

HIGH-SPEED RUNNING IN PROFESSIONAL FOOTBALL: MONITORING AND TRAINING IN ÉLITE ADULT PLAYERS

Antonio Gualtieri

Thesis submitted for the degree of Doctor of Philosophy



Faculty of Medicine and Health Sciences: School of Health Sciences

June 2025

© This copy of the thesis has been supplied on condition that anyone who consults it is understood to recognise that its copyright rests with the author and that use of any information derived therefrom must be in accordance with current UK copyright Law. In addition, any quotation or extract must include full attribution.

Declaration

I certify that the work contained in this thesis for the degree of Doctor of Philosophy is my original work except where due reference is made to other authors and has not been previously submitted for a degree, diploma or any other qualification at any other university or institution.

Abstract

Football involves two 45-minute halves requiring bursts of high-intensity activity interspersed with low-intensity movements. In the last years, the high-speed and sprint distance demand of the game increased significantly, requiring the players to be prepared for sprinting more than before. However, no standard thresholds exist for high-speed and sprint running, hindering comprehensive analysis and consistency across studies and safe ranges for running loads for elite teams playing twice weekly remain unclear. Considering the gaps reported, the aims were (1) establishing high-speed running thresholds for training, (2) comparing high-speed loads between starting and non-starting players during congested fixtures, (3) analysing running distribution across congested microcycles, and (4) quantifying peak game intensity periods.

All the existing literature was reviewed, and, given the lack of consensus, practitioners might use FIFA's thresholds such as $19 \text{ km}\cdot\text{h}^{-1}$ and $23 \text{ km}\cdot\text{h}^{-1}$ for females and $20 \text{ km}\cdot\text{h}^{-1}$ and $25 \text{ km}\cdot\text{h}^{-1}$ for males. Relative thresholds should be considered for specific training sessions to reach near to maximal velocity exposure accounting for players' maximum velocity capacity. Custom sprinting thresholds can better address the needs of players who are exposed to significantly lower loads during congested fixture periods because of the low match exposure. In fact, coaches seem to be influenced by shorter microcycles in their training proposal, preferring sessions with a reduced muscle impact when fewer days are available and decreasing training loads as match day approaches. Finally, zooming in the quantification of the peak match demand, resulted important to appropriately prepare players using football-specific drills reflecting each playing role peculiarity. In this regard, it was found that during the most intense minute of the match midfielders cover the most distance, centre-backs the least high-speed distance, and sprint distances are consistent across roles, reflecting team dynamics during the most demanding passage of the match.

Access Condition and Agreement

Each deposit in UEA Digital Repository is protected by copyright and other intellectual property rights, and duplication or sale of all or part of any of the Data Collections is not permitted, except that material may be duplicated by you for your research use or for educational purposes in electronic or print form. You must obtain permission from the copyright holder, usually the author, for any other use. Exceptions only apply where a deposit may be explicitly provided under a stated licence, such as a Creative Commons licence or Open Government licence.

Electronic or print copies may not be offered, whether for sale or otherwise to anyone, unless explicitly stated under a Creative Commons or Open Government license. Unauthorised reproduction, editing or reformatting for resale purposes is explicitly prohibited (except where approved by the copyright holder themselves) and UEA reserves the right to take immediate 'take down' action on behalf of the copyright and/or rights holder if this Access condition of the UEA Digital Repository is breached. Any material in this database has been supplied on the understanding that it is copyright material and that no quotation from the material may be published without proper acknowledgement.

Access Condition and Agreement

Each deposit in UEA Digital Repository is protected by copyright and other intellectual property rights, and duplication or sale of all or part of any of the Data Collections is not permitted, except that material may be duplicated by you for your research use or for educational purposes in electronic or print form. You must obtain permission from the copyright holder, usually the author, for any other use. Exceptions only apply where a deposit may be explicitly provided under a stated licence, such as a Creative Commons licence or Open Government licence.

Electronic or print copies may not be offered, whether for sale or otherwise to anyone, unless explicitly stated under a Creative Commons or Open Government license. Unauthorised reproduction, editing or reformatting for resale purposes is explicitly prohibited (except where approved by the copyright holder themselves) and UEA reserves the right to take immediate 'take down' action on behalf of the copyright and/or rights holder if this Access condition of the UEA Digital Repository is breached. Any material in this database has been supplied on the understanding that it is copyright material and that no quotation from the material may be published without proper acknowledgement.

