Investigating the Differences in Worst Case Scenario Across Age Group Match Play: Implications for the Transition to Senior Football

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1 Abstract

1.1 Objectives

The intermittent nature of football causes the physical match demands to fluctuate every few seconds. Traditional methods of 90-minute averages underestimate the peak physical match demands, which are otherwise known as Worst Case Scenario (WCS). However, there is limited research exploring the WCS across age groups. The present study aimed to assess the effectiveness of age group match play in preparing elite, youth football players for the demands on senior football for a single English Premier League football club and their Academy.

1.2 Methods

A total of 87 male football players were included in data collection. This resulted in 55 players for Senior match fixtures, 52 players for U21s match fixtures, and 22 players for U18s match fixtures. WCS data were obtained from 172 match fixtures. All WCS data were collected using Sportlight® LiDAR tracking system. Key performance indicators used were WCS total distance (WCS_{TRD}), WCS high-speed running distance (WCS_{HSRD}), and WCS sprint running distance (WCS_{SRD}). WCS data were collected and analysed based on three groups - epoch peaks, epoch threshold breaches, and epoch threshold counts. Data were collected using a rolling window method, applying varying epoch lengths (30- to 600-seconds). Contextual factors used were positional groups, match location (home and away), and match outcome (win, loss, and draw).

1.3 Results

WCS_{TRD} was significantly higher in U21 match fixtures during 300-second epochs (absolute: 747.7 ± 56.1 m; relative: 149.5 ± 11.2 m·min^{-1}) compared with Senior match fixtures (absolute: 728.1 ± 63.5 m; relative: 145.6 ± 12.7 m·min^{-1}) ($p = 0.05$). WCS_{TRD} was significantly higher in U21 match fixtures during 600-second epochs (absolute: 1370.1 ± 108.5 m; relative: 137.0 ± 10.9 m·min^{-1}) compared with Senior match fixtures (absolute: 1325.4 ± 119.4 m; relative: 132.5 ± 11.9 m·min^{-1}) ($p = 0.006$). No significant differences across age groups for any epoch length for WCS_{HSRD} or WCS_{SRD} ($p > 0.05$). Match location significantly affected absolute $WCS_{HSRD,}$ with U18s higher than Senior (*p*

< 0.05). Match location did not significantly affect WCS_{TRD} or WCS_{SRD} across age groups for any epoch length ($p > 0.05$). Match outcome was significantly affected absolute WCS_{SRD}, with U21 lower than Senior ($p < 0.05$). Match outcome did not significantly affect WCS_{TRD}, WCS_{HSRD} between Senior and U21 ($p > 0.05$). Significant differences were identified for 'Strikers' for WCS_{HSRD} for all epoch lengths, and for 'Wide Forward' and 'Strikers' for WCS_{SRD} for epoch lengths. Age group did not significantly affect WCS_{TRD} across age groups for any epoch length ($p > 0.05$).

No significant differences were identified across age groups for epoch threshold breaches for WCS_{TRD}, WCS_{HSRD}, and WCS_{SRD} for any epoch length. The epoch threshold counts were significantly different across age groups for WCS_{TRD}.

1.4 Conclusions

This study further developed the literature surrounding analysis of the WCS in football, by comparing across age groups and using LiDAR systems to capture it. Overall, these findings highlight the need for practitioners to consider the WCS during match play but go beyond the raw WCS data, by incorporating contextual factors, to adequately prepare Youth football players for the demands of Senior football. Limitations of the present study are predominantly due to the novel nature of the research highlighting the importance of contextual factors, playing style, and methodology.

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4 Acknowledgements

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5 Declaration

All data presented within this thesis were collected by Sportlight®. Data were analysed and presented by myself, Charlotte Richardson.

I declare that all the data presented is my own work unless stated otherwise and this thesis was constructed by myself. Appropriate referencing has been used for all published literature referred to within this thesis. None of the data presented within this thesis has previously been submitted for assessment towards a higher degree.

Charlotte Richardson, October 2025.

Word Count: 17667

6 Glossary

Abbreviation	Meaning
GNSS	Global Navigations Satellite Systems
WCS	Worst Case Scenario
TRD	Total running distance
HSRD	High-speed running distance
SRD	Sprint running distance
LiDAR	Light Detecting and Ranging
EFL	English Football League
UEFA	Union of European Football Association
FA	Football Association
EPL	English Premier League

7 Introduction

Football is one of the most widely played sports in the world, with millions of spectators each year (Castagna *et al*., 2025). A competitive game consists of two teams of eleven players who each take on specific positional roles for attacking and defensive purposes. There are multiple levels of competition, including professional, amateur, and recreational, which all include league competitions and tournaments.

The typical duration of a football match fixture is 90, extended to over 120 minutes in the case of extra time (Mohr *et al*., 2023). The game is played over two halves of 45 minutes, with additional stoppage time to account for in-game delays. In recent English Premier League (EPL) seasons, the length of added time has increased, resulting in longer overall match durations and exposing players to extended periods of physical work. For the duration of a match fixture, players are required to perform numerous physical, technical, and tactical actions, interspersed with periods of recovery (Schimpchen *et al*., 2021; Bradley & Ade, 2018; Cunningham *et al*., 2018; Delaney *et al.,* 2018). These actions are referred to in the literature as physical match demands. Their quantification provides practitioners with insight into the external load imposed on players during match play.

Load in football encompasses both external and internal load. External load is the mechanical and locomotor output performed by a player and is defined as the work done by an individual during training or competition, regardless of internal characteristics (Teixeira *et al.,* 2021). It is typically quantified by running-based metrics such as total distance (TRD), high-speed running distance (HSRD), and sprint running distance (SRD). Data on these metrics is typically collected using wearable tracking devices or camera-based systems in training and competition (Bampouras and Thomas, 2022). Internal load monitoring reflects the physiological and psychological stress a player experiences during training and competition (Bourdon *et al*., 2017; Impellizzeri *et al.,* 2019). Measures include heart rate and blood lactate, which are used to infer the internal load associated with external load (McLaren *et al*., 2018).

While internal load monitoring provides useful information for practitioners, it falls outside the scope of the present study. The present study focuses exclusively on external load monitoring to quantify the physical match demands of football. These demands are shaped by the intermittent nature of football causing physical match demands to continuously fluctuate throughout match play. Players are reported to experience between 1,000 to 1,650 changes in match activity throughout a match fixture, equating to a change in physical match demands every 3-5 seconds (Andersson *et al*., 2007; Andersson *et al*., 2010; Stølen *et al*., 2005). These fluctuations are characterised by frequent variations in running speed and direction, influenced by positional roles and match context. Such variability poses several challenges for practitioners when prescribing training as it requires replicating the volume, intensity, frequency, and situational context in which actions occur during match play. Therefore, understanding the physical match demands could address these challenges and enabling evidence-based training prescription. This is achieved by monitoring the physical match demands through motion-capture technology and using it to tailor training drills and conditioning sessions to reflect the intermittent nature of football.

Load monitoring plays a central role in football by quantifying the physical match demands to guide training prescription. By assessing external load to determine the WCS across age groups, practitioners can tailor training drills and conditioning sessions to align with the physical match demands and the needs of the team (Castagna *et al*., 2024). Measures of load have traditionally been reported as a 90-minute match average across the literature. This method assumes uniform distribution of physical match demands so could fail to capture the peak physical match demand during match play. Worst Case Scenario (WCS) emerged as a method to isolate the peak physical match demands. Identifying these peaks is critical for performance development as they represent the highest intensity efforts of players during match play. Training based solely on average demands may underprepare players these moments, increasing the risk of performance decrements or injury. The term WCS is an adoption of a broader risk-management concept, widely used in military and strategic planning literature by Herman Kahn in the early 1960s (Kahn, 1962).

However, the extent to which the physical match demands differ between youth and senior football remains underexplored. The youth-to-senior transition is thought to be one of the biggest challenges a player will face within their career (Lundqvist *et al*., 2024). Football academy programmes aim to develop youth players for progression into senior teams (Thoseby *et al*., 2023) with practitioners setting longitudinal training plans to prepare youth players for the demands of senior football (Morgans *et al*., 2014). However, only a small proportion of youth players receive a professional contract and play for the senior team (Lundqvist *et al.,* 2023). Physical and psychological factors are perceived as transitional barriers. Psychological factors include loneliness, lack of selection, and harsh environments, which all contribute to increased pressure on youth players (Lundqvist *et al*., 2023). Our understanding of the physical match demands of youth football in comparison to senior football is limited, yet it vital for age group specific training and for performance development. Lundqvist *et al*., (2023) found a club-wide playing philosophy and exposure to various playing styles to be key factors in the youth-to-senior transition. A successful transition could be achieved through exposing youth players to the same philosophy as the senior team, aiding the feeling of importance and professionalism. It should also expose players to similar load during training to better prepare youth players for competing in senior match fixtures. To address this gap, the present study employs WCS analysis to compare external load across youth and senior football.

7.1 Overall Thesis Aim

To investigate differences in WCS of competitive match play across U18, U21, and Senior football, and to explore implications for the youth-to-senior transition

7.1.1 Objective 1

To quantify and compare the WCS of competitive match fixtures across U18, U21, and Senior football, including a comparison of epoch length across age groups.

7.1.2 Objective 2

To evaluate the effect of positional group, match outcome, and match location on WCS across U18, U21, and Senior match fixtures.

7.1.3 Objective 3

To quantify and compare the frequency of the WCS and the duration above a predefined speed threshold across U18, U21, and Senior match fixtures.

7.1.4 Hypotheses

Based on the aim and objectives of the study, the following hypotheses were proposed:

H1: Senior players will demonstrate higher WCS values than U18 and U21 players across epoch lengths.

H2: Shorter rolling epochs (e.g. 30- and 60-seconds) will produce a higher WCS than longer epochs (e.g. 300- and 600-seconds).

H3: Contextual factors will have a greater influence on WCS_{HSRD} and WCS_{SRD} than WCS_{TRD}.

8 Literature Review

8.1 Load Monitoring

Load monitoring in football has been established for over two decades, initially driven by match analysis systems such as ProZone and Amisco in the early 2000s (Carling et al., 2008; Di Salvo et al., 2007). These systems allowed practitioners to quantify players physical output during match fixtures and use it as a tool to optimise performance and reduce injury risk (Bourdon *et al*., 2017). While training sessions are designed to enhance technical skills and develop aerobic and anaerobic fitness, their effectiveness relies on accurately replicating the physical demands of match play (Novak *et al*., 2021). Understanding these demands is essential for practitioners aiming to prescribe training that reflects the intensity, duration, and frequency of physical outputs during match play. Monitoring load during match play is widely used in professional football as it allows training prescription to be tailored to support player and team development (Impellizzeri *et al*., 2019). This is particularly important for the youth-to-senior transition, where it is crucial for youth players to be adequately prepared for senior football to enable a smooth, successful transition.

External load is the most widely used measure of load in football (Impellizzeri *et al*., 2019). It is easily measured using velocity and/or time and is collected through use of motion capture technology, such as Global Positioning System (GPS) (Impellizzeri *et al.,* 2019; Bampouras & Thomas, 2022). The availability and ease of use of motion capture technology make monitoring external load more appealing to practitioners. The practical relevance of external load monitoring for performance outcomes, such as player's ability to create scoring opportunities or perform football actions effectively throughout match play, mean external load monitoring is often prioritised (Mandarino *et al*., 2025). Internal load reflects the physiological and psychological stress a player experiences during training and competition (Bourdon *et al*., 2017; Impellizzeri *et al.,* 2019). However, due to practical and methodological constraints, such as technology and equipment to measure it not being readily available to all, make it a complex measure to quantify during match play (Impellizzeri *et al.,* 2019). Hence external load monitoring is more commonly used and was selected for the present study.

This review will examine current methods of monitoring load during match play, with particular focus on its quantification and the relevance of contextual factors.

8.2 Current Methods of Load Monitoring

When monitoring and assessing physical match demands, practitioners and researchers adopt one of two approaches, 90-minute match averages (average distance run throughout the match fixture) or segmenting the match into shorter time intervals to capture fluctuations in intensity (e.g. change of speed) (Novak *et al*., 2021). A study by Oliva-Lozano *et al*., (2023) compared the two methodologies and concluded using 1-minute periods of time provide a more accurate representation of the physical demands of match play than 90-minute match averages. The study used only 17 players competing in LaLiga, across 13 match fixtures, a small sample given the enormity of professional football across the world. However, Riboli *et al*., (2021) conducted a similar study using 148 Italian Serie A players, across 46 match fixtures, and reported almost identical findings to that of Oliva-Lozano *et al*., (2023). Riboli *et al*., (2021) and Oliva-Lozano *et al*., (2023), found that 90-minute averages underestimated the peak physical match demands, capturing only 53-60% of TRD, 16-26% of HSRD, and 6-9% of SRD values reported from the 1-minute peak values. The consistency of these findings across leagues ad sample sizes, provides evidence that 90-minute averages may not be the most accurate method for representing the intermittent nature of football. In a practical setting, training could be prescribed to a player based on their 90-minute average HSRD value, which could have players training at a speed 16-26% lower than the actual speed they could be exposed to during match play. As such, players would be placed at a higher risk of injury due to limited exposure to peak physical match demands in training, otherwise known as the WCS (Gualtieri *et al*., 2023; Novak *et al.,* 2021).

Exposure to training that replicates the peak physical match demands, subsequently improving fitness, has been shown to greatly reduce injury risk and improve quality of performance (Malone *et al*., 2018). For example, players exposed to higher training intensities were found to have an almost five times lower risk of injury than those training at similar volumes but lower intensities (Malone *et al*., 2018).

Although this finding was derived from rate of perceived exertion (RPE), it highlights the importance of applying appropriate load to training sessions, that replicates the physical match demands. Therefore, training should be informed by the WCS, rather than 90-minute averages, to ensure adequate preparation for match play. This is particularly important during the youth-to-senior transition, where underexposure to peak intensities in training may results in physical underdevelopment, increased injury risk, and reduced readiness for the demands of senior football. The study conducted by Thoseby *et al*., (2023) (Table 2.1), only used 31 match fixtures (youth = 8, senior = 23). While the novel findings of the previous study are of interest, the small sample size may inflate the WCS if there were performance anomalies so could misinform training prescription. Likewise, the small sample size may not capture all the contextual factors (e.g. match location and match outcome), which are thought to be highly influential on the WCS (Novak *et al*., 2021). To gain a more detailed overview of the WCS across age groups, the use of more match fixtures could be beneficial to account for all contextual factors and reduce the impact of performance anomalies.

