at All
ROLL	TD	WM	211 ± 34	-	157 ± 10	-	145 ± 8	-	-	-	-	132 ± 7	
FIXED	HSD (>19.8 km·h^{-1})	CD	50 ± 11	-	20 ± 5	-	16 ± 4	-	-	-	-	10 ± 2	Roll > Fixed at All
ROLL	HSD (>19.8 km·h^{-1})	CD	54 ± 14	-	24 ± 7	-	19 ± 5	-	-	-	-	11 ± 2	
FIXED	HSD (>19.8 km·h^{-1})	WD	65 ± 11	-	30 ± 9	-	23 ± 8	-	-	-	-	16 ± 2	Roll > Fixed at All
ROLL	HSD (>19.8 km·h^{-1})	WD	78 ± 24	-	36 ± 9	-	27 ± 6	-	-	-	-	18 ± 4	
FIXED	HSD (>19.8 km·h^{-1})	STR	60 ± 13	-	28 ± 6	-	20 ± 6	-	-	-	-	13 ± 4	Roll > Fixed at All
ROLL	HSD (>19.8 km·h^{-1})	STR	67 ± 16	-	30 ± 6	-	23 ± 7	-	-	-	-	16 ± 4	
FIXED	HSD (>19.8 km·h^{-1})	CM	43 ± 13	-	23 ± 5	-	16 ± 5	-	-	-	-	12 ± 5	Roll > Fixed at All
ROLL	HSD (>19.8 km·h^{-1})	CM	52 ± 19	-	26 ± 6	-	20 ± 6	-	-	-	-	14 ± 6	
FIXED	HSD (>19.8 km·h^{-1})	WM	64 ± 16	-	30 ± 6	-	24 ± 5	-	-	-	-	16 ± 4	Roll > Fixed at All
ROLL	HSD (>19.8 km·h^{-1})	WM	72 ± 14	-	34 ± 7	-	27 ± 6	-	-	-	-	19 ± 4	
FIXED	SD (>25.2 km·h^{-1})	CD	26 ± 10	-	10 ± 3	-	6 ± 2	-	-	-	-	4 ± 2	Roll > Fixed at All

		ROLL	SD (>25.2 $km\cdot h^{-1}$)	CD	30 ± 12	-	12 ± 5	-	7 ± 2	-	-	-	-	5 ± 2	
		FIXED	SD (>25.2 $km\cdot h^{-1}$)	WD	39 ± 12	-	13 ± 5	-	8 ± 3	-	-	-	-	5 ± 2	Roll > Fixed at All
		ROLL	SD (>25.2 $km\cdot h^{-1}$)	WD	66 ± 36	-	17 ± 9	-	11 ± 5	-	-	-	-	7 ± 3	
		FIXED	SD (>25.2 $km\cdot h^{-1}$)	STR	28 ± 16	-	12 ± 5	-	8 ± 3	-	-	-	-	4 ± 2	Roll > Fixed at All
		ROLL	SD (>25.2 $km\cdot h^{-1}$)	STR	33 ± 21	-	14 ± 6	-	9 ± 4	-	-	-	-	5 ± 2	
		FIXED	SD (>25.2 $km\cdot h^{-1}$)	CM	15 ± 18	-	5 ± 6	-	4 ± 4	-	-	-	-	3 ± 2	Roll > Fixed at All
		ROLL	SD (>25.2 $km\cdot h^{-1}$)	CM	18 ± 19	-	6 ± 6	-	19 ± 5	-	-	-	-	3 ± 3	
		FIXED	SD (>25.2 $km\cdot h^{-1}$)	WM	43 ± 13	-	15 ± 5	-	11 ± 4	-	-	-	-	8 ± 3	Roll > Fixed at All
		ROLL	SD (>25.2 $km\cdot h^{-1}$)	WM	51 ± 15	-	20 ± 6	-	14 ± 5	-	-	-	-	9 ± 3	
(Lord et al., 2020)	Australian A-League Professional n = 24 Matches = 27	Professional	MMS	CD	3.0 ± 0.9	-	-	-	2.3 ± 0.6	-	-	-	-	2.1 ± 0.6	
		Professional	MMS	WD	3.3 ± 0.8	-	-	-	2.3 ± 0.6	-	-	-	-	2.2 ± 0.6	
	Australian National Premier League Youth n = 22 Matches = 26	Professional	MMS	CM	3.4 ± 0.8	-	-	-	2.6 ± 0.5	-	-	-	-	2.4 ± 0.6	Statistics reported but variability in data would make these results inconclusive
		Professional	MMS	WM	3.5 ± 0.9	-	-	-	2.5 ± 1.1	-	-	-	-	2.4 ± 1.2	
		Professional	MMS	STR	3.3 ± 0.9	-	-	-	2.4 ± 0.9	-	-	-	-	2.3 ± 1.0	
		Youth	MMS	CD	3.2 ± 0.8	-	-	-	2.4 ± 0.9	-	-	-	-	2.3 ± 1.1	