Table of Contents

Declaration	1
Abstract	2
Access Condition and Agreement.....	3
List of tables.....	8
List of figures	9
Glossary	11
Acknowledgements	14
Chapter 1: Introduction	15
1.1 Football, high-speed running and their evolution	15
1.2 Monitoring high-speed running and measuring peak speed	17
1.3 Planning training in football.....	22
1.4 Defining starting and non-starting players	24
1.5 Defining congested fixture periods in football	25
1.6 Defining the most intense periods of the football match	27
1.7 Conclusion.....	28
1.8 Summary and aims of the thesis	30
1.8.1 Aims and objectives	30
1.8.2 Research questions.....	31
1.8.3 Main thesis hypothesis	33
Chapter 2: Systematic review of the topic.....	34
2.1 Introduction.....	34
2.2 Methods.....	37
2.2.1 Review questions	37
2.2.2 Search methods for identification of studies	37
2.2.3 Inclusion and exclusion criteria.....	38
2.2.4 Data collection and analysis	39
2.2.5 Data extraction	39
2.3 Results.....	40
2.3.1 Search results	40
2.3.2 Descriptive characteristics of the included studies	41
2.4 Discussion	55
2.4.1 Defining “absolute” thresholds: high, very high and sprint running distance.....	55
2.4.2 Relative velocity thresholds	58
2.4.3 High-speed running and sprinting during official matches	62

2.4.4 High-speed running and sprinting during training	66
2.4.5 High-speed running and injuries	71
2.5 Conclusions on the available literature	73
Chapter 3: General methods	76
3.1 Perceived exertion: the session RPE method	76
3.1.1 Psychometric scales to monitor perceived exertion	76
3.1.2 CR-10 scale	76
3.1.3 Session-RPE method	80
3.1.4 Validity of the method	80
3.1.5 Application in the original studies	81
3.2 EPTS: Electronic Performance Tracking Technologies	81
3.2.1 Technology evolution	81
3.2.2 Validity of tracking technologies	82
3.2.3 Application in the original studies	84
3.3 MIP: Most intense periods analysis	86
3.3.1 Terminology and mathematical approaches	86
3.3.2 Application in the original study	87
Chapter 4: Starting and non-starting players high-speed during congested fixture periods (original study)	88
4.1 Introduction and aims	88
4.2 Materials and Methods	89
4.2.1 Participants	89
4.2.2 Experimental Design	90
4.2.3 Procedures	90
4.2.4 Statistical analysis	91
4.3 Results	92
4.4 Discussion	95
Chapter 5: High-speed during three-, four- and five-day microcycles (original study)	98
5.1 Introduction and aims	98
5.2 Methods	100
5.2.1 Subjects	100
5.2.2 Experimental design	101
5.2.3 Methodology	102
5.2.4 Statistical Analyses	103
5.3 Results	104

5.3.1 Microcycle type.....	104
5.3.2 Training day and microcycle type	107
5.4 Discussion	111
5.4.1 Microcycle type.....	112
5.4.2 Training day and microcycle type	113
Chapter 6: The most intense periods during elite football matches (original study)	117
6.1 Introduction and aims	117
6.2 Methods.....	120
6.2.1 Experimental design	120
6.2.2 Subjects	120
6.2.3 Methodology	120
6.2.4 Statistical Analyses	121
6.3 Results.....	122
6.3.1 Home vs away games	122
6.3.2 Playing roles comparison	124
6.4 Discussion	126
Chapter 7: General discussion and future directions.....	130
7.1 Overview.....	130
7.2 Velocity thresholds for high-speed running.....	132
7.3 Starting and non-starting players workload during congested fixture periods.....	133
7.4 High-speed running distribution during congested fixture microcycles	134
7.5 The most intense periods during matches	136
7.6 Areas for future research	137
7.7 Practical applications	139
7.8 Concluding summary	140
Appendices	141
Appendix 1 – Ethical approval	141
Appendix 2 – Presentation at World Conference on Science and Soccer, Coimbra (Portugal), June 15 th -17 th 2022	142
Appendix 3 – Presentation at 29 th Annual ECSS Congress in Glasgow, July 2 nd -5 th 2024	143
Appendix 4 – Article published including aspects from Chapter 2	145
Appendix 5 – Article published from Chapter 4	146
Appendix 6 – Article published from Chapter 5	147
Appendix 7 – Article published including aspects from Chapter 6	148

Appendix 8 – Co-authored publications during the PhD Course..... 149

References 150

List of tables

Table 1: Systematic review search strategy.....	38
Table 2: High-speed running in women and men & absolute VS relative thresholds.	42
Table 3: High-speed running during training and match.	44
Table 4: High-speed running and injuries.	51
Table 5: High-speed running (HSR) and sprint match demands for elite adult female and male football players.	63
Table 6: Training/Match ratio (T/M ratio) for high-speed running (HSR) in adult male football players.....	67
Table 7: Training/Match ratio (T/M ratio) for sprint in adult male football players.....	68
Table 8: Summary of Starters and Non-Starters workload during two 21 days-congested fixture mesocycles.	93
Table 9: Differences of daily mean values in different microcycle type.....	105
Table 10: Training days comparison independently by the microcycle.	107
Table 11: Training days comparison in different microcycle types.....	110
Table 12: Team average $\pm$ standard deviation for total distance, high-speed running distance ($>20 \text{ km}\cdot\text{h}^{-1}$) and sprint distance ($> 25 \text{ km}\cdot\text{h}^{-1}$) of the most intense periods of the game using 5 seconds to 10 minutes moving average time windows and expressed in $\text{m}\cdot\text{min}^{-1}$	122
Table 13: Most intense minute (60 seconds) between playing roles comparison for full-back (FB), centre-back (CB), central midfielder (CM), wide midfielder (WM) and forward (F). Confidence level used: 0.95.	125