While 90-minute averages offer a useful overview of the total match demands, it is clear in the literature that 90-minute averages do not replicate the physical demands of match play (Cunningham *et al*., 2018). A player might be attacking the ball at full speed one minute and the next could be jogging around the pitch, something that will not be picked up in an average measurement. The speed and distance covered of such moments are of interest to practitioners so they can better understand physical match demands and replicated them in training sessions. Research suggests players should be trained based on physical match demands of which their assessment should be used to inform training prescription (Oliva-Lozano *et al*., 2020).

At present, 90-minute averages are the only method that has a consensus for methodology and is easy for practitioners to understand and use. However, splitting the match into periods of time is becoming more widely researched yet methods drastically vary. To enable players to be adequately prepared for progression, practitioners need a consensus to be established and a method that provides accurate quantification of players the most physically demanding periods of match play. Achieving this requires accuracy and precision of the technology used to capture such periods.

8.2.1 Motion Capture Technology In Football

Our understanding of traditional high-intensity activities in football, such as the distances and frequency of high-speed running, sprints, accelerations, and decelerations, has improved over recent years (Bradley & Ade, 2018; Harper et al., 2019; Nassis et al., 2020; Novak et al., 2021), particularly due to the advancements in wearable and non-wearable player tracking devices and software (Nassis et al., 2020; Novak et al., 2021; Taberner et al., 2019; Bampouras & Thomas, 2022). The most used systems are Global Navigation Satellite Systems (GNSS), a portable system that can be used in training grounds and competition venues giving practitioners consistent player tracking data (Bampouras & Thomas, 2022; Buchheit *et al*., 2014; Linke *et al*., 2018). Such devices have provided relatively accurate quantification of physical activity during match play, providing positional coordinates, velocity, and distance covered (Novak *et al*., 2021). However, Light Detecting and Ranging (LiDAR) is an emerging technology that can record variable distance and has been reported to have lower error values than GNSS, when compared to a 3D motion capture system (Bampouras & Thomas, 2022). LiDAR was approximately ten times more accurate in monitoring player movement than GNSS, suggesting LiDAR's potential for more accurate quantification of the physical match demands.

Sportlight® (Oxford, UK) are using LiDAR and artificial intelligence (AI) to monitor key performance indicators (KPIs) for athletes and provide continuous quantification of total distance, high-speed running, acceleration/deceleration, and turns for athletes. Their system consists of portable units that can be placed around indoor and outdoor environments for player tracking during training and competition and does not require calibration or placement at known distances (Clark *et al*., 2019). It does not require athletes to wear a device making the Sportlight® system a non-invasive and attractive solution for continuous player tracking and monitoring the physical match demands. The system can record measurements with a single unit, as each unit can track players independently of other units. LiDAR also

While both GNSS and GPS require players to wear a tracking device, LiDAR does not. The accuracy of LiDAR highlights the need to use it for physical match demand analysis over GNSS. The fluctuations in intensity during match play will be captured more accurately using LiDAR, offering practitioners will a clearer understanding of players external load allowing training prescription to better reflect the physical match demands (Novak *et al*., 2021; Oliva-Lozano *et al*., 2020).

The Sportlight® system has been validated against the gold standard of 3D motion analysis to assess human walking and running speed (Intraclass Correlation Coefficient > 0.88; R > 0.89 for all comparisons; Clark *et al*., 2019) and during football-specific movements (i.e. jogging, linear sprinting; Bampouras & Thomas, 2022). Bampouras and Thomas, (2022) reported that the system is able to detect meaningful differences in sprint velocity between athletes of differing ability over 5, 10, and 20 m sprints. This further supports the use of LiDAR to capture fluctuations in intensity during match play to allow quantification of the physical match demands and identify between varying running speeds.

8.3 Worst Case Scenario

Given the recent research challenging the use of 90-minute averages to monitor the physical match demands, the concept of the worst case scenario (WCS) was introduced (Novak *et al*., 2021). WCS refers to the maximal physical load in any given time window (Novak *et al*., 2021; Oliva-Lozano *et al*., 2020). It provides are more in-depth assessment of the physical match demands that 90-minute averages by isolating the peak value experienced during match play. The intended practical application of WCS is to monitor load and to be considered when prescribing training. In the literature, WCS is also known as peak match demands (Thoseby *et al*., 2023), peak locomotor demands (Baptista *et al*., 2024), most demanding passage (Niu *et al*., 2025), and maximal intensity periods (Weaving *et al*., 2022). Table 2.1 highlights the range of terminology, methodology, and results used to assess the WCS in sport. These discrepancies in definition and methodology could be misleading for practitioners, making it difficult to interpret the findings and apply them consistently to training (Novak *et al*., 2021). Without clarity on the methods to monitor load, which influence training design and subsequently injury prevention and performance development, practitioners risk under or over prescribing training to players (Oliva-Lozano *et al*., 2023). For the present study, the term WCS was selected as the most appropriate term to define these periods of maximal physical load, as it implies the absolute upper limits and demonstrates the extremity of physical match demands that players need to be able to tolerate. Given the practical importance of the WCS, it is essential to consider how practitioners and researchers currently assess load.

Despite the growing use of external load monitoring to quantify physical match demands, only Thoseby *et al.,* (2023) has investigated its application across age groups (Table 2.1). However, their study was limited to football players from a single Australian club, where tactical approach and playing style may differ to teams in the English Premier League (EPL). Differences across competition level has potential to influence external load, therefore limiting the generalisation of the findings reported by Thoseby *et al.,* (2023) and highlights the need for further research across various competitions. While the present study also focuses on a single club, it offers a novel contribution to the literature with the inclusion of Academy and Senior teams from an EPL club. This approach may provide the club and its practitioners with a framework to align training prescription to the developmental stage of each age group, supporting youth players in preparing for the physical match demands of senior football. Aligning training could enhance physical readiness, reduce injury risk, and improve performance during match play.

Most WCS studies have utilised a global positioning system (GPS) which is a type of GNSS (Table 8.1). No study has used a Sportlight® system or employed LiDAR technology to this area of research. So, while both WCS and 90-minute averages were reported similar between senior and youth football matches by Thoseby *et al.,* (2023), the use of a GNSS poses concern about the accuracy of the findings. Using a LiDAR system for WCS analysis ensures the data available to practitioners is the most accurate quantification and reflects the physical match demands.

8.4 Methodological Considerations

8.4.1 Speed Thresholds

High-intensity running is a key component when profiling the external load of match play (Castagna *et al.*, 2024). It is commonly categorised using arbitrary speed thresholds (Castagna *et al.*, 2024). Gualtieri *et al.*, (2023) reported the most widely used arbitrary speed thresholds in male football as >330($m \cdot min^{-1}$) for HSRD and

>416(m·min^{-1}) for SRD. Governing bodies, including the FA and UEFA, have adopted similar thresholds, with HSRD as ~333(m·min^{-1}) and SRD as ~416(m·min^{-1}) to standardise load monitoring across football (Gualtieri *et al*., 2023).

Arbitrary speed thresholds are widely accepted across the literature, due to their practicality and suitability for benchmarking performance and for between-group comparisons (Gualtieri *et al.,* 2023). Their standardised nature allows practitioners to track longitudinal changes and apply a consistent speed criterion across age groups, positions, and competition level. However, running speed is influenced by an individual's physiological capacity which is not accounted for in arbitrary speed thresholds hence the previous proposal of individualised speed thresholds to account for physiological variability. While individualised speed thresholds may provide a more accurate representation of the external load experienced by players, their implementation limits comparability between players and teams (Castagna *et al*., 2024). Despite arbitrary speed thresholds may not be the most accurate representation of sustained external load, the standardisation that arbitrary speed thresholds offer enables between-group comparisons and facilitates longitudinal tracking (Gualtieri *et al.,* 2023). It offers practitioners and researchers an appropriate compromise between precision of results and the practical demands on large-scaled WCS analysis in elite football.

Thoseby *et al*., (2023) set a HSRD speed threshold as 330(m·min^{-1}), consistent with recommended thresholds for WCS, and reported physical match demands to be similar between youth and senior football match fixtures. While this threshold enhances methodological consistency across WCS research in football, the absence of positional groups presents a limitation. Players were not grouped by position due to a small sample size, yet positional roles have been reported to elicit different speed profiles. For example, Abbott *et al*., (2018) found that wide defenders and attackers recorded the highest running speed, and central defenders produced the lowest running speed and total running distance. Therefore, the findings of Thoseby *et al*., (2023) may not accurately reflect the physical match demands experienced by all players on the pitch. Aggregating physical match demands without accounting for positions poses a risk of masking intra-squad variability and could limit the validity of training prescribed from such analysis. This holds potential performance implications for the youth-to-senior transition as misaligned training prescription may lead to players being underprepared for their position (Gualtieri *et al*., 2023; Fereday *et al*., 2020). It may increase risk of injury due to inadequate exposure to the intensity of their position (Malone *et al*., 2018).

Injury prevention is a key factor in determining a club's on-pitch performance hence it has been recommended to practitioners that the WCS should be considered when prescribing training and seeking competitive success (Malone *et al.,* 2018; Delaney *et al.,* 2018). However, further research is required to determine how the WCS differ across youth and senior football as it is thought to be a related to the high injury prevalence in youth football players progressing into the senior team. A recent report by Howden's Group Holdings (2024) highlighted that youth players, competing in senior teams, are spending increasingly more time injured. In the 2023-24 season, under-21 EPL players spent an average of 44 days out per injury, compared to 13 days out in the 2020-21 season (Howden Group Holdings, 2024). This increase may reflect the heightened physical demands placed on young players as they transition into senior football, highlighting the importance of training that prepares them for sustained external load. Beyond performance implications, this increase in injury prevalence brings financial consequences to the club. Previous research has established a link between injury incidence, financial loss, and negative team success (Akenhead *et al*., 2016). Youth players typically enter football academy systems for little to no cost, so adequate preparation for senior football could yield a higher transfer value. However, prolonged injury time during the youth-to-senior transition could reduce the chance or financial value of the transfer. Hence, aligning training to the physical match demands of senior football is vital for both the performance of players and teams, and financially for the club.

8.4.2 Influence of Epoch Length

Epoch length, in the context of WCS, is a time window used to quantify peak physical match demands. Previous WCS studies have selected epoch lengths of one to ten minutes, with more recent studies applying epoch lengths as short as 15-seconds (Rico-González *et al*., 2022; Baptista *et al*., 2024). Longer epoch lengths (five and ten minutes) significantly underestimate WCS, particularly HSRD and SRD, suggesting longer epoch lengths dilute peak efforts (Oliva-Lozano *et al*., 2021). This could misinform training prescription causing players to be trained at a lower intensity to that experienced during match play. Shorter epoch lengths consistently observe higher intensities of WCS than longer epoch lengths (Cunningham *et al*., 2018; Martín-García *et al*., 2018; Olivia-Lozano *et al*., 2020; García, Fernández *et al*., 2022). Hence, shorter epochs of <1-minute have been suggested when analysing WCS, specifically HSRD and SRD (Baptista *et al*., 2024).

A previous study, that analysed WCS in basketball, futsal, handball, hockey, and soccer, reported HSRD for the 30-second WCS to be lower than 60-second WCS (63.8 vs. 72.8 m; García, Fernández *et al*., 2022). As expected, the distance is lower, yet the intensity is greater in 30-second than 60-second (127.6 m·min^{-1} vs. 72.8 m·min^{-1}). This suggests shorter epochs are better for isolating the WCS, providing practitioners with more precise values to later use to guide training prescription. Despite the study by García, Fernández *et al*., (2022) using a range of sports, they all follow a similar intermittent nature, so the findings are somewhat applicable to football. However, the previous study only used senior players so consideration of youth players WCS at shorter epoch length is important before applying the findings to practice.

Baptista *et al.,* (2024) studied WCS using 100 professional female football players, accounting for TRD, HSRD, and SRD, and applied epochs of 15-, 30-, 45-, and 60-seconds. The largest WCS difference between metrics was reported for TRD (15-seconds = 72.4 m vs. 60-seconds = 182.6 m) and the smallest WCS difference for SRD (15-seconds = 38.4 m vs. 60-seconds = 41.9 m). In fact, the study reported WCS high-speed metrics to be concentrated in the first 15-seconds of 60-second epochs (HSRD: 77.6%; SRD: 91.3%). The remaining 45-seconds of activity for SRD represented 8-9% of the total 60-second epoch. As such, the study's conclusion suggested shorter epochs (15- and 30-seconds) should be used for quantifying intensity-related metrics, such as HSRD and SRD, and longer epochs used for volume-related metrics, such as TRD (Baptista *et al*., 2024). This highlights the importance of epoch length selection when using WCS to aid training prescription. For example, when training SRD, 60-second epochs could underestimate the WCS and only train players at ~0.70 m·s^{-1}. Whereas, using 15-second epochs will impose an intensity three times higher (~2.56 m·s^{-1}). However, the previous study was completed in female athletes, and the present study will use male athletes, an important acknowledgement given the previously reported differences in TRD (Females: 182.6 m; Males: 186-201 m) (Baptista *et al.,* 2024; Casamichana *et al*., 2019; Oliva-Lozano *et al*., 2021). Likewise, 60-second WCS SRD (>333 $m \cdot min^{-1}$) was reported as 41.9 m in females (>333 $m \cdot min^{-1}$; Baptista *et al*., 2024) compared to 60 m covered by males (>330 $m \cdot min^{-1}$; Oliva-Lozano *et al*., 2021; Fereday *et al*., 2020; Thoseby *et al*., 2023). Therefore, direct comparisons cannot be made between previous studies in females and the present study that uses males but can be used to inform a general idea of shorter epochs being more applicable for high-speed activity.

Thoseby *et al*., (2023) assessed WCS in senior and youth football players using epoch lengths of one to ten minutes. For most epoch (two to ten minutes), the differences between age group for TRD and HSRD were trivial (SMD = 0.25). The study also reported 90-minute average for TRD and HSRD, reporting no differences across age groups (Table 8.1). Despite the limited differences between the two methodologies, previous research has suggested 90-minute averages to underestimate the WCS compared to using epoch lengths (Riboli *et al*., 2021; Oliva-Lozano *et al*., 2023). Hence the present study will use a similar approach to epoch length. The present study will use a LiDAR system to quantify the WCS given it has lower error values than GNSS, which was used in Thoseby *et al*., (2023).

8.4.3 Fixed-Time vs. Rolling Window Epochs

Rolling epochs were first established as superior to fixed-time epochs by Varley *et al*., (2012), who showed rolling epochs to capture fluctuations in intensity which fixed-time epochs fail to do. Building on the foundational work by Varley *et al*., (2012), a systematic review conducted by Whitehead *et al*., (2018) highlighted the methodological variability of how WCS is quantified across football. The review identified three methods: fixed-time epochs, rolling epochs, and ball-in-play periods. Rolling epochs were concluded as the most accurate representation of WCS due to the ability to capture fluctuating intensities yet encouraged methodology to be selected based on their specific needs of analysis.