Youth	MMS	WD	3.4 ± 0.8	-	-	-	2.6 ± 1.1	-	-	-	-	2.5 ± 1.3	
Youth	MMS	CM	3.5 ± 0.8	-	-	-	2.7 ± 0.6	-	-	-	-	2.5 ± 0.7	
Youth	MMS	WM	3.4 ± 0.6	-	-	-	2.5 ± 0.4	-	-	-	-	2.4 ± 0.5	
Youth	MMS	STR	3.4 ± 0.8	-	-	-	2.5 ± 0.7	-	-	-	-	2.3 ± 0.6	
Professional	MP	CD	17.7 ± 1.3	-	-	-	12.6 ± 0.8	-	-	-	-	11.6 ± 0.9	
Professional	MP	WD	19.1 ± 1.5	-	-	-	13.2 ± 1.0	-	-	-	-	12.3 ± 1.0	
Professional	MP	CM	18.8 ± 1.3	-	-	-	14.0 ± 0.8	-	-	-	-	13.0 ± 0.8	
Professional	MP	WM	20.0 ± 2.0	-	-	-	14.2 ± 1.6	-	-	-	-	13.2 ± 1.7	
Professional	MP	STR	19.2 ± 1.2	-	-	-	13.8 ± 1.8	-	-	-	-	12.9 ± 1.9	Statistics reported but variability in data would make these results inconclusive
Youth	MP	CD	18.3 ± 1.4	-	-	-	13.6 ± 1.6	-	-	-	-	12.9 ± 1.9	
Youth	MP	WD	19.5 ± 1.5	-	-	-	14.8 ± 2.4	-	-	-	-	14.0 ± 2.8	
Youth	MP	CM	19.5 ± 0.9	-	-	-	14.9 ± 1.2	-	-	-	-	14.1 ± 1.4	
Youth	MP	WM	19.5 ± 1.0	-	-	-	14.4 ± 1.6	-	-	-	-	13.6 ± 1.8	
Youth	MP	STR	18.7 ± 1.0	-	-	-	13.4 ± 0.8	-	-	-	-	12.6 ± 0.7	

(Ju et al., 2021)	English Premier League Professional n = 583 Matches = 50	Match Analysis	HSD (>19.8 km·h^{-1})	CD	55 ± 17	-	24 ± 7	-	17 ± 5	-	-	-	-	-	
		Match Analysis	HSD (>19.8 km·h^{-1})	WD	76 ± 18	-	35 ± 8	-	26 ± 7	-	-	-	-	-	WD > CD and CM at All
		Match Analysis	HSD (>19.8 km·h^{-1})	CM	68 ± 17	-	32 ± 10	-	23 ± 7	-	-	-	-	-	CM > CD at All
		Match Analysis	HSD (>19.8 km·h^{-1})	WIN	76 ± 16	-	36 ± 7	-	27 ± 5	-	-	-	-	-	WIN > CD at All; WIN > CM at 1' and 5'
		Match Analysis	HSD (>19.8 km·h^{-1})	STR	71 ± 14	-	32 ± 7	-	25 ± 6	-	-	-	-	-	STR > CD at All
		Match Analysis	HSD (>19.8 km·h^{-1})	Team	67 ± 19	-	31 ± 9	-	23 ± 7	-	-	-	-	-	
(Martín-Fuentes et al., 2021)	Spanish La Liga 2 Professional n = 21 Matches = 14	Match Analysis	TD	WM	204 ± 3	-	156 ± 13	-	146 ± 7	-	-	-	-	133 ± 4	WM > CD at All
		Match Analysis	TD	CM	201 ± 3	-	156 ± 11	-	143 ± 13	-	-	-	-	133 ± 7	CM > CD at All
		Match Analysis	TD	WD	208 ± 5	-	160 ± 19	-	143 ± 11	-	-	-	-	130 ± 7	WD > CD at All
		Match Analysis	TD	STR	204 ± 6	-	156 ± 14	-	143 ± 13	-	-	-	-	132 ± 11	STR > CD at All
		Match Analysis	TD	CD	181 ± 2	-	137 ± 9	-	127 ± 9	-	-	-	-	118 ± 7	
		Match Analysis	HSD (19.8-25.2 km·h^{-1})	WM	72 ± 13	-	36 ± 5	-	27 ± 7	-	-	-	-	21 ± 2	WM > CM and CD at All; WM > STR at 3-10' (P< 0.05)
		Match Analysis	HSD (19.8-25.2 km·h^{-1})	CM	54 ± 15	-	26 ± 8	-	20 ± 4	-	-	-	-	14 ± 5	
		Match Analysis	HSD (19.8-25.2 km·h^{-1})	WD	70 ± 13	-	34 ± 9	-	26 ± 6	-	-	-	-	17 ± 4	WD > CM and CD at All; WD > STR at 3-10' (P< 0.05)
		Match Analysis	HSD (19.8-25.2 km·h^{-1})	STR	63 ± 15	-	30 ± 7	-	23 ± 5	-	-	-	-	16 ± 5	