List of figures

Figure 1: Football pitch and classical players' disposition.....	15
Figure 2: Example of GNSS based EPTS unit (from https://pro.statsports.com/apex/).	18
Figure 3: Example of video tracking-based EPTS.	19
Figure 4: Metrics provided by EPTS (from https://pro.statsports.com/apex/).	20
Figure 5: Training & Match Load distribution during a typical week with 1 single match day.	23
Figure 6: 3-day and 4-day microcycles.	24
Figure 7: Microcycle length distribution during an entire season of a top-level football team.	26
Figure 8: Graphical representation of thesis hypothesis.	33
Figure 9: PRISMA flow diagram for the description of the overall process for the systematic review.	41
Figure 10: High-speed running (HSR), very high-speed running (VHSR) and sprint thresholds for elite adult female and male football players expressed in km·h ⁻¹	56
Figure 11: CR10® RPE scales: Italian version	78
Figure 12: CR10® RPE scales: English version	79
Figure 13: Part of the database organized to record the sRPE-TL data.	81
Figure 14: Changes in GNSS speed accuracy since 2018.	83
Figure 15: Changes in video tracking speed accuracy since 2018.	83
Figure 16: Software for the analysis of GNSS data.	85
Figure 17: Part of the database organised to record the GNSS and video tracking data...	85
Figure 18: Summary of training and match workload for Starters and Non-Starters during two 21 days-congested fixture mesocycles.....	94
Figure 19: Competitive microcycles analysed and their prevalence during the season. ...	101
Figure 20: Microcycle type and total distance (a), high-speed running distance (b), sprint distance (c) and individualised sprint distance, i.e. >80% of the individual maximum speed (d).	106
Figure 21: Microcycle type and accelerations (a), decelerations (b), sRPE, session Rating of Perceived Exertion (c) and exposure (d).....	106
Figure 22: Microcycle type and training day type: total distance (a), high-speed running distance (b), sprint distance (c) and individualised sprint distance, i.e. >80% of the individual maximum speed (d).	109
Figure 23: Microcycle type and training day type: accelerations (a), decelerations (b), sRPE, session Rating of Perceived Exertion (c) and exposure (d).	109

Figure 24: Power law models for home and away matches for (A) total distance, (B) high-speed running distance ($>20 \text{ km}\cdot\text{h}^{-1}$) and (C) sprint distance ($>25 \text{ km}\cdot\text{h}^{-1}$). 123

Figure 25: Power law models for (A) total distance, (B) high-speed running distance ($>20 \text{ km}\cdot\text{h}^{-1}$) and (C) sprint distance ($>25 \text{ km}\cdot\text{h}^{-1}$) run by full-back (FB), centre-back (CB), central midfielder (CM), wide midfielder (WM) and forward (F). 124

Glossary

ACC = Accelerations

ACWR = Acute:Chronic Workload Ratio

AMP = Average Metabolic Power

ASR = Anaerobic Speed Reserve [MSS – MAS]

AU = Arbitrary Units

BFIh = Biceps Femoris long head

Bpm = Beats per minute

CB = Central Backs

CF = Central Forwards

CM = Central Midfielders

CR = Coefficient Ratio

CSV = Comma Separated Values

CV = Coefficient of Variation

DEC = Decelerations

EMG = electromyography

EPTS = Electronic Performance Tracking Technologies

FB = Full-Backs

FIFA = *Fédération Internationale de Football Association*

GK = Goalkeepers

GNSS = Global Navigations Satellite Systems

HIA = High-Intensity Activities

HIR = High-Intensity Running

HMLD = High Metabolic Load Distance

HRDP = heart rate deflection point

HSD = High-Speed Distance

HSI = Hamstring Strain Injury

HSR = High-Speed Running

ICC = Intra Class Coefficient

LSG = Large Sided Game

MAS = maximal aerobic speed

MIP = Maximum Intensity Period

MSG = Medium Sided Game

MSR = Moderate Speed Running

MSS = Maximal Sprint Speed

MTU = muscle-tendon unit

MVIC = Maximum Isometric knee flexion Contraction

NHE = Nordic Hamstring Exercise

PS = peak speed

RD = Running Distance

RMSD = root mean square difference

ROM = Range Of Motion

RPA = Relative Pitch Area

SAFT 90 = a multi-directional, intermittent 90 min exercise protocol representative of football match-play

sEMG = surface electromyography

SM = semimembranosus

SR = Sprint Running

sRPE-TL = session Rating of Perceived Exertion Training Load

SSG = Small Sided Game

ST = Semitendinosus

TD = Total Distance

TMr = Training/Match ratio

TRIMP = TRaining IMPulse

UEFA = *Union of European Football Associations*

VAM-EVAL = a modified version of the Montreal Track test

VHSR = Very High-Speed Running

vIFT = final velocity of the 30:15 intermittent fitness test

Wks = weeks

WL = Workload

WM = Wide Midfielders

Acknowledgements

I would like to express my deepest gratitude to Juventus Football Club that believed in the educational opportunity and generously funded this project. In particular, my heartfelt thanks go to Roberto Sassi, who initiated this journey by explaining the vision and defining the goals.