Fixed-time epochs split the match into pre-defined periods of time that do not cross over and are typically around 600-seconds (e.g. 1-600, 601-1200, 1201-1800 seconds; Cunningham *et al*., 2018). Rolling window epochs also split the game into pre-defined periods of time, but instead are a moving window of time, typically lasting 10-seconds to 10-minutes (e.g. 0-10, 1-11, 2-12 seconds; Novak *et al*., 2021; Cunningham *et al*., 2018).

Research that has applied both methodologies when analysing WCS in football, reported fixed-time epochs to underestimate rolling averages by ~7-10% for TRD and ~12-25% for HSRD (Fereday *et al*., 2020). This underestimation was irrespective of epoch length (60- to 600-seconds) or positional group (defenders, midfielder, and attackers). For example, for the whole sample, 60-second WCS HSRD was reported as 173.1 ± 19.7 $m \cdot min^{-1}$ for fixed-time epoch vs. 190.1 ± 20.4 $m \cdot min^{-1}$ for rolling window epoch. WCS was reported significantly greater in rolling window for epoch lengths 60- to 480-seconds, strongly agreeing with the suggestion that fixed-time epochs underestimate WCS. Oliva-Lozano *et al*., (2021) rolling window epochs to be reported significantly greater WCS for TRD, HSRD, and SRD for all positional groups at each epoch length (1-, 3-, 5-, and 10-minutes). These findings highlight to practitioners that relying on 90-minute averages or fixed-time epochs could significantly underprepare players for the physical demands of match play. If wrongly chosen, players will be at an increased risk of injury when exposed to physically demanding periods they have not been prepared for in training. To create an effective training environment, sessions must develop players' physical abilities to meet or exceed the demands of match play (Gualtieri *et al*., 2023).

Doncaster *et al*., (2020) analysed WCS in youth football players using fixed-time and rolling average windows. Relative TRD and HSRD were significantly higher in rolling average compared to fixed-time (TRD: $p < 0.0001$, MD = 6.3 $m \cdot min^{-1}$; HSRD: $p = 0.001$, MD = 2.9 $m \cdot min^{-1}$, respectively). Fixed-time underestimated TRD by ~4.3% and HSRD by ~11.88%, when compared to rolling average. Such findings support that of Fereday *et al*., (2020) and highlights that fixed-time epochs underestimate the WCS, in both senior and youth football. However, the previous literature focuses on within-group comparisons, which limits the comparability of multiple papers across age groups.

Hence the present study will focus on between-group comparisons with a rolling average method applied.

As shown, both 90-minute averages and fixed-time epochs are more likely to underestimate or miss the WCS than a rolling window epoch is. 90-minute averages assume uniform distribution of physical output which can obscure peaks in the physical match demands. This causes moments of, for example, sprint running distance to be averaged out and subsequently underestimate the peak demand (Cunningham *et al*., 2018). While more focused, fixed-time epochs may miss the WCS if it occurs across the boundary of two adjacent epochs. In which case, the intensity of the WCS will be split resulting in lower WCS values in the data. Hence, rolling window windows are preferable for identifying the WCS as the sliding window is more likely to capture the WCS in full by moving forward incrementally.

This outline of the available literature highlights the complexity of analysing WCS and the challenges practitioners face when attempting to gain competitive advantage. The literature surrounding WCS is ever-growing and continues to use varying methodology.

8.4.4 Contextual Factors

Adding to the already complex methodology of analysing WCS, contextual factors such as match location, match outcome, and positional groups, are thought to highly influence WCS (Novak *et al*., 2021; Oliva-Lozano *et al.,* 2020). Once accounted for, the WCS can be useful to understand the physical demands of match play and the subsequent physiological characteristics that need to be targeted in training to better prepare players (Novak *et al*., 2021).

The WCS was reported as being always greater for TRD, HSRD, and SRD when match fixtures were away (Oliva-Lozano *et al.,* 2020). This novel finding contradicts previous research that used 90-minute averages and reported TRD to be greater at home matches (262-383 m) (Aquino *et al*., 2017; Oliva-Lozano *et al*., 2020). No differences in WCS were previously reported for HSRD and SRD between match location when using 90-minute averages (Castellano *et al*., 2011). Given the underestimation of 90-minute averages compared to rolling windows, the findings of

Oliva-Lozano *et al.,* (2020) were deemed the most accurate representation. Such findings suggest significant effect of match location on WCS and the potential that home-field advantage causes the opposition to have increased WCS (Oliva-Lozano *et al.,* 2020). The previous study used senior players from LaLiga, who may be better acclimatised to high pressure match fixtures than youth players (Teixeira *et al*., 2021). This could influence their physical response to match play and limit to generalisation of previous findings across age groups. Hence the present study will apply match location as a contextual factor when comparing WCS between senior and youth players to potentially identify psychological improvements.

Match outcome was also reported to have a significant effect on WCS for one minute and three minute epochs (Oliva-Lozano *et al.,* 2020). For one minute epochs, TRD, HSRD, and SRD, the WCS was greater in all match fixtures resulting in a win compared to a draw or loss ($p < 0.05$). For three minute epochs, the WCS for TRD was greater in all match fixtures resulting in a win or draw compared to a loss ($p < 0.05$), while the WCS for SRD remained greater in match fixtures resulting in a win compared to a draw or loss ($p < 0.05$). However, no effect was reported for five or ten minute epoch lengths. Players are more likely to maximise their physical output during important, high-intensity passages of play (e.g. counterattack), often associated with intensity-related metrics (HSRD and SRD) (Baptista *et al*., 2023). Shorter epochs (one and three minutes) are often more sensitive to metrics such as HSRD and SRD, whereas longer epochs (five and ten minutes) are more suited to measuring volume-based metrics (TRD). This could explain why match outcome has more of an effect on shorter epochs yet research that includes match outcome is limited. The present study will include match outcome as a contextual factor to further the findings of Oliva-Lozano *et al.,* (2020) and add comparisons between senior and youth players.

Positional differences in WCS have been acknowledged in elite football, with TRD, HSRD, and SRD being significantly different between epoch length ($p < 0.01$; Oliva-Lozano *et al*., 2020). While the previous study by Oliva-Lozano *et al*., (2020) did not provide a detailed statistical breakdown of positional means and standard deviations, it can be inferred from the graphical data that wide midfielders, forwards, and fullbacks exhibited the highest WCS for TRD, HSRD, and SRD. This pattern aligns with their tactical role, often involving frequent transitions, pressing actions, and high-intensity movements (Fereday *et al*., 2020). However, the absence of explicit positional data limits the interpretation by practitioners and researchers, hence the need to compare positional groups for WCS between youth and senior match fixtures. This will provide detail on the effect of tactical role and age group on the WCS. It is important to understand positional differences across age groups as youth players often exhibit higher WCS due to psychological pressure, which has potential to manifest differently between positional groups.

Doncaster *et al*., (2020) analysed WCS in youth football players reporting relative TRD and HSRD to be significantly higher in one minute epochs compared to three and five minute epochs ($p < 0.0001$; TRD: MD = 35.9 ± 0.9 m·min^{-1}; 44.8 ± 1.1 m·min^{-1}; HSRD: MD = 29.4 ± 0.9 m·min^{-1}; 36.2 ± 1.0 m·min^{-1}, respectively). Such finding validates the use of short epochs (e.g. one minute) for more accurate quantification of the WCS as they are more sensitive at identifying the WCS than longer epochs (three and five minute epochs). The consistency across the literature that short epochs elicit higher WCS in both senior and youth football players suggest underlying similarities across age groups. However, previous research has focused on within-group analysis, limiting the ability to draw definitive conclusions about age group differences. Therefore, the present study uses previous literature to support the use of short epochs whilst incorporating between-group comparisons to address the gap in the literature.

8.4.5 Frequency of WCS

Whilst quantifying the magnitude of WCS is essential for informing the intensity of training drills, it is equally important to understand the frequency with which players are exposed to during a match fixture. Understanding the distribution and reoccurrence of the WCS will allow practitioners to design training programmes that reflect the intensity of match play and the repetition of the WCS. The present study adopts the term 'Epoch Threshold Counts' to quantify the number of times each player exceeds the predefined speed threshold.

Bortnik *et al.,* (2023) analysed the frequency of high-intensity transitional activities in elite football. Transitional activities refer to short, high-intensity passages of play following a change in possession. They occur in clusters and place substantial physical load players, closely replicating the WCS (Bortnik *et al.,* 2023). These transitional activities were grouped into clusters based on proximity and repetition, reporting players to be exposed to an average of 12.2 clusters and 50 transitional activities per match. Whilst this provides insight into the frequency of high-intensity activities during match play, the event-based methodology uses manual coding, making it time consuming when analysing large datasets. It lacks standardisation, in particular time windows (e.g. epoch lengths of 30- and 60-seconds) and locomotor metrics (e.g. TRD and HSRD), limiting the reproducibility. Hence the present study will use a reproducible methodology with an aim to understand the frequency of the WCS during match play. To our knowledge, Bortnik *et al.,* (2023) is the only study that applied a similar methodology to what will be applied in the present study.

8.4.6 Duration of WCS

Quantifying the duration of the WCS in seconds, above a defined threshold, provides an insight into the sustained physical output during the WCS in match play. Without this, training may replicate the intensity of the WCS but could fail to prepare them for how long that intensity must be sustained for. An understanding of how players are exposed to the WCS during match play, can aid development of physiological resilience and aerobic capacity (Whitehead *et al*., 2018). For example, a player who exceeds the sprint thresholds for 60-seconds, may require different training strategies to someone who only exceeds it for 10-seconds, even if they reach similar peak velocity. This has implications for load management, especially during congested fixture periods (Oliva-Lozano *et al*., 2020). The present study adopts the term 'Epoch Threshold Breaches' to describe periods whereby players exceed the predefined speed threshold for a sustained duration.

Baptista *et al*., (2023) suggested that high-intensity passages of play typically occur in short periods. However, longer periods could be reflective of positional responsibilities (add about volume-based stuff). Therefore, analysing the duration of the WCS aids practitioners in determining between high-intensity repeated efforts and prolonged tactical demands, enabling more accurate training. To our knowledge, there are no studies that have examined WCS duration, particularly across age groups. Most research has focused on the peak values which quantify intensity and have not explored how long they experience that intensity for.

Table 8.1 - Summary of WCS literature to identify difference in methodological approaches and alternative terminology used to describe WCS.

Research Paper	Sport	Methodology	Result
Varley *et al.*, (2012)	Football – Elite	**<u>Form of Measure</u>** - GPS units (MinimaxX, Catapult) **<u>Metrics</u>** - Total running distance ($m \cdot min^{-1}$) **<u>Epoch Length</u>** - Rolling window - 1-10 minutes	**<u>Total Running Distance</u>** Peak 5-minute period: First half - Predefined = 142 ± 24 m - Rolling = 177 ± 91 m Second half - Predefined = 138 ± 41 m - Rolling = 166 ± 43 m
Baptista *et al.*, (2024)	Football - Norwegian Women's Premier Division	**<u>Form of Measure</u>** - GPS Units (STATSports, Northern Ireland) **<u>Metrics</u>** - Total running distance (m) - High-speed running distance (>226 $m \cdot min^{-1}$) - Sprint running distance (>333 $m \cdot min^{-1}$) **<u>Epoch Length</u>** - Rolling window - 15-, 30-, 45-, 60-seconds	**<u>Total Running Distance</u>** Largest difference: 15-seconds = 72.4 ± 0.8 m 60-seconds = 182.6 ± 0.8 m **<u>High-Speed Running Distance</u>** 15-seconds = 55.2 ± 1.0 $m \cdot min^{-1}$ 60-seconds = 70.4 ± 1.0 $m \cdot min^{-1}$ **<u>Sprint Running Distance</u>** Smallest difference: 15-seconds = 38.4 ± 0.9 $m \cdot min^{-1}$ 60-seconds = 41.9 ± 0.9 $m \cdot min^{-1}$
Thoseby *et al.*, (2023)	Football – Elite Youth & Senior	**<u>Form of Measure</u>** - GPS units (STATSports, Northern Ireland) **<u>Metrics</u>** - Total running distance ($m \cdot min^{-1}$) - High-speed running distance (>330 $m \cdot min^{-1}$) **<u>Epoch Length</u>** - Incremental moving average - 1-10 minutes	**<u>Total Distance</u>** Senior: 114 ± 8 $m \cdot min^{-1}$ Youth: 116 ± 11 $m \cdot min^{-1}$ **<u>High-Speed Running Distance</u>** Senior: 8 ± 3 $m \cdot min^{-1}$ Youth: 7 ± 3 $m \cdot min^{-1}$
Doncaster *et al.*, (2020)	Football – Youth	**<u>Form of Measure</u>** - GPS units (STATSports, Northern Ireland)	**<u>TRD</u>** 1-min>3-min, 5-min epoch

		Sample Split by positional groups: Central Defender (CD), Full backs (FB), Wingbacks (WB), Central midfielders (CM), Wide midfielders (WM), Attackers (ATT) **Metrics** Peak relative TRD & HSRD (>330 m·min^{-1}) **Epoch Length** 1-, 3-, and 5-minute epochs Fixed-time epochs - E.g. 1-3, 4-6, 7-9 Rolling window epochs - E.g. 1-3, 2-4, 3-5	- 35.9 ± 0.9, 44.8 ± 1.1 ($p < 0.0001$) 3-min>5-min epoch - 8.8 ± 0.9 ($p < 0.0001$) **HSRD** 1-min>3-min epoch - 29.4 ± 0.9 ($p < 0.0001$) 1-min>5-min epoch - 36.2 ± 1.0 ($p < 0.0001$) 3-min>5-min epoch - 6.8 ± 0.9 ($p < 0.0001$) **Positional Groups** TRD - 1-min CM & WB highest - CM mean = 192.4m·min^{-1} - WB mean = 192.4 m·min^{-1} - 3-min CM highest - CM mean = 161.5 m·min^{-1} - 5-min CM highest - CM mean = 151.2 m·min^{-1} HSRD - 1-min WM & WB highest - WM mean 64.4 m·min^{-1} - WB mean 64.9 m·min^{-1} - 3-min CB highest - CB mean 22.5 m·min^{-1} - 5-min CB highest - CB mean 16.0 m·min^{-1}
Fereday *et al*., (2020)	Football – English Championship (Senior)	**Form of measure** Global Navigation Satellite System (GNSS) - Optimeye S5, Catapult Sports, Melbourne, Australia **Sample**	**Method** Fixed-time underestimated rolling window for TRD and HSRD across all epoch lengths ($p < 0.001$). No interaction between method and positional group for TRD.