		Match Analysis	HSD (19.8-25.2 km·h^{-1})	CD	54 ± 14	-	26 ± 7	-	19 ± 4	-	-	-	-	12 ± 4	
		Match Analysis	SD (>25.2 km·h^{-1})	WM	41 ± 13	-	17 ± 7	-	12 ± 4	-	-	-	-	7 ± 4	WM > CM, STR and CD at All
		Match Analysis	SD (>25.2 km·h^{-1})	CM	22 ± 13	-	8 ± 4	-	6 ± 3	-	-	-	-	3 ± 2	
		Match Analysis	SD (>25.2 km·h^{-1})	WD	34 ± 11	-	14 ± 5	-	10 ± 3	-	-	-	-	6 ± 2	WD > CM at All; WD > CD at 5-10'
		Match Analysis	SD (>25.2 km·h^{-1})	STR	31 ± 14	-	12 ± 6	-	9 ± 2	-	-	-	-	5 ± 1	STR > CM at 1-5'
		Match Analysis	SD (>25.2 km·h^{-1})	CD	27 ± 8	-	11 ± 5	-	7 ± 2	-	-	-	-	4 ± 1	
		Substitute Match Analysis	TD	Starters	201 ± 21	-	156 ± 17	-	144 ± 11	-	-	-	-	132 ± 11	
		Substitute Match Analysis	TD	Subs	199 ± 20	-	154 ± 14	-	144 ± 11	-	-	-	-	130 ± 11	
		Substitute Match Analysis	HSD (19.8-25.2 km·h^{-1})	Starters	64 ± 15	-	31 ± 7	-	24 ± 5	-	-	-	-	16 ± 5	Starters > Subs at All
		Substitute Match Analysis	HSD (19.8-25.2 km·h^{-1})	Subs	54 ± 17	-	26 ± 7	-	21 ± 7	-	-	-	-	14 ± 5	
		Substitute Match Analysis	SD (>25.2 km·h^{-1})	Starters	32 ± 13	-	13 ± 6	-	9 ± 4	-	-	-	-	6 ± 2	Starters > Subs at All
		Substitute Match Analysis	SD (>25.2 km·h^{-1})	Subs	23 ± 15	-	8 ± 6	-	6 ± 4	-	-	-	-	3 ± 2	
(Calder & Gabbett, 2022)	USA Major League Soccer Professional n = 24 Matches = 31	1st Half - 4-2-3-1	TD	CD	176 ± 13	148 ± 8	139 ± 7	-	130 ± 10	-	-	-	-	119 ± 9	1st Half > 2nd Half at 2-10'; 4-2-3-1 > 3-4-3 at 1'
		1st Half - 4-2-3-1	TD	WD	198 ± 15	164 ± 11	154 ± 9	-	142 ± 8	-	-	-	-	128 ± 8	1st Half > 2nd Half at 1-5'; 4-2-3-1 > 4-3-3 at 3-5'
		1st Half - 4-2-3-1	TD	CDM	203 ± 15	173 ± 11	162 ± 9	-	153 ± 8	-	-	-	-	140 ± 8	1st Half > 2nd Half at All