I am profoundly grateful to Professor Marco Beato for his mentorship, support, and for helping me navigate the world of science applied to sport. Special thanks to Ermanno Rampinini, a meticulous reviewer and a master of the critical approach essential in the scientific community. I also extend my gratitude to all the co-authors of the works produced and published during this project: Dr. Antonio Dello Iacono, Dr. Jordi Vicens-Bordas, Duccio Ferrari Bravo, Maria Angonese and Massimo Maddiotto.

Finally, I am deeply thankful to my family, especially my wife, for her unwavering support and for making it possible for me to dedicate the necessary time to my studies and scientific work.

Chapter 1: Introduction

1.1 Football, high-speed running and their evolution

Football is a team-based sport in which two squads, each comprising eleven players, compete on a field measuring 105 meters in length and 68 meters in width (Figure 1). At each end of the field, goals are positioned. The primary objective of the game is to score more goals than the opposing team. The player we represented in yellow in Figure 1, the goalkeeper, is allowed to handle the ball with the hands to protect the goal, while the other ten players may use any part of their body except their arms and hands. The ten outfield players are categorized according to their positions on the field. Those located in the dark grey central area of Figure 1 include central defenders, central midfielders, and central attackers. Conversely, players positioned on the light grey flanks are known as wide defenders or fullbacks, wide midfielders, and wide attackers or wingers. Additionally, three primary lines of players can be defined: the red players in Figure 1 form the defensive line, the green players make up the midfield, and the black players constitute the attacking line.

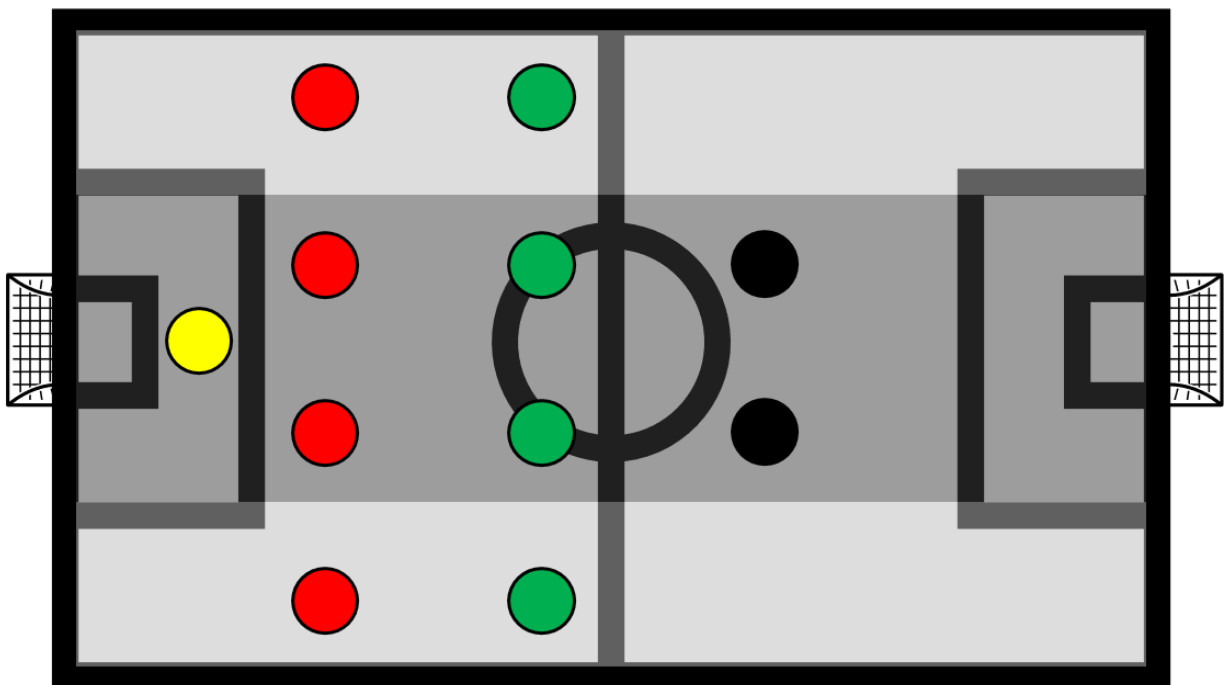


Figure 1: Football pitch and classical players' disposition.