		Split by positional groups: Central defenders (CD), wide defenders (WD), central defensive midfielders (CDM), wide midfielders (WM), central (CA), wide attackers (WA) **Metrics** TRD (m) & HSRD (>330 m·min^{-1}) **Method** 60- to 600-seconds Fixed-time & rolling window **Contextual Factors** Match outcome Match location	Over 120-seconds, fixed-time HSRD was lower than rolling window HSRD for defenders than attackers (p = 0.021). **Positional Groups** Midfielders (p < 0.001) and defenders (p < 0.05) had higher TRD across all epoch lengths compared to attackers. TRD rolling: - CDM, CM > CD ($p \leq 0.05$; 60- to 600-seconds), - WD > CD (p < 0.05; <480-seconds), - WM > CD (p < 0.05; 60- & 120-seconds). HSRD rolling: - CM, WM, WD > CD (p < 0.05; 60- to 600-seconds), - WA, CA > CD (p < 0.05; 480-, 540-, & 600-seconds). **Contextual Factors** TRD rolling: - Win > Draw (p < 0.05; 60- to 600-seconds), - Loss > Draw (p < 0.05; 300- & 600-seconds), - Win > Loss (p < 0.05; 60- & 540-seconds) - No influence of match location HSRD: - Win > Draw (p < 0.05; 60-, 420-, & 600-seconds) - No influence of match location

9 Methods

9.1 Research Design

This study used a longitudinal between-subject comparative design to assess WCS. Data were compared across age groups and positional groups to assess the differences in WCS.

9.2 Match Analysis and Player Data

A total of 87 male football players were included in data collection. All players were given a player identifier prior to data collection and no personally identifiable information was retained. Data obtained was categorised according to the age group of the match (Senior, U21s, and U18s), rather than the recorded age group of the individual player. This approach was adopted to reflect to demands of the competitive environment rather than player's individual age group. For example, an U21s player competing in the Senior team is exposed to the same match demands as the Senior players, and such demands could differ across age groups. Several players participated in more than one age group during the data collection period due to promotion to a higher team; 54 players appeared in one age group, 24 players appeared in two age groups, and 9 players appeared in three age groups. This resulted in 55 individual players for Senior match fixtures, 52 individual players for U21s match fixtures, and 22 individual players for U18s match fixtures. Given the study aim to assess match demands of age groups, rather than individual performance, grouping by age group of the match was deemed most appropriate.

WCS data were collected from 172 match fixtures spanning three, consecutive, competitive seasons, 2022-23, 2023-24, and 2024-25, from a single EPL football club and their Academy (Table 9.1). Data were collected from the EPL, UEFA Europe League, League Cup, FA Cup, UEFA Champions League, U21s EPL, EPL International Cup, EFL Trophy, U18 EPL, UEFA Youth League, EPL U18 Cup, and FA Youth Cup. Each match was assigned a session identifier to distinguish between duplicate match titles across the data collection period.

Table 9.1 – Number of match fixtures per season and age group.

Season	Senior (n)	U21s (n)	U18s (n)	Total Match Fixtures
2022-23	50	2	0	52
2023-24	44	7	3	54
2024-25	51	10	5	66
Total	145	19	8	172

All WCS data were collected using Sportlight® LiDAR tracking system (Sportlight®, Oxford, UK; LiDAR) as part of the club's routine monitoring process. The tracking systems validity and accuracy have been presented elsewhere (Bampouras and Thomas, 2022). For home matches, a single-sensored system was permanently mounted seven metres above pitch height, sampling at 1.2million spatial readings per second over a 200m range at 10Hz. Data were collected for away matches where Sportlight® was installed.

The proprietary software utilized in conjunction with the LiDAR system facilitated the tracking of all movements occurring on the pitch. This was achieved through the allocation of distinct elements: a ground plane corresponding to the pitch itself, a background model encompassing static objects, and a foreground model capturing dynamic points within the LiDAR data (Dos'Santos et al., 2022). Clusters of moving points were detected to pinpoint the positions of players. The software then determined the centre of each cluster, a method proven to yield precise positional data when compared to a 3D motion capture system utilizing a four-marker pelvis model (Bampouras & Thomas, 2022; Dos'Santos et al., 2022).

Furthermore, three cameras captured high-resolution imagery (Sony IMX253, 12.4MPx, 10fps synchronized with the LiDAR data). Their output was fed into an artificial intelligence system, which undertook the temporal tracking of individual clusters and the re-identification of players using previously captured imagery. The Sportlight® system's output provided the WCS data.

Through freely available online information, a predominant 4-2-3-1 formation was determined for Senior match fixtures in the 2022-23 (n = 44) and 2023-24 seasons (n = 37), and a predominant 3-4-2-1 formation in the 2024-25 season (n = 31). For

U21s, a predominant 4-2-3-1 formation was determined for the 2022-23 (n = 1), 2023-24 (n = 4), and 2024-25 seasons (n = 5). For U18s, no match data were obtained for the 2022-23 season, and a predominant 4-2-3-1 formation was determined for the 2023-24 (n = 2) and 2024-25 seasons (n = 5).

Within each age group, all players were categorised into their respective position group, as used by Sportlight® and broadly aligning to previously used groupings (Oliva-Lozano *et al.,* 2021; Oliva-Lozano *et al.,* 2020; Oliva-Lozano *et al.,* 2023; Fereday *et al.,* 2020; Baptista *et al.,* 2024; Niu *et al.,* 2025; Novak *et al.,* 2021): centre back (CB), full back (FB), defensive midfield (CDM), central midfield (CM), attacking midfield (CAM), wide midfield (WM), wide forward (WF), and striker (S). No players were recorded for the positional group 'wide midfield', and goalkeepers were not included in this study due to their positional demands not being reflective of the group (Thoseby *et al*., 2022; Novak *et al*., 2021; Baptista *et al*., 2024). Players who played multiple positions were categorised into the positional group in which they played most matches (Table 9.2).

Table 9.2 – Positional group sample sizes across age groups.

Position	Senior (n)	U21s (n)	U18s (n)
CB	10	10	4
FB	8	5	3
CDM	6	6	2
CM	6	11	4
CAM	7	5	1
WF	9	8	5
S	9	7	3

Based on the recommendation by Novak *et al*., (2021) to apply contextual factors to WCS analysis, match outcome and match location were included in data collection and analysis (Table 9.3).

Table 9.3 - Match outcome & match location of all match fixtures across the data collection period, split by age group of the match.

		Senior	U21s	U18s
Win	Home	57	8	5
	Away	21	1	3
Draw	Home	11	4	0
	Away	12	1	0
Loss	Home	19	5	0
	Away	25	0	0
Total		**145**	**19**	**8**

Ethical approval was granted by Lancaster Medical School (ID: LMS-25-1-Richardson) and consent given by the football club, via Sportlight®.

9.3 Worst Case Scenario KPIs

Prior to data collection, key performance indicators (KPIs) were chosen to measure WCS. The KPIs used were WCS total distance (WCS_{TRD}) defined as the total distance run at any speed, within each epoch length (m·min^{-1}), WCS high-speed running distance (WCS_{HSRD}) defined as the total distance run, above 330m·min^{-1}, within each epoch length, and WCS sprint running distance (WCS_{SRD}) defined as the total distance run, above 420 m·min^{-1}, within each epoch length. Speed thresholds were defined by Sportlight® and correlate with speed thresholds previously used in the literature (Thoseby *et* al., 2023; Thoseby *et al*., 2020; Novak *et al*., 2021; Delaney *et al.,* 2018; Akenhead and Nassis, 2016).

WCS data were collected and analysed based on three groups - epoch peaks, epoch threshold breaches, and epoch threshold counts. Data were obtained from the three groups for each KPI. Epoch peaks were defined as the peak metric value recorded within individual epoch lengths; epoch threshold breaches defined as the duration, in seconds, above a defined threshold within each individual epoch length; epoch threshold counts defined as the number of times the individual exceeds the defined threshold for each epoch length. Data were collected using a rolling window method

(Novak *et al.*, 2021), applying varying epoch lengths; epoch peak data used six epoch lengths (30-, 60-, 120-, 180, 300-, 600-seconds), and epoch threshold breaches and counts data were collected using three epoch lengths (30-, 60-, 120-seconds). The defined threshold for epoch threshold breaches and counts was set by Sportlight® (Table 9.4) and was derived from EPL representative data.

Table 9.4 - Relative distance definitions of epoch thresholds for 'epoch threshold breaches' and 'epoch threshold counts', set by Sportlight®.

KPI	Epoch Length	Men's Threshold
TRD	30s	250 $m \cdot min^{-1}$
TRD	60s	200 $m \cdot min^{-1}$
TRD	120s	170 $m \cdot min^{-1}$
HSRD	30s	115 $m \cdot min^{-1}$
HSRD	60s	65 $m \cdot min^{-1}$
HSRD	120s	40 $m \cdot min^{-1}$
SRD	30s	65 $m \cdot min^{-1}$
SRD	60s	35 $m \cdot min^{-1}$
SRD	120s	20 $m \cdot min^{-1}$

For epoch peaks, the recorded value is the peak value of each combination of KPI and epoch length (Baptista *et al.*, 2024). In context, the recorded WCS for TRD in a 30-second epoch is the peak TRD run in any given 30-second time frame within a 90-minute match fixture. A total of 41,217 observations were recorded for epoch peaks. For epoch threshold breaches, one observation was recorded per combination of KPI and epoch length that exceeded the defined threshold. A total of 25,490 observations were recorded for epoch threshold breaches. For epoch threshold counts, one observation was recorded per combination of KPI and epoch length, per player, per match. A total of 20,637 observations were recorded for epoch threshold counts. Data were not removed where the epoch threshold count was zero because it was deemed important for comparing across age groups. Removing zero counts could introduce bias by removing younger or less physically developed players who did not reach the predefined threshold. Retaining zero allows a more accurate representation of the distribution and frequency of WCS. Not all players will always met the WCS thresholds, an important outcome to be aware of particularly when it comes to prescribing training.

9.4 Data Analysis

All statistical analyses were performed using R Studio (Version 2025.05.0+496; Posit Software, Boston, MA, USA). Statistical significance was defined using conventional thresholds (***$p < 0.001$, **$p < 0.01$, *$p < 0.05$). All 87 players were included in each statistical analysis yet the method of grouping by age varied slightly. All identifiers were converted to factors (kpi_id: Total Distance, High-Speed Running Distance, and Sprint Running Distance; squad_id: Senior, U21s, and U18s; epoch_id: 30-, 60-, 120-, 180-, 300-, 600-seconds; position_id: CB, FB, CDM, CM, CAM, WM, WF, S). As per the club's request to compare across age groups, analysis grouped players by three age groups (Senior, U21s, and U18s) and used 55 individual players who were tagged to the 'Senior' age group, the Men's First Team, 52 individual players who were tagged to the 'U21s' age group, and 22 individual players who were tagged to the 'U18s' age group.

A series of linear mixed-effects models were fitted using the "lmer()" function from the "lme4" package in R. Data were filtered by KPI to isolate the specific KPI of interest. To explore the effect of squad_id, the WCS (epoch_peak_value) was the dependant variable, squad_id was the fixed effect, and player_id was a random effect to account for repeated measures. Estimated marginal means were computed using the emmeans package to assess pairwise comparisons across age groups. Bonferroni adjustment was applied to control for multiple comparisons. Effect size (Cohen's *d*) was calculated to quantify the magnitude of differences; < 0.010 (negligible effect), 0.10 – 0.19 (very small effect), 0.20 – 0.49 (small effect), 0.50 – 0.79 (moderate effect), and > 0.80 (large effect) (Cohen, 1988).

To explore the effect of position_id and squad_id on WCS, a separate model was fitted for each KPI. The WCS (epoch_peak_value) was the dependant variable, position_id and squad_id were the fixed effect and included their interaction, and player_id was a random effect to account for repeated measures. Estimated marginal means were computed using the emmeans package to assess pairwise comparisons across age groups. Bonferroni adjustment was applied to control for multiple comparisons.

10 Results

10.1 Epoch Peaks: Age Group Comparison

10.1.1 WCS Total Distance

A total of 13,739 observations were analysed for WCS_{TRD} (Senior: n = 11,841; U21s: n = 1,562; U18: n = 336). Descriptive statistics of WCS_{TRD} for each age group across six different epoch lengths are presented in Table 10.1.

U21 match fixtures recorded significantly higher absolute WCS_{TRD} in 300- and 600-second epoch, compared to Senior match fixtures ($p = 0.05$, $p = 0.006$, respectively). The difference remained significant for relative WCS_{TRD} ($p = 0.05$, $p = 0.006$, respectively; Figure 10.1). The effect size was small-to-moderate ($d = -0.37$; Cohen, 1988).

Across all other epoch lengths, no significant differences in absolute or relative WCS_{TRD} were observed between age groups ($p > 0.05$). Effect sizes for these were consistently negligible-to-small ($d = 0.003$ to 0.37; Cohen, 1988).

Match location did not significantly affect absolute or relative WCS_{TRD} across age groups for any epoch length ($p > 0.05$). No U18s match fixture resulted in a draw or loss, so no interaction between WCS_{TRD} and match outcome was assessed. Match outcome did not significantly affect WCS_{TRD} between Senior and U21s for any epoch length ($p > 0.05$).