1st Half - 4-2-3-1	TD	AM	199 ± 8	175 ± 8	164 ± 8	-	153 ± 9	-	-	-	-	139 ± 15	1st Half > 2nd Half at 2-10'; 4-2-3-1 > 3-4-3 at 2-10'
1st Half - 4-2-3-1	TD	WIN	199 ± 13	169 ± 14	158 ± 12	-	146 ± 12	-	-	-	-	133 ± 9	1st Half > 2nd Half at All; 4-2-3-1 > 3-4-3 at 3-5'
1st Half - 4-2-3-1	TD	STR	174 ± 13	147 ± 8	139 ± 9	-	129 ± 9	-	-	-	-	117 ± 9	1st Half > 2nd Half at All
2nd Half - 4-2-3-1	TD	CD	173 ± 17	143 ± 15	134 ± 13	-	122 ± 11	-	-	-	-	111 ± 9	
2nd Half - 4-2-3-1	TD	WD	190 ± 22	159 ± 14	147 ± 12	-	137 ± 12	-	-	-	-	125 ± 11	4-2-3-1 > 4-3-3 at 2' and 5-10'
2nd Half - 4-2-3-1	TD	CDM	194 ± 18	165 ± 13	155 ± 12	-	144 ± 13	-	-	-	-	130 ± 11	
2nd Half - 4-2-3-1	TD	AM	199 ± 12	171 ± 8	159 ± 7	-	148 ± 9	-	-	-	-	136 ± 8	4-2-3-1 > 3-4-3 at All
2nd Half - 4-2-3-1	TD	WIN	185 ± 18	156 ± 12	144 ± 12	-	134 ± 13	-	-	-	-	122 ± 11	
2nd Half - 4-2-3-1	TD	STR	167 ± 19	139 ± 13	127 ± 13	-	116 ± 12	-	-	-	-	106 ± 9	4-2-3-1 > 4-3-3 at 1-2'
1st Half - 3-4-3	TD	CD	170 ± 10	147 ± 9	136 ± 19	-	129 ± 9	-	-	-	-	117 ± 9	1st Half > 2nd Half at 10'
1st Half - 3-4-3	TD	CDM	199 ± 18	174 ± 10	163 ± 11	-	150 ± 12	-	-	-	-	138 ± 10	
1st Half - 3-4-3	TD	AM	197 ± 15	167 ± 11	158 ± 11	-	147 ± 9	-	-	-	-	136 ± 7	1st Half > 2nd Half at 2-10'
1st Half - 3-4-3	TD	WIN	196 ± 15	165 ± 13	152 ± 12	-	142 ± 10	-	-	-	-	130 ± 9	
1st Half - 3-4-3	TD	STR	171 ± 21	144 ± 15	135 ± 19	-	129 ± 16	-	-	-	-	117 ± 12	1st Half > 2nd Half at 10'
2nd Half - 3-4-3	TD	CD	182 ± 28	152 ± 15	139 ± 12	-	127 ± 13	-	-	-	-	113 ± 11	2nd Half > 1st Half at 1-2'; 3-4-3 > 4-3-3 at 1-5'; 3-4-3 > 4-2-3-1 at 2' and 5'

2nd Half - 3-4-3	TD	CDM	202 ± 14	174 ± 9	164 ± 10	-	150 ± 11	-	-	-	-	138 ± 6	3-4-3 > 4-2-3-1 at All
2nd Half - 3-4-3	TD	AM	192 ± 11	161 ± 15	150 ± 10	-	136 ± 9	-	-	-	-	125 ± 8	
2nd Half - 3-4-3	TD	WIN	194 ± 17	165 ± 14	152 ± 11	-	139 ± 10	-	-	-	-	124 ± 11	3-4-3 > 4-2-3-1 at 1-5'
2nd Half - 3-4-3	TD	STR	171 ± 17	142 ± 14	130 ± 14	-	119 ± 12	-	-	-	-	107 ± 9	3-4-3 formation > 4-3-3 at 1-3'
1st Half - 4-3-3	TD	CD	179 ± 15	152 ± 13	145 ± 10	-	133 ± 7	-	-	-	-	119 ± 6	1st Half > 2nd Half at All; 4-3-3 > 3-4-3 at 1-5'
1st Half - 4-3-3	TD	WD	192 ± 22	159 ± 16	149 ± 11	-	137 ± 9	-	-	-	-	128 ± 9	1st Half > 2nd Half at 3-10'
1st Half - 4-3-3	TD	CDM	205 ± 16	181 ± 13	172 ± 10	-	162 ± 7	-	-	-	-	146 ± 6	1st half > 2nd Half at 2-10'; 4-3-3 > 3-4-3 and 4-2-3-1 at 2-10'
1st Half - 4-3-3	TD	CM	198 ± 12	171 ± 13	160 ± 14	-	152 ± 15	-	-	-	-	137 ± 12	1st Half > 2nd Half at 1' and 10'
1st Half - 4-3-3	TD	WIN	201 ± 15	172 ± 8	161 ± 7	-	150 ± 8	-	-	-	-	136 ± 9	1st Half > 2nd Half at All; 4-3-3 > 3-4-3 at 2-10'
1st Half - 4-3-3	TD	STR	188 ± 18	154 ± 15	143 ± 15	-	132 ± 14	-	-	-	-	117 ± 9	1st Half > 2nd Half at All; 4-3-3 > 3-4-3 at 2'
2nd Half - 4-3-3	TD	CD	170 ± 13	145 ± 9	133 ± 9	-	121 ± 9	-	-	-	-	109 ± 7	
2nd Half - 4-3-3	TD	WD	184 ± 14	153 ± 7	144 ± 8	-	132 ± 7	-	-	-	-	117 ± 8	
2nd Half - 4-3-3	TD	CDM	203 ± 16	170 ± 10	160 ± 11	-	151 ± 8	-	-	-	-	136 ± 11	4-3-3 > 4-2-3-1 at 1' and 5-10'
2nd Half - 4-3-3	TD	CM	190 ± 13	167 ± 12	154 ± 11	-	145 ± 11	-	-	-	-	129 ± 13	
2nd Half - 4-3-3	TD	WIN	194 ± 10	161 ± 5	147 ± 6	-	141 ± 5	-	-	-	-	126 ± 7	4-3-3 > 4-2-3-1 at 1-2' and 5-10'