For adult players, the match consists of two 45-minute halves, each characterized by an intermittent activity profile. This profile includes a variety of high-intensity activities such as accelerations, decelerations, changes of direction, sprinting, jumping, and tackling (Stolen *et al.*, 2005; Reynolds *et al.*, 2021). These high-intensity actions are interspersed with low-intensity phases, which involve both passive recovery (e.g., standing) and active recovery (e.g., walking and jogging). This dynamic interplay between high and low-intensity activities demands a high level of physical fitness and strategic planning to optimize performance and manage fatigue throughout the match. The latest data from the 2022 World Cup indicate that a player, depending on their position, needs to cover approximately 115 meters per minute, run at high speeds for about 15 meters per minute, and sprint for 2 meters per minute (Branquinho *et al.*, 2023; Chaize, Allen and Beato, 2024).

The capacity to maintain high-speed running and sprinting is a crucial attribute for football players aspiring to compete at the professional level (Chmura *et al.*, 2017). This ability not only enhances a player's overall performance but also significantly impacts their effectiveness during critical moments of the game. Sustaining high-speed runs and sprinting allows players to execute rapid transitions from the defensive to the attacking line and vice versa, cover large distances quickly, and respond dynamically to the evolving demands of the match. Consequently, these skills are essential for both offensive and defensive players, making them indispensable for professional footballers aiming to excel in high-stakes competitions.

Moreover, the demands of the game are continually increasing (Barnes *et al.*, 2014; Bush *et al.*, 2015; Lago-Peñas *et al.*, 2022). In particular, as football evolves, the intensity and frequency of high-speed running and sprinting required during matches are rising in the major European leagues (Barnes *et al.*, 2014; Reynolds *et al.*, 2021; Lago-Peñas *et al.*, 2022) and the prevision for the near future suggest that these demands will continue to rise, driven by advancements in training methodologies, tactical innovations, and the overall pace of the game. More specifically, analysing data from the Premiere League from 2006 to 2013, high-intensity running distance increased by ~30% (890 ± 299 vs 1151 ± 337 m, $p < 0.001$; ES: 0.82) and ~50% (118 ± 36 vs 176 ± 46 , $p < 0.001$; ES: 1.41), respectively (Barnes *et al.*, 2014). Sprint distance and number of sprints increased by ~35% (232 ± 114 vs. 350 ± 139 m, $p < 0.001$; ES: 0.93) and ~85% (31 ± 14 vs. 57 ± 20 , $p < 0.001$; ES: 1.46), respectively (Barnes *et al.*, 2014). Aggregating players by playing position, full backs displayed the greatest increase in high-speed running (~36% higher in 2012-13) and sprint distance (36-63%, $p < .001$, ES: 0.8-1.3). Similarly, analysing data from 2012 to 2020 from the Spanish LaLiga,

the number of efforts made at high-intensity running increased across the eight seasons analysed, ranging from 14.6% in external defenders to 9.2% in external midfielders (Lago-Peñas *et al.*, 2022).

As illustrated above, playing position affects the physical demand of the match. More specifically, players occupying the central area of the pitch (refer to the dark grey area in Figure 1) engage in less high-speed running compared to those operating on the flanks. Midfielders (depicted as green players in Figure 1) are required to cover a greater total distance than players in any other position. Lastly, attackers and central defenders experience higher demands in terms of accelerations and decelerations. In the Premier League, elite male football players, depending on whether they are playing as centre-backs or wide midfielders, are required to cover between 750 meters and 1200 meters of high-speed running distance and between 225 meters and 330 meters of sprint distance, respectively (Bush *et al.*, 2015).

Another factor influencing match demands is the age of the players. Specifically, when comparing the match load demands of U18, U23, and 1st team players, the most significant differences between these groups were observed in high-speed running, sprint distance, and high-intensity burst distance (Reynolds *et al.*, 2021). Based on these results, it appears that the greater the level of practice of the players, the higher the physical demands of the match, particularly in terms of high-speed running distance.

1.2 Monitoring high-speed running and measuring peak speed

It is evident that to accurately quantify the demands of both games and training sessions, practitioners must implement a systematic monitoring system. Currently, the most reliable system available for football teams is the Global Navigation Satellite System (GNSS)-based Electronic Performance Tracking System (EPTS). These systems are highly regarded for their ability to track player movements and performance metrics with precision, utilizing GNSS technology to provide detailed data on player positioning, speed, and overall physical exertion during both training and matches. An example of GNSS-based EPTS unit can be observed in Figure 2 and it will be deeply described in Chapter 2.