*Table 10.1 – Absolute (m) and (relative (m·min^{-1})) WCS_{TRD} expressed as mean ± SD, for each age group across six different epoch lengths. *Significantly different to Senior (p < 0.05), **Significantly different to Senior (p < 0.01).*

Epoch Length (s)	Senior	U21s	U18s
30	127.6 ± 12.7 (255.2 ± 25.5)	127.9 ± 12.8 (255.9 ± 25.5)	127.5 ± 12.5 (255.0 ± 25.0)
60	204.6 ± 18.9 (204.6 ± 18.9)	207.0 ± 17.4 (207.0 ± 17.4)	206.0 ± 18.3 (206.0 ± 18.3)
120	343.1 ± 29.5 (171.5 ± 14.7)	347.8 ± 25.2 (173.9 ± 12.6)	347.0 ± 23.7 (173.5 ± 11.8)
180	475.5 ± 40.8 (158.5 ± 13.6)	485.6 ± 37.7 (161.9 ± 12.6)	481.6 ± 33.4 (160.5 ± 11.1)
300	728.1 ± 63.5 (145.6 ± 12.7)	747.7 ± 56.1 * (149.5 ± 11.2) *	740.8 ± 48.1 (148.2 ± 9.6)
600	1325.4 ± 119.4 (132.5 ± 11.9)	1370.1 ± 108.5 ** (137.0 ± 10.9) **	1357.5 ± 103.2 (135.8 ± 10.3)

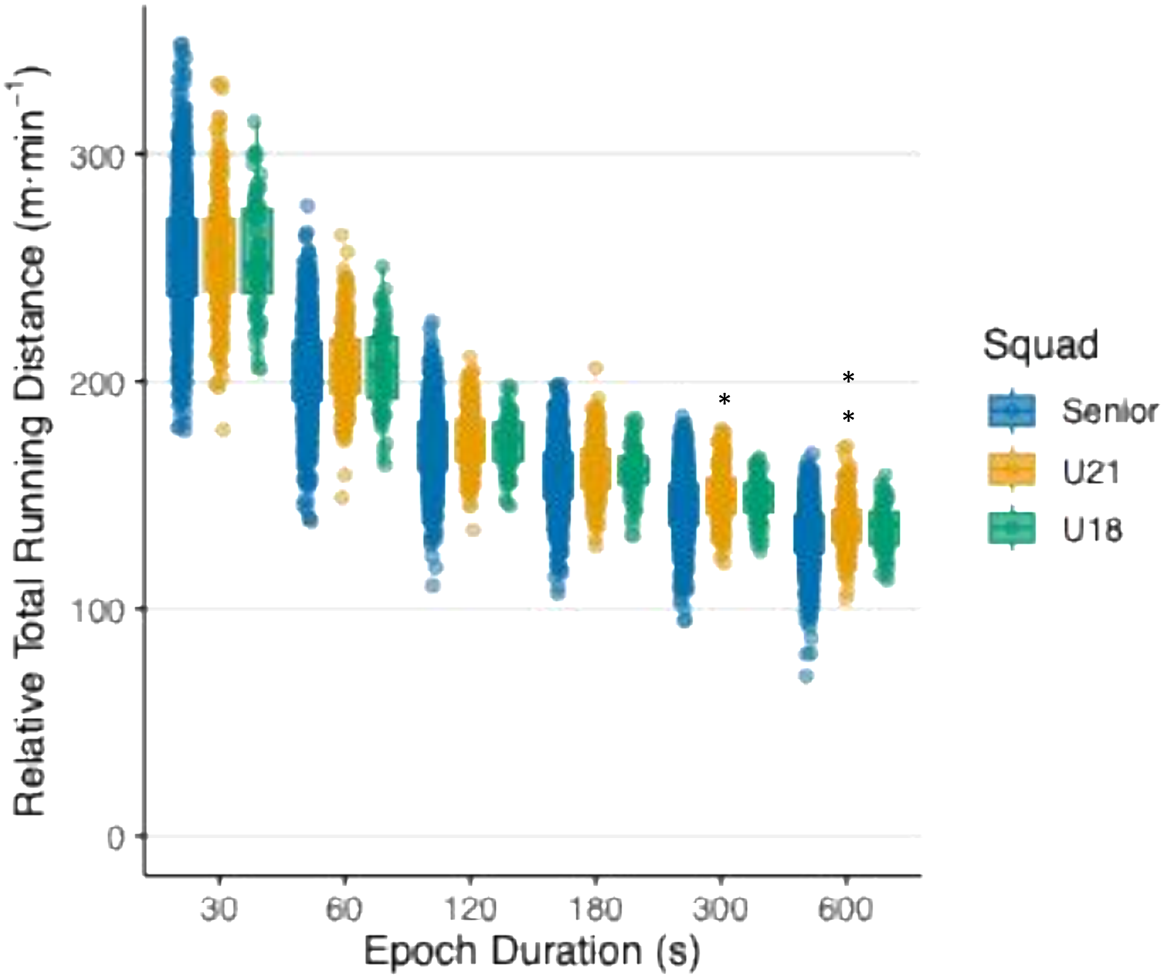

*Figure 10.1 - Relative WCS$_{TRD}$ (m·min^{-1}) categorised by age group (Senior, U21s, and U18s), split by epoch duration (s). *Significantly different to Senior ($p < 0.05$), **Significantly different to Senior ($p < 0.01$).*

10.1.2 WCS High-Speed Running Distance

A total of 13,739 observations was analysed for WCS_{HSRD} (Senior: n = 11,841; U21s: n = 1,562; U18: n = 336). Descriptive statistics for WCS_{TRD} for each age group across six different epoch lengths are presented in Table 10.2.

No significant differences were identified across age groups for any epoch length for WCS_{HSRD} ($p > 0.05$). The effect sizes for these were negligible to small (d = 0.0008 to 0.33; Cohen, 1988).

U18s had significantly higher WCS_{HSRD} than Senior at both home and away match fixtures for all epoch lengths ($p < 0.05$). Match location did not significantly affect absolute WCS_{HSRD} between other age group comparisons for any epoch length ($p > 0.05$). Match location did not significantly affect relative WCS_{HSRD} between any age group for any epoch length ($p > 0.05$).

No U18s match fixture resulted in a draw or loss, so no interaction between WCS_{HSRD} and match outcome was assessed. Match outcome did not significantly affect WCS_{TRD} between Senior and U21s for any epoch length ($p > 0.05$).

Table 10.2 - Absolute (m) and (relative (m·min^{-1})) WCS_{HSRD} expressed as mean ± SD, for each age group across six different epoch lengths.

Epoch Length (s)	**Senior**	**U21s**	**U18s**
30	60.6 ± 16.8 (121.2 ± 33.7)	59.9 ± 16.8 (119.8 ± 33.6)	63.1 ± 17.7 (126.1 ± 35.3)
60	67.9 ± 18.8 (67.9 ± 18.8)	66.8 ± 18.0 (66.8 ± 18.0)	69.9 ± 19.5 (69.9 ± 19.5)
120	84.4 ± 23.9 (42.2 ± 12.0)	83.1 ± 23.0 (41.6 ± 11.5)	85.9 ± 23.5 (42.9 ± 11.7)
180	98.8 ± 28.4 (32.9 ± 9.5)	99.5 ± 28.1 (33.2 ± 9.4)	97.6 ± 26.5 (32.5 ± 8.8)
300	125.1 ± 36.7 (25.0 ± 7.3)	125.5 ± 36.0 (25.1 ± 7.2)	126.3 ± 35.0 (25.3 ± 7.0)
600	180.6 ± 55.0 (18.1 ± 5.5)	184.1 ± 56.5 (18.4 ± 5.7)	183.8 ± 56.2 (18.4 ± 5.6)

10.1.3 WCS Sprint Running Distance

A total of 13,739 observations were analysed for WCS_{SRD} (Senior: n = 11,841; U21s: n = 1,562; U18: n = 336). Descriptive statistics for WCS_{TRD} for each age group across six different epoch lengths are presented in Table 10.3.

No significant differences were identified across age groups for any epoch length for WCS_{SRD} ($p > 0.05$). The effect sizes for WCS_{SRD} across all epoch length and age group comparison combinations ranged from negligible to small ($d = 0.017$ to 0.31; Cohen, 1988).

U18s and U21s recorded significantly higher WCS_{SRD} at home and away match fixtures than Senior, for all epoch lengths ($p < 0.05$). There was no significant effect on absolute WCS_{SRD} between U21 and U18 for any epoch length ($p > 0.05$). Match location did not significantly affect relative WCS_{SRD} between any age group for any epoch length ($p > 0.05$).

No U18s match fixture resulted in a draw or loss, so no interaction between WCS_{SRD} and match outcome was assessed. Match outcome significantly affected absolute WCS_{SRD}, with U21 being significantly lower than Senior for all match outcomes and all epoch lengths ($p < 0.01$). There was no significant effect on relative WCS_{SRD} between U21 and Senior for any epoch length ($p > 0.05$).

Table 10.3 - Absolute (m) and (relative ($m \cdot min^{-1}$)) WCS_{SRD} expressed as mean ± SD, for each age group across six different epoch lengths.

Epoch Length (s)	Senior	U21s	U18s
30	34.8 ± 14.9 (69.6 ± 29.8)	31.9 ± 14.8 (63.8 ± 29.5)	35.4 ± 15.6 (70.8 ± 31.3)
60	36.1 ± 15.6 (36.1 ± 15.6)	32.6 ± 15.1 (32.6 ± 15.1)	36.0 ± 15.7 (36.0 ± 15.7)
120	39.9 ± 18.2 (19.9 ± 9.1)	35.5 ± 17.0 (17.8 ± 8.5)	39.7 ± 17.2 (19.8 ± 8.6)
180	43.6 ± 20.6 (14.5 ± 6.9)	40.4 ± 20.6 (13.5 ± 6.9)	43.1 ± 18.7 (14.4 ± 6.2)
300	49.9 ± 24.8 (10.0 ± 5.0)	45.3 ± 23.5 (9.1 ± 4.7)	49.5 ± 20.8 (9.9 ± 4.2)
600	63.5 ± 33.6 (6.4 ± 3.4)	56.5 ± 31.6 (5.7 ± 3.2)	62.2 ± 28.2 (6.2 ± 2.8)

10.2 Epoch Peaks: Positional Group Comparison

10.2.1 WCS Total Running Distance

No significant differences were identified for absolute WCS_{TRD} for each positional group, between age group, for any epoch length ($p > 0.05$). No significant differences were identified in relative WCS_{TRD} between any other age groups for any epoch length ($p > 0.05$).

10.2.2 WCS High-Speed Running Distance

Descriptive statistics of WCS_{HSRD} for each positional group, per age group, across six different epoch lengths are presented in Table 10.4.

Across age groups, absolute and relative WCS_{HSRD} was significantly different between positional groups (Figure 10.2).For 30-second epoch (S: U21>Senior, $p < 0.05$; U18>Senior, $p < 0.01$), 60-second epoch (S: U18>Senior, $p < 0.001$; U18>U21, $p < 0.05$), 120-second epoch (S: U18>Senior, $p < 0.01$), 180-second epoch (S: U18>Senior, $p < 0.01$), 300-second epoch (S: U18>Senior, $p < 0.01$), and 600-second (S: U18>Senior, $p < 0.01$; U18>U21, $p < 0.05$). No significant differences were identified between positional groups for any other epoch length for absolute WCS_{HSRD} ($p > 0.05$). The effect sizes for WCS_{HSRD} across all positional group and epoch length comparison combinations were negligible.

*Table 10.4 - WCS_{HSRD} descriptives for positional group differences across age groups, split by epoch length. Significantly different to Senior *p<0.05, **p<0.01, ***p<0.001. Significantly different to U21 $^{\dagger}p<0.05$. Presented as absolute mean ± SD (m) (relative mean ± SD ($m \cdot min^{-1}$).*

Epoch Length (s)	Positional Group	Senior	U21	U18
	CB	50.6 ± 15.0 (101.2 ± 29.9)	50.0 ± 16.7 (99.9 ± 33.4)	57.5 ± 22.1 (114.9 ± 44.3)
	FB	65.7 ± 17.2 (131.4 ± 34.3)	61.4 ± 16.0 (122.9 ± 31.9)	63.2 ± 17.0 (126.4 ± 34.0)
	CDM	55.3 ± 15.0 (110.6 ± 30.0)	56.0 ± 18.2 (112.0 ± 36.4)	59.5 ± 20.0 (119.0 ± 40.0)
30	CM	57.3 ± 13.9 (114.6 ± 27.7)	57.5 ± 15.8 (115.0 ± 31.7)	54.7 ± 15.2 (109.5 ± 30.3)
	CAM	66.9 ± 16.2 (133.7 ± 32.3)	71.1 ± 17.8 (142.2 ± 35.7)	70.6 ± 12.6 (141.3 ± 25.2)
	WF	66.6 ± 16.0 (133.2 ± 32.0)	64.1 ± 12.3 (128.3 ± 24.5)	64.8 ± 15.6 (129.6 ± 31.3)
	S	56.9 ± 14.0 (113.7 ± 27.9)	64.0 ± 16.0 * (128.0 ± 32.1) *	75.6 ± 15.0 ** (151.2 ± 30.0) **
	CB	54.3 ± 15.4 (54.3 ± 15.4)	54.4 ± 16.9 (54.4 ± 16.9)	63.6 ± 19.4 (63.6 ± 19.4)
	FB	74.1 ± 19.5 (74.1 ± 19.5)	68.7 ± 16.2 (68.7 ± 16.2)	66.1 ± 19.8 (66.1 ± 19.8)
	CDM	61.4 ± 16.4 (61.4 ± 16.4)	63.0 ± 20.9 (63.0 ± 20.9)	63.4 ± 18.1 (63.4 ± 18.1)
60	CM	64.2 ± 14.9 (64.2 ± 14.9)	64.3 ± 15.9 (64.3 ± 15.9)	57.6 ± 11.9 (57.6 ± 11.9)
	CAM	75.5 ± 17.8 (75.5 ± 17.8)	79.2 ± 16.3 (79.2 ± 16.3)	81.3 ± 18.6 (81.3 ± 18.6)
	WF	75.6 ± 17.2 (75.6 ± 17.2)	72.1 ± 15.7 (72.1 ± 15.7)	74.9 ± 19.6 (74.9 ± 19.6)
	S	65.1 ± 15.3 (65.1 ± 15.3)	71.6 ± 16.4 (71.6 ± 16.4)	87.9 ± 15.2 ***† (87.9 ± 15.2) ***†
	CB	64.9 ± 18.1 (32.4 ± 9.1)	64.5 ± 18.2 (32.2 ± 9.1)	76.0 ± 19.0 (38.0 ± 9.5)
	FB	90.9 ± 22.8 (45.4 ± 11.4)	84.5 ± 23.6 (42.2 ± 11.8)	89.1 ± 24.3 (44.6 ± 12.2)
	CDM	76.7 ± 22.3 (38.3 ± 11.2)	76.3 ± 27.1 (38.1 ± 13.6)	79.3 ± 26.8 (39.7 ± 13.4)
120	CM	81.1 ± 19.9 (40.6 ± 10.0)	84.2 ± 23.1 (42.1 ± 11.5)	72.0 ± 17.5 (36.0 ± 8.8)
	CAM	94.5 ± 22.5 (47.3 ± 11.3)	96.3 ± 19.6 (48.2 ± 9.8)	102.7 ± 23.6 (51.3 ± 11.8)
	WF	95.1 ± 21.9 (47.5 ± 11.0)	91.4 ± 19.6 (45.7 ± 9.8)	87.2 ± 21.5 (43.6 ± 10.7)
	S	82.7 ± 20.2 (41.4 ± 10.1)	89.1 ± 16.0 (44.5 ± 8.0)	104.1 ± 22.6 ** (52.0 ± 11.3) **
	CB	73.8 ± 19.9 (24.6 ± 6.6)	76.0 ± 22.5 (25.3 ± 7.5)	84.5 ± 20.0 (28.2 ± 6.7)
	FB	106.7 ± 26.9 (35.6 ± 9.0)	101.4 ± 26.5 (33.8 ± 8.8)	94.7 ± 24.6 (31.6 ± 8.2)
	CDM	90.3 ± 26.0 (30.1 ± 8.7)	94.3 ± 34.4 (31.4 ± 11.5)	95.6 ± 28.7 (31.9 ± 9.6)
180	CM	95.3 ± 23.8 (31.8 ± 7.9)	98.6 ± 25.4 (32.9 ± 8.5)	82.5 ± 23.5 (27.5 ± 7.8)
	CAM	111.0 ± 26.3 (37.0 ± 8.8)	118.0 ± 27.7 (39.3 ± 9.2)	114.4 ± 27.8 (38.1 ± 9.3)
	WF	112. ± 25.9 (37.4 ± 8.6)	107.9 ± 22.8 (36.0 ± 7.6)	98.2 ± 23.7 (32.7 ± 7.9)
	S	97.1 ± 23.9 (32.4 ± 8.0)	108.2 ± 23.4 (36.1 ± 7.8)	125.9 ± 19.0 ** (42.0 ± 6.3) **
	CB	91.9 ± 25.4 (18.4 ± 5.1)	93.9 ± 24.4 (18.8 ± 4.9)	102.7 ± 21.9 (20.5 ± 4.4)
	FB	134.9 ± 34.7 (27.0 ± 6.9)	125.6 ± 32.3 (25.1 ± 6.5)	115.5 ± 29.9 (23.1 ± 6.0)
	CDM	113.3 ± 34.3 (22.7 ± 6.9)	118.1 ± 45.4 (23.6 ± 9.1)	119.7 ± 42.9 (23.9 ± 8.6)
300	CM	120.0 ± 30.3 (24.0 ± 6.1)	125.2 ± 30.8 (25.0 ± 6.2)	109.9 ± 27.7 (22.0 ± 5.5)
	CAM	140.4 ± 31.6 (28.1 ± 6.3)	150.8 ± 38.7 (30.2 ± 7.7)	151.2 ± 32.5 (30.2 ± 6.5)
	WF	144.1 ± 33.8 (28.8 ± 6.8)	136.8 ± 29.4 (27.4 ± 5.9)	137.6 ± 38.7 (27.5 ± 7.7)
	S	123.1 ± 30.3 (24.6 ± 6.1)	138.8 ± 31.4 (27.8 ± 6.3)	161.2 ± 12.7 ** (32.2 ± 2.5) **
	CB	125.0 ± 33.9 (12.5 ± 3.4)	134.3 ± 34.6 (13.4 ± 3.5)	143.9 ± 26.7 (14.4 ± 2.7)
	FB	197.2 ± 52.1 (19.7 ± 5.2)	184.4 ± 47.1 (18.4 ± 4.7)	168.4 ± 49.1 (16.8 ± 4.9)
	CDM	161.7 ± 50.2 (16.2 ± 5.0)	169.3 ± 70.7 (16.9 ± 7.1)	167.8 ± 45.5 (16.8 ± 4.6)
600	CM	175.2 ± 45.6 (17.5 ± 4.6)	180.5 ± 40.2 (18.1 ± 4.0)	154.2 ± 57.0 (15.4 ± 5.7)
	CAM	203.8 ± 46.4 (20.4 ± 4.6)	226.7 ± 64.2 (22.7 ± 6.4)	221.8 ± 33.1 (22.2 ± 3.3)
	WF	210.6 ± 48.1 (21.1 ± 4.8)	206.1 ± 46.6 (20.6 ± 4.7)	196.2 ± 52.8 (19.6 ± 5.3)
	S	180.9 ± 44.5 (18.1 ± 4.5)	205.9 ± 58.0 (20.6 ± 5.8)	256.6 ± 25.7 **† (25.7 ± 2.6) **†