2nd Half - 4-3-3	TD	STR	157 ± 13	129 ± 7	122 ± 8	-	113 ± 10	-	-	-	-	103 ± 7	
1st Half - 4-3-1-2	TD	CD	178 ± 9	157 ± 13	145 ± 12	-	135 ± 9	-	-	-	-	127 ± 12	4-3-1-2 >3-4-3 at All; 4-3-1-2 > 4-2-3-1 at 2-10'; 4-3-1-2 > 4-3-3 at 10'
1st Half - 4-3-1-2	TD	WD	199 ± 11	167 ± 8	157 ± 8	-	145 ± 8	-	-	-	-	133 ± 5	1st Half > 2nd Half at 10'; 4-3-1-2 > 4-3-3 at 2-10'; 4-3-1-2 > 4-2-3-1 at 10'
1st Half - 4-3-1-2	TD	CM	206 ± 7	176 ± 7	166 ± 10	-	156 ± 8	-	-	-	-	142 ± 6	1st Half > 2nd Half at 5-10'; 4-3-1-2 > 4-3-3 at 1'
1st Half - 4-3-1-2	TD	AM	221 ± 9	188 ± 17	178 ± 18	-	168 ± 15	-	-	-	-	150 ± 5	1st Half > 2nd Half at All; 4-3-1-2 > 3-4-3 and 4-2-3-1 at All
1st Half - 4-3-1-2	TD	STR	187 ± 16	168 ± 19	158 ± 20	-	141 ± 15	-	-	-	-	128 ± 8	1st Half > 2nd Half at All; 4-3-1-2 > 3-4-3 and 4-2-3-1 at All; 4-3-1-2 > 4-3-3 at 2-3' and 10'
2nd Half - 4-3-1-2	TD	CD	186 ± 9	161 ± 17	153 ± 15	-	142 ± 14	-	-	-	-	123 ± 11	2nd Half > 1st half at 1' and 3-5'; 4-3-1-2 > 4-3-3 and 4-2-3-1 at All; 4-3-1-2 > 3-4-3 at 2-10'
2nd Half - 4-3-1-2	TD	WD	197 ± 9	169 ± 16	154 ± 13	-	140 ± 12	-	-	-	-	126 ± 11	4-3-1-2 > 4-3-3 at All; 4-3-1-2 > 4-2-3-1 at 1-5'
2nd Half - 4-3-1-2	TD	CM	210 ± 9	175 ± 4	164 ± 8	-	152 ± 5	-	-	-	-	138 ± 7	2nd Half > 1st Half at 1'; 4-3-1-2 > 4-3-3 at All; 4-3-1-2 > 4-2-3-1 at 1-5'
2nd Half - 4-3-1-2	TD	AM	207 ± 5	170 ± 1	158 ± 10	-	146 ± 11	-	-	-	-	133 ± 8	4-3-1-2 > 3-4-3 at All; 4-3-1-2 > 4-2-3-1 at 1'
2nd Half - 4-3-1-2	TD	STR	173 ± 18	150 ± 17	137 ± 12	-	126 ± 14	-	-	-	-	113 ± 12	4-3-1-2 > 4-3-3 at All; 4-2-3-1 > 4-2-3-1 at 2-10'