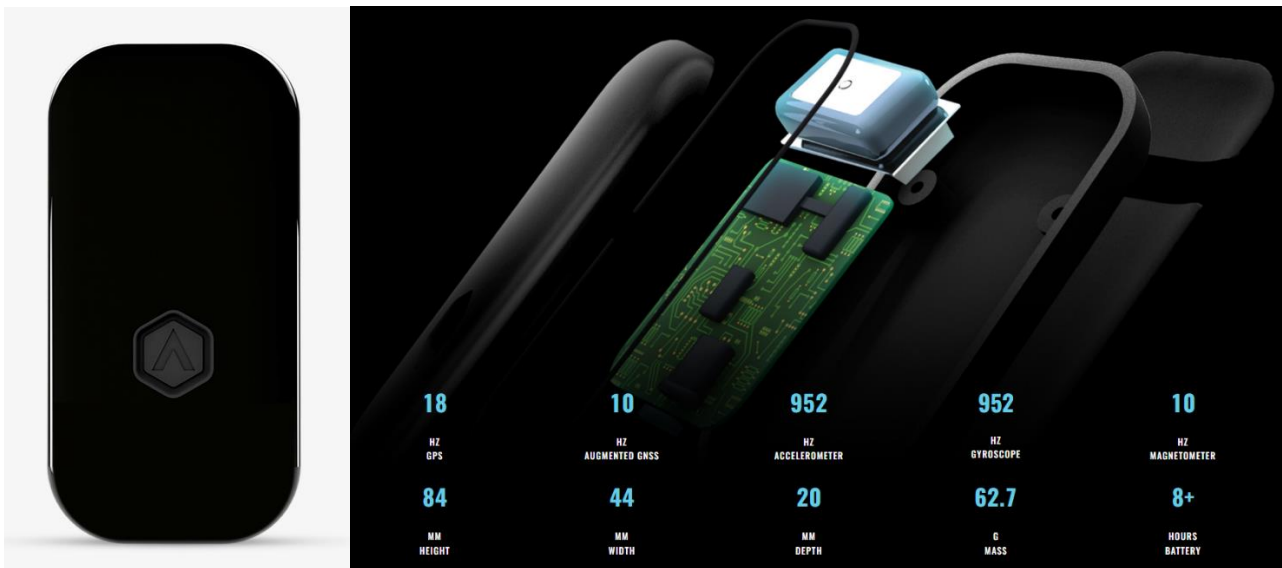


Figure 2: Example of GNSS based EPTS unit (from <https://pro.statsports.com/apex/>).

In everyday practice, whenever a player steps onto the pitch, they are required to wear this type of technology. Typically, this involves using a bib worn under the t-shirt, which securely holds the EPTS unit between the scapulae. This placement ensures accurate data collection throughout the session. Such data is indispensable for calculating the player's velocity at every moment, which in turn allows for the derivation of acceleration and deceleration intensities. By continuously monitoring these metrics, coaches and sports scientists can gain valuable insights into a player's performance, tailor training programs to individual needs, and optimize recovery strategies to enhance overall athletic development.

During matches, an alternative type of EPTS is available, which relies on video-tracking cameras. Figure 3 illustrates the setup of these systems, showing the distribution of cameras around the pitch. The cameras marked in blue represent the minimum number required for the system to function effectively, while the cameras marked in yellow indicate additional units that can be deployed to gather more detailed information. In fact, the flexibility and scalability of video-tracking systems allow them to be adjusted based on specific analytical needs, with additional cameras enhancing data accuracy and detail. The latest advancements in video-tracking systems enable users to model the human skeleton by pursuing all the major joints and principal body segments of the player.

For these reasons, video-tracking systems can offer a comprehensive view of player movements and are extensively used in professional football contexts. They provide data about position, speed, and distance covered, allowing for a thorough analysis of both individual and team dynamics. Their validity and interchangeability with GNSS-based EPTS have been previously reported (Taberner *et al.*, 2019), but, unlike wearable devices, video-

tracking systems are non-invasive, meaning players do not need to wear any additional equipment, which ensures they can perform naturally without physical constraints. The high sampling rate of video-tracking systems captures precise, real-time information on player actions, making them particularly useful for analysing rapid movements and high-intensity activities. Additionally, these systems can track the ball and opponent's movement, which is essential for tactical analysis and understanding player-ball interactions during different phases of the game. Coaches can leverage video-tracking data for detailed tactical analysis, examining team formations, player positioning, and movement patterns to devise effective strategies and make informed decisions. Furthermore, the recorded footage from video-tracking systems enables comprehensive post-match reviews, helping coaches and analysts identify strengths, weaknesses, and areas for improvement, both for their own team and their opponents. Overall, video-tracking systems are a powerful tool for enhancing the understanding of player performance and team dynamics, contributing to more effective training and strategic planning.