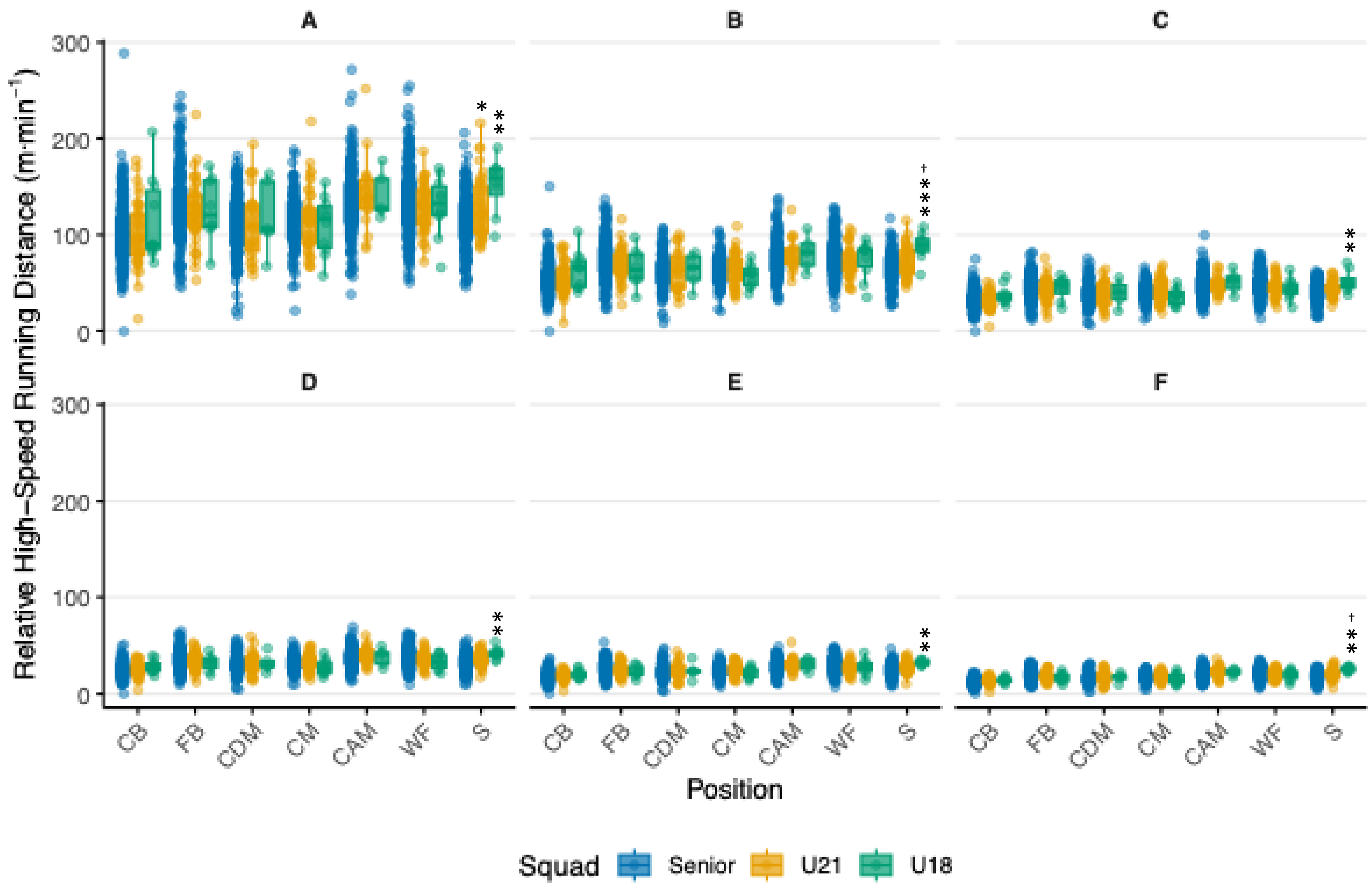

*Figure 10.2 - Relative WCS$_{HSRD}$ (m·min-1) categorised by age group (Senior, U21s, and U18s), split by epoch duration (s) and positional group (CB: Centre Back, FB: Full back, CDM: Defensive Midfield, CM: Central Midfield, CAM: Attacking Midfield, WF: Wide Forward, S: Striker. Panels: A = 30-s, B = 60-s, C = 120-s, D = 180-s, E = 300-s, F = 600-s. Significantly different to Senior *p<0.05, **p<0.01, ***p<0.001. Significantly different to U21 †p<0.05*

10.2.3 WCS Sprint Running Distance

Descriptive statistics of WCS_{SRD} for each positional group, per age group, across six different epoch lengths are presented in Table 10.5.

Across age groups, absolute WCS_{SRD} was significantly different between positional groups. For 30-second epoch (S: U21>Senior, $p < 0.05$), 120-second epoch (WF: U21, U18>Senior, $p < 0.05$), 180-second epoch (S: U21, U18>Senior, $p < 0.05$), 300-second epoch (WF: U21>Senior, $p < 0.01$), 600-second epoch (WF: U21>Senior, $p < 0.01$, U18>Senior, $p < 0.05$). No significant differences were identified between positional groups for any other epoch length for absolute WCS_{SRD} ($p > 0.05$).

Across age groups, relative WCS_{SRD} was significantly different between positional groups (Figure 10.3). For 30-second epoch (S: U18>Senior, $p < 0.05$), 120-second epoch (WF: U21>Senior, $p < 0.05$; S: U18>Senior, $p < 0.05$), 180-second epoch (S: U21, U18>Senior, $p < 0.05$), 300-second epoch (WF: U21>Senior, $p < 0.01$), 600-second epoch (WF: U21>Senior, $p < 0.01$, U18>Senior, $p < 0.05$). No significant differences were identified between positional groups for any other epoch length for relative WCS_{SRD} ($p > 0.05$). The effect sizes for absolute and relative WCS_{SRD} across all positional group and epoch length comparison combinations were consistently *small*.

*Table 10.5 - WCS_{SRD} descriptives for positional group differences across age groups, split by epoch length. Significantly different to Senior *p<0.05, **p<0.01. Presented as absolute mean ± SD (m) (relative mean ± SD (m·min^{-1}).*

Epoch Length (s)	Positional Group	Senior	U21s	U18s
30	CB	27.9 ± 13.6 (55.8 ± 27.2)	25.4 ± 11.5 (50.8 ± 22.9)	34.5 ± 17.1 (69.1 ± 34.2)
	FB	39.2 ± 12.9 (78.3 ± 25.8)	34.0 ± 12.9 (68.0 ± 25.9)	39.3 ± 20.9 (78.6 ± 41.7)
	CDM	27.0 ± 13.0 (53.9 ± 26.0)	25.4 ± 15.9 (50.9 ± 31.7)	27.1 ± 10.8 (54.2 ± 21.6)
	CM	26.9 ± 13.9 (53.8 ± 27.8)	28.0 ± 14.9 (55.9 ± 29.7)	29.5 ± 18.9 (59.0 ± 37.9)
	CAM	36.6 ± 14.0 (73.3 ± 27.9)	37.6 ± 15.4 (75.2 ± 30.7)	38.0 ± 9.4 (76.1 ± 18.8)
	WF	42.9 ± 13.9 (85.8 ± 27.9)	35.9 ± 12.5 (71.9 ± 25.1)	34.7 ± 13.3 (69.4 ± 26.6)
	S	34.9 ± 13.8 (69.8 ± 27.5)	38.3 ± 16.0 * (76.6 ± 32.1)	44.3 ± 9.7 (88.5 ± 19.3) *
60	CB	28.3 ± 13.7 (28.3 ± 13.7)	26.3 ± 11.6 (26.3 ± 11.6)	34.5 ± 17.1 (34.5 ± 17.1)
	FB	40.7 ± 13.4 (40.7 ± 13.4)	34.7 ± 13.5 (34.7 ± 13.5)	39.3 ± 20.9 (39.3 ± 20.9)
	CDM	27.6 ± 13.4 (27.6 ± 13.4)	26.2 ± 16.4 (26.2 ± 16.4)	27.1 ± 10.8 (27.1 ± 10.8)
	CM	27.5 ± 14.4 (27.5 ± 14.4)	28.1 ± 14.8 (28.1 ± 14.8)	29.8 ± 19.1 (29.8 ± 19.1)
	CAM	38.1 ± 14.8 (38.1 ± 14.8)	38.0 ± 15.3 (38.0 ± 15.3)	38.0 ± 9.4 (38.0 ± 9.4)
	WF	44.9 ± 14.6 (44.9 ± 14.6)	36.7 ± 12.9 (36.7 ± 12.9)	37.8 ± 13.3 (37.8 ± 13.3)
	S	36.3 ± 14.2 (36.3 ± 14.2)	39.4 ± 16.7 (39.4 ± 16.7)	44.3 ± 9.7 (44.3 ± 9.7)
120	CB	29.8 ± 14.8 (14.9 ± 7.4)	27.3 ± 12.0 (13.7 ± 6.0)	37.4 ± 15.4 (18.7 ± 7.7)
	FB	45.3 ± 16.0 (22.7 ± 8.0)	37.2 ± 15.3 (18.6 ± 7.7)	41.0 ± 21.1 (20.5 ± 10.6)
	CDM	29.6 ± 14.3 (14.8 ± 7.1)	30.0 ± 18.8 (15.0 ± 9.4)	32.4 ± 18.3 (16.2 ± 9.2)
	CM	29.2 ± 15.5 (14.6 ± 7.7)	31.1 ± 17.2 (15.5 ± 8.6)	30.9 ± 20.6 (15.5 ± 10.3)
	CAM	41.5 ± 16.5 (20.7 ± 8.2)	41.9 ± 17.8 (21.0 ± 8.9)	46.6 ± 11.4 (23.3 ± 5.7)
	WF	51.5 ± 17.4 (25.8 ± 8.7)	41.1 ± 15.9 * (20.6 ± 8.0) *	40.9 ± 12.1 * (20.4 ± 6.0)
	S	40.9 ± 16.8 (20.5 ± 8.4)	42.3 ± 17.1 (21.1 ± 8.6)	50.8 ± 15.1 (25.4 ± 7.6) *
180	CB	31.5 ± 15.5 (10.5 ± 5.2)	30.1 ± 14.5 (10.0 ± 4.8)	37.6 ± 15.3 (12.5 ± 5.1)
	FB	50.2 ± 18.6 (16.7 ± 6.2)	42.5 ± 18.0 (14.2 ± 6.0)	42.8 ± 21.7 (14.3 ± 7.2)
	CDM	32.0 ± 16.0 (10.7 ± 5.3)	34.4 ± 24.3 (11.5 ± 8.1)	33.2 ± 18.3 (11.1 ± 6.1)
	CM	31.7 ± 18.2 (10.6 ± 6.1)	33.7 ± 17.8 (11.2 ± 5.9)	39.0 ± 24.8 (13.0 ± 8.3)
	CAM	44.8 ± 18.3 (14.9 ± 6.1)	50.3 ± 23.4 (16.8 ± 7.8)	49.0 ± 15.8 (16.3 ± 5.3)
	WF	57.6 ± 19.9 (19.2 ± 6.6)	45.9 ± 20.2 (15.3 ± 6.7)	43.8 ± 10.4 (14.6 ± 3.5)
	S	44.3 ± 18.4 (14.8 ± 6.1)	49.9 ± 20.5 * (16.6 ± 6.8) *	56.9 ± 18.5 * (19.0 ± 6.2) *
300	CB	34.3 ± 17.0 (6.9 ± 3.4)	32.1 ± 14.7 (6.4 ± 2.9)	42.2 ± 18.1 (8.4 ± 3.6)
	FB	57.9 ± 22.0 (11.6 ± 4.4)	48.4 ± 20.1 (9.7 ± 4.0)	44.9 ± 20.8 (9.0 ± 4.2)
	CDM	35.7 ± 18.7 (7.1 ± 3.7)	38.4 ± 28.4 (7.7 ± 5.7)	40.1 ± 22.2 (8.0 ± 4.4)
	CM	35.5 ± 21.2 (7.1 ± 4.2)	37.9 ± 20.4 (7.6 ± 4.1)	43.3 ± 27.2 (8.7 ± 5.4)
	CAM	50.5 ± 21.4 (10.1 ± 4.3)	56.1 ± 26.9 (11.2 ± 5.4)	57.1 ± 11.0 (11.4 ± 2.2)
	WF	68.4 ± 24.6 (13.7 ± 4.9)	52.1 ± 21.7 ** (10.4 ± 4.3) **	56.8 ± 17.6 (11.4 ± 3.5)
	S	51.2 ± 21.2 (10.2 ± 4.2)	56.1 ± 25.4 (11.2 ± 5.1)	63.1 ± 17.4 (12.6 ± 3.5)
600	CB	40.6 ± 20.8 (4.1 ± 2.1)	36.6 ± 17.0 (3.7 ± 1.7)	47.3 ± 19.2 (4.7 ± 1.9)
	FB	75.6 ± 30.4 (7.6 ± 3.0)	58.9 ± 27.4 (5.9 ± 2.7)	63.3 ± 27.3 (6.3 ± 2.7)
	CDM	43.4 ± 23.8 (4.3 ± 2.4)	50.2 ± 38.2 (5.0 ± 3.8)	49.2 ± 25.2 (4.9 ± 2.5)
	CM	43.3 ± 26.7 (4.3 ± 2.7)	45.9 ± 26.0 (4.6 ± 2.6)	48.1 ± 30.4 (4.8 ± 3.0)
	CAM	63.9 ± 28.1 (6.4 ± 2.8)	70.0 ± 35.0 (7.0 ± 3.5)	83.4 ± 25.0 (8.3 ± 2.5)
	WF	89.2 ± 33.7 (8.9 ± 3.4)	67.1 ± 27.6 ** (6.7 ± 2.8) **	68.5 ± 26.2 * (6.9 ± 2.6) *
	S	66.6 ± 28.7 (6.7 ± 2.9)	74.5 ± 36.0 (7.4 ± 3.6)	84.4 ± 23.4 (8.4 ± 2.3)