Acc = Accelerations; Acc/Dec = Acceleration and deceleration; AM = Attacking midfielder; AMP = Average metabolic power; ATT = Attackers; AveAcc = Average acceleration; CD = Central defender; CDM = Central defensive midfielder; CM = Central midfielder; Dec = Decelerations; DEF = Defenders; FIXED = Fixed average duration; HMLD = High metabolic load distance; HSD = High-speed distance; MID = Midfielders; MMS = Maximal mean speed; MP = Metabolic power; MSD = Moderate speed distance; n = Number of players; ROLL = Rolling average duration; STR = Striker; TD = Total distance; Team = Team average; VHSD = Very high-speed distance; WD = Wide defender; WIN = Winger; WM = Wide midfielder

Appendix B

Participant Information Statement, Consent Form and Withdrawal of Consent Form

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Participant Information Statement for the Research Project:
THE EFFECT OF TRAINING LOADS ON IMMUNE-ENDOCRINE FUNCTION AND SLEEP ACTIVITY IN ELITE FOOTBALL
Document Version 1; dated 29/07/2022

You are invited to participate in the research project being conducted by Mr Bradley Thoseby, under the supervision of Dr Ben Dascombe, from the School of Allied Health at La Trobe University as part of a PhD thesis in exercise and sport science.

Why is the research being done?

The primary aim of the research is to investigate the interactions between acute and chronic training loads, match demands, sleep activity and immune-endocrine status in elite football athletes across a competitive season. The data aims to inform coaching staff on the varying individual physiological responses that occur in response to the imposed training loads in order to further the understanding of athlete monitoring and reduce the risk of injury and illness.

Who can participate in the research?

We are seeking elite male and female football players aged 18-40 to participate in the research. To be able to participate the participant must be free of any medical conditions that may identify the participant to be at higher risk of injury or discomfort during the activities. Participants should have no pre-existing medical issues that may be worsened as a result of completing the research project. Pregnant women are excluded from the study.

What choice does the participant have?

Only those people who provide informed consent will be included in the project. No one will be disadvantaged by their choice to participate or not. You have the right to withdraw from active participation in this project at any time. At any stage during the study, you will be able to withdraw your consent for the use of any previously collected data, with no resultant adverse consequences. You may also request that data arising from your participation are not used in the research

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project provided that this right is exercised within four weeks of the completion of your participation in the project. You are asked to complete the "Withdrawal of Consent Form" or to notify the researcher by email or telephone that you wish to withdraw your consent for your data to be used in this research project

What would the participant be asked to do?
The participant will be asked to complete the following testing protocols:

Exercise Testing
During all training and matches the amount of exercise completed by participants will be quantified in order to identify physical loads undertaken.

GPS Monitoring: Participants will be required to wear a GPS monitor during both training and matches in order to analyse the distance and speeds that exercise is performed at. No extra commitments will be required outside of what is required as part of your regular training and match schedules scheduled as per your club and FFA governing body.

Resistance Training: Participants will be required to complete regular gym programs as scheduled by your club.

Player Monitoring
In order to quantify internal training loads, participants will be required to report on difficulty of training sessions. This will allow us to understand how different individuals respond to similar training stimuli.

Internal Training Loads: Participants will be required to give a self-reported rating of perceived exertion score after each training and gym session, as well as post-match reflecting how hard the session or game was, on a scale of 1-10.

Sleep Measures
Sleep activity will be assessed in order to both understand how sleep affects recovery and how varying training loads affect sleep. These measures will be collected non-invasively.
Sleep Activity: Participants will be required to wear a Fitbit® Charge HR wrist actigraphy watch for two nights prior to a match, the night after a match and two nights post-match on a fortnightly basis.

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Physiological Measures

During your clubs weekly post-match screening slots, physiological responses will be measured to gain an understanding of what's happening within the body. As such, the following physiological measures will be monitored during the exercise testing. All measures are collected non-invasively.

> *Saliva sample:* A passive saliva sample (~0.5 mL) will be collected by yourself, using an oral collection fluid swab, fortnightly during club screening procedures, in order to monitor hormonal concentrations and immune function. This saliva will be stored for analysis within a laboratory for the analysis of hormones and immune markers. Saliva will be analysed for salivary cortisol, salivary testosterone and salivary immunoglobin A. No other tests of saliva will be undertaken other than those listed for the purposes of the study.

How much time will it take?

Data collection will run for the entirety of the season, however, time required outside of standard procedures set by the football club will be minimal. Each saliva collection will take 2-3 minutes, every fortnight, to complete. Fitbits will be worn for five nights of sleep on a fortnightly basis, however, all you will need to do is wear the fitbit. Charging and data download will be conducted by the researcher.

What are the risks and benefits of participating?

All training and gym sessions, as well as matches, will be performed as part of your contractual agreements to the club under the supervision of both coaches and high-performance staff. No extra physical injury risks will be present as a result of participating in this study. Saliva collection will be conducted by the participant themselves, using sterile oral fluid collection swabs, ensuring no risk of cross contamination or infection.