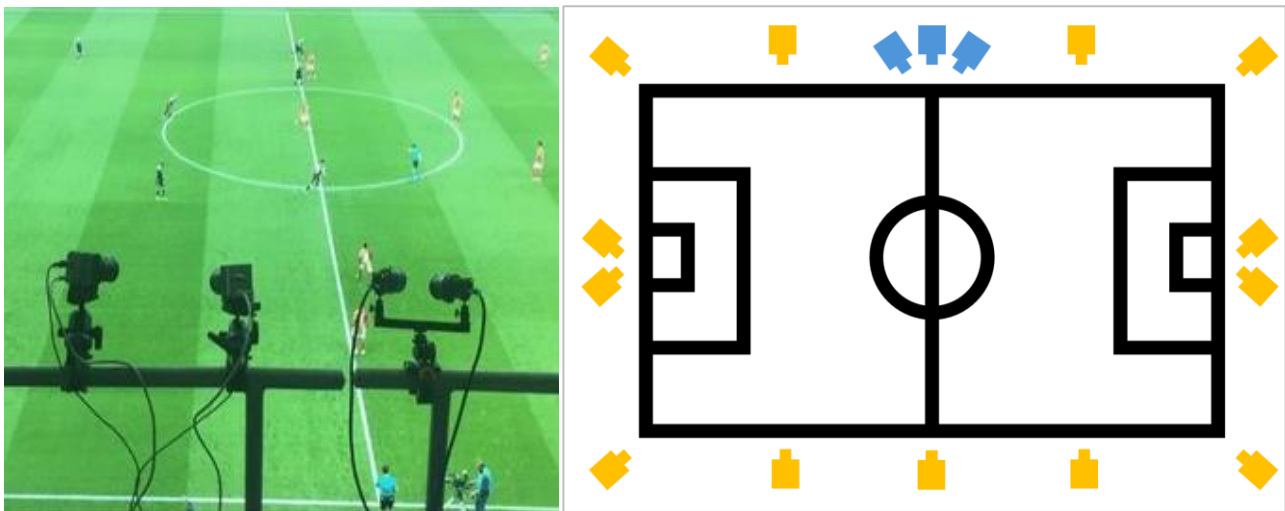


Figure 3: Example of video tracking-based EPTS.

Both EPTS described (i.e. GNSS and video tracking technology) offer a vast array of performance metrics. GNSS, in particular, provide over 260 metrics (Figure 4). Some of these metrics are directly measured by the system, while others are derived from primary measurements or estimated using more complex formulas. In addition to the metrics obtained via the GNSS antenna, EPTS can also integrate data from other sensors, typically connected through Bluetooth protocols. The most commonly used sensor for monitoring a player's internal response is the heart rate monitor. This device records the heart rate on a

beat-by-beat basis and provides various derived metrics, such as average heart rate, time spent in different metabolic intensity zones, and more complex heart rate exertion indexes.

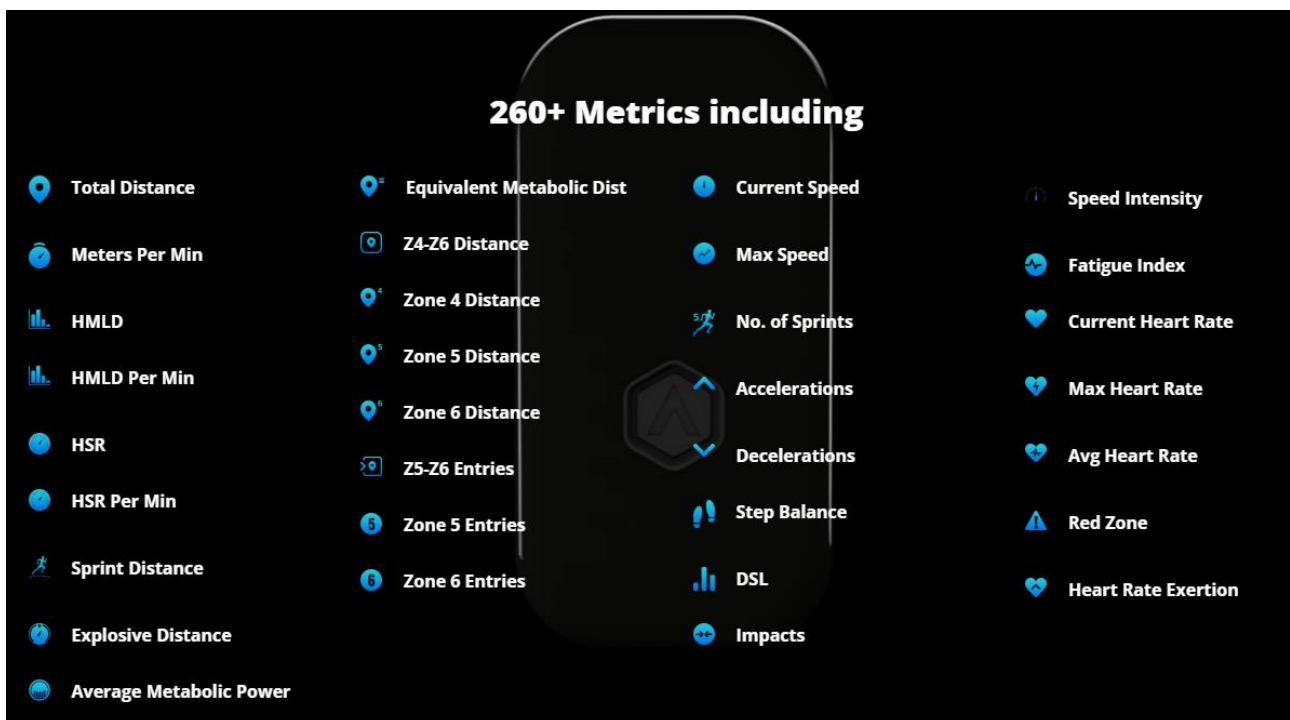


Figure 4: Metrics provided by EPTS (from <https://pro.statsports.com/apex/>).