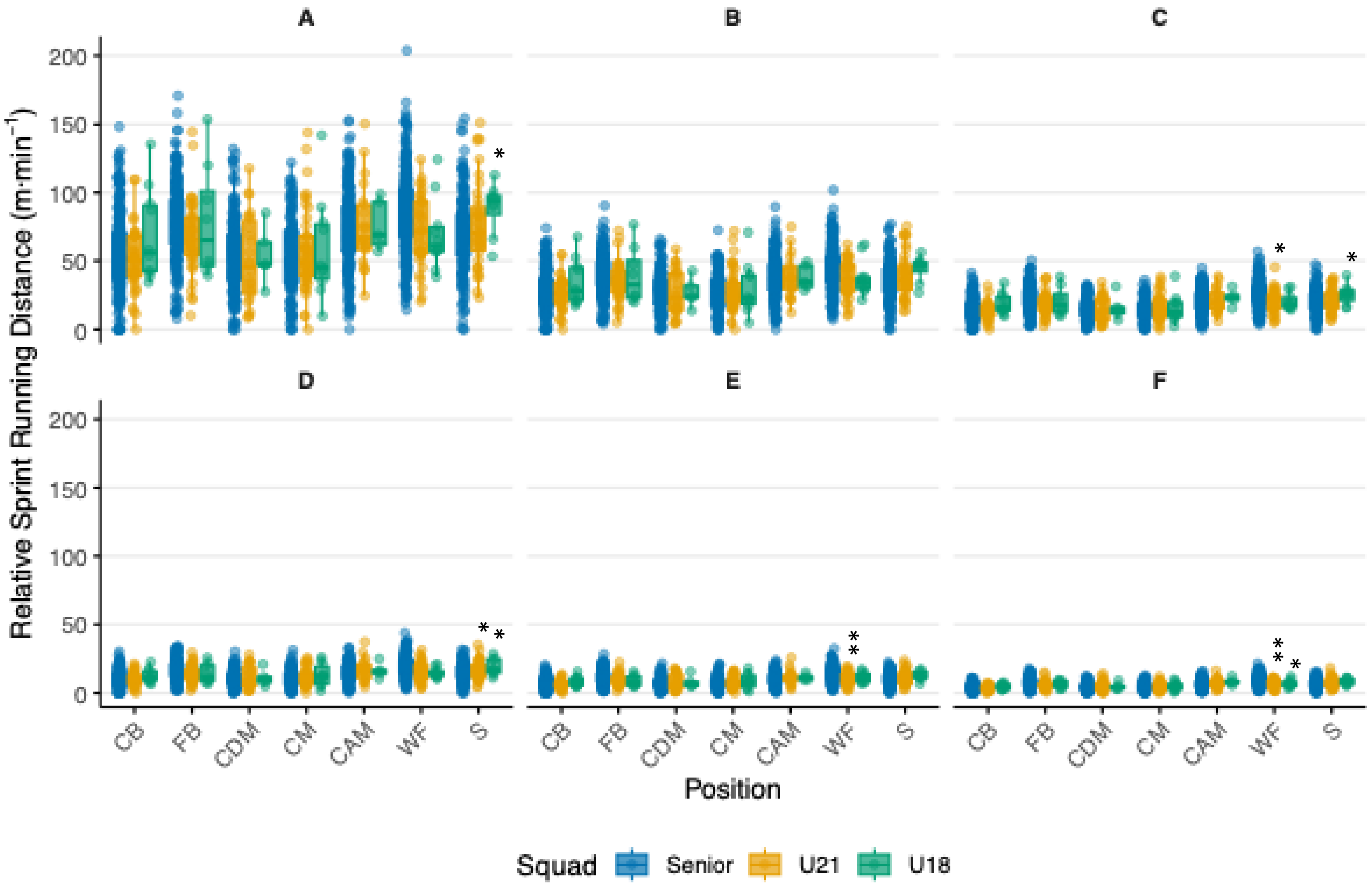

*Figure 10.3 - Relative WCS$_{SRD}$ (m·min^{-1}) categorised by age group (Senior, U21s, and U18s), split by epoch duration (s) and positional group (CB: Centre Back, FB: Full back, CDM: Defensive Midfield, CM: Central Midfield, CAM: Attacking Midfield, WF: Wide Forward, S: Striker. Panels: A = 30-s, B = 60-s, C = 120-s, D = 180-s, E = 300-s, F = 600-s. Significantly different to Senior *p<0.05, **p<0.01.*

10.3 Epoch Threshold Breaches: Age Group Comparison

10.3.1 WCS Total Distance

A total of 11,297 observations were analysed for epoch threshold breaches WCS_{TRD} (Senior: 9,393; U21: 1,351; U18: 553). Descriptive statistics for WCS_{TRD} for each age group across three different epoch lengths are presented in Table 10.6.

No significant differences were identified across age groups for any epoch length for WCS_{TRD} ($p > 0.05$). The effect sizes for WCS_{TRD} across all epoch length and age group comparison combinations ranged from negligible to small ($d = 0.005$ to $d = 0.15$, Cohen, 1988).

Table 10.6 – Epoch Threshold Breaches WCS_{TRD} (s) descriptives across age groups, split by epoch length. Recorded as duration above threshold in seconds.

Epoch Length (s)	Senior	U21	U18
30	7.84 ± 5.62	7.65 ± 5.94	8.47 ± 6.04
60	12.5 ± 11.1	12.4 ± 10.9	12.5 ± 10.4
120	19.9 ± 21.5	16.4 ± 17.0	19.2 ± 20.4

10.3.2 WCS High-Speed Running Distance

A total of 7,816 observations were analysed for epoch threshold breaches WCS_{HSRD} (Senior: 6,663; U21: 767; U18: 386). Descriptive statistics for WCS_{TRD} for each age group across three different epoch lengths are presented in Table 10.7.

No significant differences were identified across age groups for any epoch length for WCS_{HSRD} ($p > 0.05$). The effect sizes for WCS_{HSRD} across all epoch length and age group comparison combinations ranged from negligible to small ($d = 0.02$ to $d = 0.21$; Cohen, 1988).

Table 10.7 - Epoch Threshold Breaches WCS_{HSRD} (s) descriptives across age groups, split by epoch length. Recorded as duration above threshold in seconds.

Epoch Length (s)	Senior	U21	U18
30	18.1 ± 7.25	18.2 ± 6.96	18.5 ± 6.95
60	31.3 ± 18.8	30.3 ± 18.2	30.8 ± 18.1
120	43.0 ± 33.6	40.8 ± 33.0	47.6 ± 33.1

10.3.3 WCS Sprint Running Distance

A total of 6,377 observations were analysed for epoch threshold breaches WCS_{SRD} (Senior: 5,468; U21: 497; U18: 232). Descriptive statistics for WCS_{TRD} for each age group across three different epoch lengths are presented in Table 10.8.

No significant differences were identified across age groups for time spent above the WCS_{SRD} speed threshold for each epoch length ($p > 0.05$). The effect sizes for WCS_{SRD} across all epoch length and age group comparison combinations ranged from negligible to small ($d = 0.003$ to $d = 0.24$; Cohen, 1988).

Table 10.8 - Epoch Threshold Breaches WCS_{SRD} (s) descriptives across age groups, split by epoch length. Recorded as duration above threshold in seconds.

Epoch Length (s)	Senior	U21	U18
30	26.0 ± 4.30	25.7 ± 4.74	26.4 ± 3.77
60	50.1 ± 15.5	50.1 ± 14.7	50.2 ± 15.5
120	83.2 ± 41.7	77.2 ± 43.5	88.1 ± 40.9

10.4 Epoch Threshold Counts: Age Group Comparison

10.4.1 WCS Total Distance

A total of 6,879 observations were analysed for epoch threshold counts WCS_{TRD} (Senior: 5,904; U21: 660; U18: 315). Descriptive statistics for WCS_{TRD} for each age group across three different epoch lengths are presented in Table 10.9.

Across age groups, the number of times above the WCS_{TRD} speed threshold was significantly different for 120-second epoch (U21>Senior, $p < 0.05$). No significant differences were identified between any other age groups for any other epoch length ($p > 0.05$). The effect sizes for the WCS_{TRD} across all epoch length and age group comparison combinations ranged from negligible to small ($d = 0.03$ to 0.43; Cohen, 1988).

*Table 10.9 - Epoch Threshold Counts WCS_{TRD} descriptives for age groups, split by epoch length. Recorded as count per epoch. *Significantly different to Senior (p < 0.05).*

Epoch Length (s)	Senior	U21	U18
30	1.2 ± 1.5	1.3 ± 1.6	1.0 ± 1.3
60	1.6 ± 2.1	1.9 ± 2.5	1.7 ± 2.0
120	1.8 ± 2.8	2.5 ± 3.8 *	2.4 ± 2.8

10.4.2 WCS High-Speed Running Distance

A total of 6,879 observations were analysed for epoch threshold counts WCS_{HSRD} (Senior: 5,904; U21: 660; U18: 315). Descriptive statistics for WCS_{HSRD} for each age group across three different epoch lengths are presented in Table 10.10.

No significant differences were identified across age groups for the number of times above the WCS_{HSRD} speed threshold, for any epoch length ($p > 0.05$). The effect sizes for the WCS_{HSRD} across all epoch length and age group comparison combinations ranged from negligible to small ($d = 0.02$ to 0.11; Cohen, 1988).

Table 10.10 - Epoch Threshold Counts WCS_{HSRD} descriptives for age groups, split by epoch length. Recorded as count per epoch.

Epoch Length (s)	Senior	U21	U18
30	1.0 ± 1.2	1.0 ± 1.2	1.1 ± 1.4
60	1.0 ± 1.3	1.0 ± 1.2	1.1 ± 1.3
120	1.2 ± 1.6	1.3 ± 1.6	1.3 ± 1.6

10.4.3 WCS Sprint Running Distance

A total of 6,879 observations were analysed for WCS_{SRD} (Senior: 5,904; U21: 660; U18: 315). Descriptive statistics for WCS_{SRD} for each age group across three different epoch lengths are presented in Table 10.11.

No significant differences were identified across age groups for the number of times above the WCS_{SRD} speed threshold, for any epoch length ($p > 0.05$). The effect sizes for WCS_{SRD} across all epoch length and age group comparison combinations were negligible ($d = 0.0002$ to 0.047; Cohen, 1988).

Table 10.11 - Epoch Threshold Counts WCS_{SRD} descriptives for age groups, split by epoch length. Recorded as count per epoch.

Epoch Length (s)	Senior	U21	U18
30	1.0 ± 1.3	0.8 ± 1.0	0.8 ± 1.0
60	0.9 ± 1.2	0.7 ± 1.0	0.7 ± 0.9
120	0.9 ± 1.2	0.7 ± 1.1	0.6 ± 0.9

11 Discussion

The study hypothesised that there would be a significant difference in WCS across age groups, and the contextual factors would have an influence on WCS. Overall, the results did not support the hypotheses with WCS being predominantly similar across age groups for all three KPIs. Some significant differences were identified across age groups and positional groups, with the match location and match outcome having an influence on some WCS across age groups. The study provides insight into the WCS of Senior, U21, and U18 football match fixtures within a single club that employed similar playing formation and tactical approaches and can be used by practitioners to gain a better knowledge of the physical match demands of youth and senior football. The study provides a novel contribution to the WCS literature by quantifying the duration and frequency of WCS.

11.1.1 Influence of Age Group Match Play on WCS

WCS_{TRD} was similar across age groups for epochs 30- to 180-seconds, for both absolute and relative. However, significantly greater distance was covered in 300- and 600-second epoch in U21 compared to Senior match fixtures, indicating age group related differences in sustained running distance. Thoseby *et al*., (2023) found WCS_{TRD} to be comparable across age groups for all epoch lengths (60- to 600-seconds), somewhat contradicting the findings of the present study. As highlighted in Table 8.1, Thoseby *et al*., (2023) used football players from a single Australian club whereas the present study used football players from a single EPL club, suggesting competition level and/or tactical approach may influence WCS_{TRD}. Given the suggestion that longer epochs are better for assessing volume-related metrics, this comparison between findings is important for practical application. Practitioners should apply caution when applying findings across cohorts and should consider competition level and playing style of each team. Specifically, practitioners of the EPL club should consider the age group related differences in WCS_{TRD} to better prepare players for U21 match fixtures and progression into the Senior squad. This could be achieved by incorporating extended periods of exercise to replicate the peak running distance during match play.