Following the study, you will be able to receive a report detailing the general findings of the study, with individual performance results, including training loads and sleep activity been given weekly. Further, this research will benefit the wider scientific and athletic community by identifying interactions between training loads, sleep and immune-endocrine function, in order to better understand how athletes respond to training.

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How will privacy be protected?

The confidentiality of this study is assured. Under no circumstances will any names appear on publications associated with this research. The individual results will be provided in verbal and written form to participants. High performance staff at Melbourne City FC will also have access to the data as part of routine monitoring practices. The data been presented to the staff is in line with your current monitoring practices, with no new data or method of monitoring occurring from your inclusion in this study. Results will only be available to the research team and Melbourne City FC high performance staff. Hard copies of results will be stored in a locked filing cabinet along with backed up data stored securely in the filing cabinet. All electronic data will be stored in password protected databases on password protected hard drives. Data will not be managed and stored as per the club's internal legal policies.

Following the completion of the study, confidentiality will be ensured by replacing names with a numerical code. The data will be retained for a minimum of seven (7) years, at La Trobe University (Bundoora Campus). This is in accordance with the La Trobe University Data and Materials Management Policy. All data will be discarded as per the La Trobe University policy to ensure that confidentiality is assured. Participants may request a copy of their personal data collected throughout the course of the research.

How will the information collected be used?

Data will be presented in scientific journals and conferences following the conclusion of the project. All presentation and use of data will be as group and descriptive measures, not individual responses. All collected information will be de-identified and be made available to Melbourne City FC high-performance staff. The data collected from this research may also be used for any additional future closely related research.

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College of Science, Health and Engineering

School of Allied Health

Department of Rehabilitation, Nutrition and Sport

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What needs to be done to participate?

Please read this Information Statement and be sure you understand its contents before you consent to participate. If there is anything you do not understand, or you have questions, contact the researcher.

If you would like to participate, please email the chief investigator on the details below. You will then be required to complete a consent form prior to participation.

If you are a suitable participant for this study, you will be informed of this upon completion of the consent form and clearance from your club.

Further information

If you would like further information, please contact Bradley Thoseby or Ben Dascombe.

Thank you for considering this invitation.

[redacted]

[redacted]

Bradley Thoseby
Student Investigator
Investigator
Mobile: 0432 971 775
Email: bthoseby@ltu.edu.au
B.Dascombe@latrobe.edu.au

Dr Ben Dascombe
Project Supervisor/Chief

Phone: +613 9479 6277
Email:

Complaints about this research

This project has been approved by the University's Human Research Ethics Committee, Approval No. 18056

If you have any complaints or concerns about your participation in the study that the researcher has not been able to answer to your satisfaction, you may contact the Senior Human Ethics Officer, Ethics and Integrity, Research Office, La Trobe University, Victoria, 3086 (P: 03 9479 1443, E: humanethics@latrobe.edu.au). Please quote the application reference number 18056

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LA TROBE UNIVERSITY

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Consent Form for the Research Project:

THE EFFECT OF TRAINING LOADS ON IMMUNE-ENDOCRINE FUNCTION AND SLEEP ACTIVITY IN ELITE FOOTBALL

Document Version 1; dated 15/6/18

I (the participant) have read (or, where appropriate, have had read to me) and understood the participant information statement and consent form, and any questions I have asked have been answered to my satisfaction. I agree to participate in the project, realising that I may withdraw consent at any time. I agree that research data provided by me or with my permission during the project may be included in a thesis, presented at conferences and published in journals on the condition that neither my name nor any other identifying information is used. I also agree that any collected data may be shared with the high-performance staff at Melbourne City Football Club.

Name of Participant: ___________________________________

Signature: ___________________________________

Date: ___________________________________

Please indicate whether or not you wish to receive a summary of the results Y N

Phone: ____

Email: ____

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Name of Investigator: ___________________________________

Signature: ___________________________________

Date: ___________________________________

Name of Student Supervisor: ___________________________________

Signature: ___________________________________

Date: ___________________________________

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La Trobe University
University Human Ethics Committee

Withdrawal of Consent for Use of Data Form

Project Title: THE EFFECT OF TRAINING LOADS ON IMMUNE-ENDOCRINE FUNCTION AND SLEEP ACTIVITY IN ELITE FOOTBALL

I, ________________ , wish to WITHDRAW my consent to the use of data arising from my participation in this project. Data arising from my participation must NOT be used in this research project as described in the Participant Information Statement and Consent Form. I understand that data arising from my participation will be destroyed provided this request is received within **four weeks** of the completion of my participation in this project. I understand that this notification will be retained together with my consent form as evidence of the withdrawal of my consent to use the data I have provided specifically for this research project.