Beyond physical capacity, psychological factors may also contribute to the elevated WCS_{TRD} in U21 vs. Senior match fixtures. The youth-to-senior transition is one of the biggest challenges a player will face due to increased pressure to impress coaches to secure progression opportunities (Lundqvist *et al*., 2024). Players in the U21 match fixtures may have increased physical output due to heightened pressure to impress coaches, leading to more frequent and constant movement around the pitch which could explain the elevated WCS_{TRD} (Lundqvist *et al*., 2024). Players in U18 match fixtures may experience some pressure to impress but due to the infancy in the development pathway, it may not be to the same extent as the U21 (Lundqvist *et al*., 2024). This could explain the lack of significant difference in WCS_{TRD} between U18 and Senior match fixtures. However, there is no literature encompassing both WCS and psychological pressures of each age group so further research is required to identify causation.

Whereas players in Senior match player may have adopted a more strategic approach towards physical output so they can conserve energy by only exerting themselves when necessary (Bradley & Noakes, 2013). This highlights the importance of contextualising WCS to understand the whole picture. U21 match fixtures having a higher absolute WCS_{TRD} than Senior match fixtures do not necessarily mean training should be changed. Based on this conclusion, the club may need to provide U21 players with more resources to help them understand the importance of a strategic approach to physical output and the association with injury. Further, if U21 players lack a strategic approach towards physical output, they are likely to tire quicker once they progress to the senior team (Bradley & Noakes, 2013). This could result in them not meeting the demands of senior football and subsequently hindering performance. This reinforces that the developmental support goes beyond physical capacity and practitioners should be cautious when using raw WCS data to inform training prescription and should consider factors outside of external load.

Further, given the absence of a significant difference between U21 and Senior for WCS_{HSRD} and WCS_{SRD}, it can be concluded that the heightened WCS_{TRD} in U21 match fixtures reflects low-intensity activity (e.g. jogging or walking) rather than high-speed movements. The 600-second epoch likely dilutes the intensity of physical output by averaging across the epoch, so high absolute WCS_{TRD} may be a result of sustained low-intensity activity rather than repeated efforts at high-speed. Contextualising the type of movement completed in the WCS_{TRD} is important for prescribing accurate training across age groups. Practitioners should recognise that players in U21 match fixtures may benefit from more exposure to low-intensity activity during training to better prepare them for the internal load experienced during match play, which will likely benefit their external load in the longer term. This reinforces the need for between-group comparisons to better prepare youth players for the match demands of senior football.

While WCS provides a valuable indication of the highest running intensities players face during match fixtures, these peaks do not occur in isolation of players underlying physical capabilities. Senior football players typically achieve higher WCS than youth players, which may reflect greater physiological fitness (ref). As such, WCS and fitness interact with higher aerobic and anaerobic capacity enabling players to tolerate or perform higher running intensities during match fixtures. Insufficient physiological fitness could limit players ability to cope with the typically higher WCS of senior football. In applied settings, practitioners should monitor both WCS and fitness within a cyclical process: establishing the WCS for each age group, designing training that progressively exposes players to these intensities, and then reassessing whether players are consistently operating at or above the WCS of senior football. This integration of WCS monitoring and fitness development helps ensure that youth players are physically prepared for the demands of senior match play.

When preparing players for the demands of Senior match play, it is important to understand whether a youth player is capable of the physical outputs seen in Senior football (Thoseby *et al*., 2023). The present study reported no significant differences in absolute or relative WCS_{TRD}, WCS_{HSRD}, and WCS_{SRD} across age groups for any epoch length, apart from WCS_{TRD} 300- and 600-second epoch. This suggests that those players competing in U18 and U21 match fixtures have comparable physical outputs to Senior football, highlighting that current training methods employed by the EPL club are relatively appropriate for preparing players for the youth-to-senior transition. However, the cause of increased injury prevalence in youth players, as reported by Howden's Group Holdings (2024), is likely to not be caused by differences in physical match demands. Instead, the increase of injuries in youth players may be more closely linked to factors such as the psychological influence of youth-to-senior transition (Lundqvist *et al*., 2024). Clubs should support youth players with the youth-to-senior transition accounting for challenges in increased training load and match demands but should also focus on psychological factors that could hinder performance development (Lundqvist *et al*., 2024).

In the present study, the observed range of WCS_{TRD}, WCS_{HSRD}, and WCS_{SRD} was similar across age groups (Table 10.1). Although direct comparisons are limited due to the sample comprising of only WCS from senior matches fixtures, Fereday *et al*., (2020) reported a shorter range of WCS_{TRD} and WCS_{HSRD}, than observed in the present study. Interestingly, similar findings to Fereday *et al*., (2020) were reported in Australian A-league soccer (Delaney *et al*., 2018; Varley *et al*., 2012). This suggests that contextual factors such as playing style should be considered by practitioners when prescribing training based on the WCS.

11.1.2 Influence of Epoch Length

The use of 90-minute averages to assess the WCS has been scrutinised in recent literature, reporting underestimation of WCS_{TRD} by 53-60%, WCS_{HSRD} by 16-26%, and WCS_{SRD} 6-9% (Riboli *et al*., 2021; Oliva-Lozano *et al*., 2023). Despite this limitation, Thoseby *et al*., (2023) reported 90-minute averages for TRD and HSRD to be similar across youth and senior football, as well as similar WCS. The finding of the present study that only two significant differences existed between Senior, U21, and U18 WCS_{TRD}, WCS_{HSRD}, and WCS_{SRD}, reinforces that youth match fixtures require similar physical output to senior match fixtures. However, the presence of significance in longer epochs for WCS_{TRD} supports the suggestion of Baptista *et al.,* (2024). Furthermore, while 90-minute averages can be used for identifying between-group differences, WCS offers a more in-depth analysis of physical match demands (Oliva-Lozano *et al*., 2023).

García, Fernández *et al*., (2022) reported 30- and 60-second absolute WCS_{HSRD} as 63.8 m and 72.8 m, respectively, across a variety of intermittent sports. The present study reported 30-second and 60-second absolute WCS_{HSRD} in senior match fixtures as 60.6 vs. 67.9 m, respectively. Whilst the present study reported lower values, likely due to sport specific differences, such comparison supports the use of epochs less than one minute when analysing the WCS (Baptista *et al*., 2024). This has important training implications as if only 60-second epochs were used, training drills could be misinformed by the data and could cause players to be trained below what is necessary to meet the demands of match play, increasing injury risk or hinder performance development. It could also mean they cannot keep up with their opposition which could ultimately lose them the match.

Previous research has suggested shorter epoch lengths of ~30-seconds to be most suitable for quantifying intensity-related metrics, such as WCS_{HSRD} and WCS_{SRD}, while longer epochs (>one minute) are better for volume-related metrics, such at WCS_{TRD} (Baptista *et al*., 2024). The present study identified a single significance for a volume-related metric ($p < 0.05$, U21 vs. Senior, WCS_{TRD}, 600-seconds), supporting the suggestion of Baptista *et al*., (2024). The absence of significance in shorter epochs signifies the comparability of the WCS in U21 and U18 match fixtures with Senior match fixtures, using the conclusion of Baptista *et al*., (2024). This has important implications for training prescription, as it supports the inclusion of drills in youth sessions that mirror the intensity of senior drills. To note, Baptista *et al*., (2024) used female athlete and the present study used male athletes, yet the generalised idea of intensity-related and volume-related metrics for different epoch lengths, still applies.

11.1.3 Influence of Match Location

The present study identified WCS_{HSRD} to be significantly higher for specific locations and epoch lengths in U18 match fixtures than Senior match fixtures. U18 home match fixtures had significantly higher WCS_{HSRD} for shorter epoch lengths (30-, 60-, 120-seconds), than Senior home match fixtures. Whereas, for longer epochs (180-, 300-, and 600-seconds), U18 had significantly lower WCS_{HSRD} than Senior. This may reflect the heightened psychological pressures in youth football, with players often experiencing increased performance anxiety and selection pressure (Lundqvist *et al*., 2024). This pressure could have led to increased intensity for short bursts, yet it may not be sustained for longer periods due to lower aerobic capacity or lack of strategic approach to their physical output (Whitehead *et al*., 2018).

WCS_{SRD} followed a similar pattern for U18 home match fixtures, but U21 home match fixtures were significantly lower than Senior home match fixtures. This could reflect a transitional phase in the U21 psychological development, whereby players may adopt a more cautious approach to physical load as they develop. Alternatively, U21 players may be more reluctant to make sprint efforts if want to avoid making errors in front of coaches to improve their chances of selection (Lundqvist *et al*., 2024). Away match fixtures also saw significantly lower WCS_{SRD} in U18 and U21 compared to Seniors, further supporting the potential of psychological development.

In contrast, U18 away match fixtures had consistently higher WCS_{HSRD} than Senior away match fixtures for all epoch lengths. This finding aligns with previous research by Oliva-Lozano *et al*., (2020), who reported WCS to always be higher at away match fixtures, suggesting that match location can influence WCS. The increased demands of U18 away match fixtures may reflect a combination of increased performance anxiety, selection pressure, and the location of the match (Lundqvist *et al*., 2024; Oliva-Lozano *et al*., 2020). These findings highlight the complexity of the interaction between psychological readiness, physiological development, and the environmental context that all shape WCS demands across age groups.

11.1.4 Influence of Match Outcome

Across all match outcomes, U21 match fixtures exhibited lower WCS_{SRD} than Senior. This could reflect the developmental differences in tactical awareness. Baptista *et al*., (2023) suggested players are more likely to maximise their physical output during important, high-intensity passages of play (e.g. counterattacks or defensive transitions). The previous used senior players, who typically have better tactical awareness and are more able to adapt to the demands of the game (e.g. increase defensive pressure). In contrast, U21 players may lack the experience or confidence to adapt their physical output to response to the important, high-intensity passages of play, resulting in fewer sprint efforts during crucial phases. This suggests that lower WCS_{SRD} in U21 match fixtures may not reflect a reduced physical capacity compared to Senior, but instead a limited ability to identify and adapt to the important passages. Developing tactical adaptability and decision-making under pressure in training could better prepare youth players to meet the demands of senior match play.

11.1.5 Influence of Positional Groups

The present study found no significant differences in positional groups across age groups for WCS_{TRD}, suggesting overall locomotor volume during match play is relatively consistent across the pitch. However, WCS_{HSRD} and WCS_{SRD} were significantly difference across age groups for specific positional groups. Strikers exhibited consistently higher WCS_{HSRD} in U18 compared to Senior. There were some significant differences in strikers and WF positional groups, with youth (U21 and U18) match fixtures exhibiting higher WCS_{SRD} than senior match fixtures (Table 15). These findings align with previous research that indicates attacking positions are exposed to higher external loads compared to all other positional groups (Oliva-Lozano et al., 2020).

The elevated WCS_{HSRD} and WCS_{SRD} in youth strikers and WF may reflect the psychological and tactical pressures experienced during match play. Youth players often feel more pressure to impress coaches during match play to secure selection, which can manifest into a larger physical output (Lundqvist *et al*., 2024). This tendency may be amplified in attacking roles, where explosive movements are more frequent (Oliva-Lozano et al., 2020). In practice, youth strikers and WF players may benefit from targeted psychological preparation to manage their physical output better by taking a more strategic approach which is often seen in senior players (Bradley & Noakes, 2013). This would help support their long-term development, particularly as players transition into senior match fixtures.

While the present study examined positional differences in WCS, it is important to acknowledge the limitations posed by small sample sizes within specific positional groups. Thoseby *et al*., (2023) compared age groups but did not use positional groups in analysis as the small sample size could limit the statistical power. This may explain the absence of consistent positional effects and reinforces the need for larger datasets. The present study is sufficient in providing a general guide, especially given the early stages of such comparisons, but large sample sizes of age groups and positional groups would provide a more accurate insight into WCS.

11.1.6 Duration & Frequency of WCS

The duration and frequency of WCS, expressed through threshold breaches across each epoch length, represent a novel contribution to the current WCS literature. While previous research has predominantly focused on the intensity of WCS, far less is known about how long players are able to sustain these most demanding periods of match play. By quantifying threshold breaches across multiple epoch lengths, the present study provides new insight into the temporal characteristics of WCS across age groups.

Despite age-related differences in peak intensities, the duration and recurrence of WCS were highly comparable between Senior, U21, and U18 players for WCSTRD, WCSHSRD, and WCSSRD. This is a novel finding, indicating that youth players are not only capable of reaching similar peak intensities but are also able to sustain high-intensity efforts for similar lengths of time. Practically, this suggests that existing WCS-based training drills designed for senior players are already appropriate for younger squads, as the sustained demands of peak match passages do not differ meaningfully with age.

12 Limitations

Limitations of the present study are predominantly due to the novel nature of the research and the need to determine an appropriate methodology for capturing the most physically demanding periods of match play. The data were collected from a single club from the EPL, and its academy. The uneven distribution of match fixtures could have affected the statistical power and the reliability of comparisons across age groups. Due to the data collection period covering multiple seasons, players appearing in multiple age groups could introduce within-subject variability. No data were collected for WM, limiting positional comparisons. Data for away matches was only available where Sportlight was installed which could affect the comparability of match location. The setup of Sportlight may differ between stadiums, so future research should state a consistent height of all systems to ensure affective tracking accuracy. Although some contextual factors were applied, others including minutes played, were not recorded during data collection, which may influence the WCS as reported by Novak *et al*., (2021).

13 Conclusion

To conclude, this study further developed the literature surrounding analysis of the WCS in football, by comparing across age groups and using LiDAR systems to capture it. This was achieved through analysis of external metrics, total distance, high-speed running distance, and sprint running distance. It accounted for contextual factors, match location, match outcome, and positional groups. The study used peak values for the WCS and included novel methods of data collection through epoch threshold breaches and epoch threshold counts. WCS was largely similar across age groups, with only isolated differences. A single significant difference was found in the WCS_{TRD} for the 600-second epoch, with U21 match fixtures eliciting higher values than Senior match fixtures. Match location had an effect of the WCS, with Youth match fixtures showing significantly different WCS to Senior match fixtures. Despite some positional differences across age groups, the WCS remained mainly consistent between positional groups. Overall, these findings highlight the need for practitioners to consider the WCS during match play but go beyond the raw WCS data to adequately prepare Youth football players for the demands of Senior football.

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