Participant's name (printed):

……………………………………………………

Signature:

……………………………………………………

Date:

Please return this form to Bradley Thoseby, E: bthoseby@ltu.edu.au, Tel: 0432 971 775.
Ethics approval reference number: 18056

Appendix C

Author Contribution to Published Research

All studies presented in this thesis (Chapters 3-6) were contributed to by the same supervisory panel as per the contributions outlined below.

Chapter 3: Between-match variation of peak match running intensities in elite football.

Bradley Thoseby and Ben Dascombe developed the concept and design of the research project. Acquisition of all research data was conducted solely by Bradley Thoseby. Andrew Govus contributed statistical knowledge in developing the statistical analyses undertaken in this study. Manuscript write-up was completed by Bradley Thoseby, with critical revision of the study conducted by Andrew Govus, Ben Dascombe, Anthea Clarke and Kane Middleton. Revisions were made by Bradley Thoseby considering feedback provided by Andrew Govus, Ben Dascombe, Anthea Clarke and Kane Middleton.

Chapter 4: Positional and Temporal Differences in Peak Match Running Demands of Elite Football

Bradley Thoseby and Ben Dascombe developed the concept and design of the research project. Acquisition of all research data was conducted solely by Bradley Thoseby. Andrew Govus contributed statistical knowledge in developing the statistical analyses undertaken in this study. Manuscript write-up was completed by Bradley Thoseby, with critical revision of the study conducted by Andrew Govus, Ben Dascombe, Anthea Clarke and Kane Middleton. Revisions were made by Bradley Thoseby considering feedback provided by Andrew Govus, Ben Dascombe, Anthea Clarke and Kane Middleton.

Chapter 5: Peak Match Acceleration Demands Differentiate Between Elite Youth and Professional Football Players

Bradley Thoseby and Ben Dascombe developed the concept and design of the research project. Acquisition of all research data was conducted solely by Bradley Thoseby. Andrew Govus contributed statistical knowledge in developing the statistical analyses undertaken in this study. Manuscript write-up was completed by Bradley Thoseby, with critical revision of the study conducted by Andrew Govus, Ben Dascombe, Anthea Clarke and Kane Middleton. Revisions were made by Bradley Thoseby considering feedback provided by Andrew Govus, Ben Dascombe, Anthea Clarke and Kane Middleton.

Chapter 6: Temporal Distribution of Peak Running Demands Relative to Match Minutes in Elite Football.

Bradley Thoseby and Ben Dascombe developed the concept and design of the research project. Acquisition of all research data was conducted solely by Bradley Thoseby. Andrew Govus contributed statistical knowledge in developing the statistical analyses undertaken in this study. Manuscript write-up was completed by Bradley Thoseby, with critical revision of the study conducted by Andrew Govus, Ben Dascombe, Anthea Clarke and Kane Middleton. Revisions were made by Bradley Thoseby considering feedback provided by Andrew Govus, Ben Dascombe, Anthea Clarke and Kane Middleton.

Appendix D

Confirmed Submission of Chapter 5

em.pone.0.79f709.2fff6592@editorialmanager.com on behalf of PLOS ONE <em@editorialmanager.com>
Mon 14/03/2022 18:48

To:
Bradley Thoseby
PONE-D-22-07525
Peak Match Acceleration Demands Differentiate Between Elite Youth and Professional Football Players
PLOS ONE

Dear Dr. Thoseby,

Thank you for submitting your manuscript entitled 'Peak Match Acceleration Demands Differentiate Between Elite Youth and Professional Football Players' to PLOS ONE. Your assigned manuscript number is PONE-D-22-07525.

We will now begin processing your manuscript and may contact you if we require any further information. You will receive an update once your manuscript passes our in-house technical check; you can also check the status of your manuscript by logging into your account at https://www.editorialmanager.com/pone/.

If during submission you selected the option for your manuscript to be posted on the bioRxiv preprint server (http://biorxiv.org), we will be assessing the manuscript for suitability shortly. If suitable, your preprint will be made publicly available on bioRxiv and you will receive an email confirmation from them when it has posted. Please check your response to this question and email us as soon as possible at plosone@plos.org if it has been answered incorrectly. Further information about our partnership with bioRxiv to facilitate the rapid availability of life sciences research is available at http://journals.plos.org/plosone/s/preprints.

If you have any inquiries or other comments regarding this manuscript please contact plosone@plos.org.

Thank you for your support of PLOS ONE.

Kind regards,
PLOS ONE

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