Each metric recorded by the EPTS is typically reported using various thresholds to differentiate between low and high-intensity activities. By dividing the velocity spectrum into thresholds, it is possible to categorize running velocities into at least four distinct levels: low, medium, high, and sprint running velocity. Since we are focusing on "running velocity," values below $7 \text{ km}\cdot\text{h}^{-1}$, which correspond to walking, are excluded. Low-speed running is slightly more demanding than walking but can be sustained for extended periods without significant effort, usually falling below $14\text{-}15 \text{ km}\cdot\text{h}^{-1}$. Medium-speed running, typically between 14 and $21 \text{ km}\cdot\text{h}^{-1}$, is primarily supported by aerobic energy systems. High-speed running, which ranges from 18 to $25 \text{ km}\cdot\text{h}^{-1}$, relies heavily on anaerobic systems. Sprinting, defined as running at speeds above $23\text{-}25 \text{ km}\cdot\text{h}^{-1}$, is a less frequent but highly intense activity compared to the other intensities mentioned.

In addition to fixed absolute thresholds, which are essential for comparing player performance, relative or individual thresholds can also be calculated. These relative thresholds are particularly useful for defining sprint training, as they take into account the individual differences of each player. In this context, thresholds can be arbitrarily defined as a percentage of the player's maximum velocity, considering that muscle activation

significantly changes above 85% of the individual's maximum velocity (Higashihara *et al.*, 2010). Therefore, the thresholds of 80%, 85%, 90%, and 95% are commonly used to define submaximal, near-maximal, and maximal sprint velocities.

To establish these relative thresholds, coaches need to know the maximum velocity of each player. Testing batteries for football players often include sprinting tests to assess their abilities, and these tests can also be useful for setting individual thresholds. Typical test distances range from 20 to 40 meters, with 20-30 meters being sufficient for measuring peak running speed in football players (Buchheit *et al.*, 2020). Linear sprint tests are reliable and easy to measure when running time is the goal, but peak running speed requires advanced equipment like radar guns or EPTS. While some suggest measuring peak running speed during matches or drills (Massard, Eggers and Lovell, 2018), other studies show that only 40-meter linear sprints accurately estimate it (Kyprianou *et al.*, 2019).

Matches and drills have too much variability and may not allow all players to reach peak running speed, especially players playing in the central area of the pitch. A test combining match play and linear sprints could be more practical, allowing coaches to test peak running speed regularly while integrating some specificity to the task at hand (Kyprianou *et al.*, 2019). Increasing pitch size in large-sided games can lead to more sprints, but contextual effects on player variability must be considered. Technical drills with enough space for sprints can help measure peak running speed while minimizing disruptions, but variability among players can still be an issue.

In conclusion, linear sprinting, despite the majority of sprints in games being curvilinear, remains crucial for assessing peak running speed, which is essential for making training adjustments and preventing injuries. However, even when testing opportunities are limited, sport scientists can derive peak running speed from official match data. It is important to note that the recorded peak speed will be slightly lower than the player's maximum achievable velocity, but it will realistically be around 90% of their true peak speed (Mendez-Villanueva *et al.*, 2011).

1.3 Planning training in football

The first consideration when planning training for football players is the time unit. The longest time unit is the sport season, which typically starts in July for most European clubs and ends in May, or mid-July for players involved with their national teams. The season is divided into macro-cycles, usually three: the pre-season period, the in-season, and the off-season. The pre-season begins in July and ends in mid-August when the national championship starts. The competitive season lasts from mid-August to the end of May, while the off-season occurs in June. Each macro-cycle can be divided into meso-cycles, typically spanning three to eight weeks, although this depends on the coaching staff's philosophy and the fixture calendar. A classic example of a meso-cycle is the period between two consecutive international breaks. In September, October, November, and March, key players are called up by their national teams for ten-day periods to participate in competitions. The 20-25 days between the September and October breaks can be considered a meso-cycle. Each meso-cycle is further divided into micro-cycles, which refer to the period between two consecutive matches. Micro-cycles are composed of two or more days, each filled with exercises, which are further broken down into series and repetitions. Knowing these time units, along with monitoring and accurately describing the demands of a match, is crucial for planning training sessions and defining the parameters of each exercise. Understanding the training load is essential to achieve the objectives of each session, which are typically determined by the interval between the previous and upcoming games, as well as established training principles and available scientific evidence. The most common approach in professional adult football involves a structured weekly cycle (Lopategui, Paulis and Escudero, 2021). This cycle generally includes two recovery days following a match, characterized by minimal or no load to allow for physical recuperation. These are followed by two days of high-load acquisition, where the focus is on intensive training to build fitness and skills. Finally, the cycle concludes with two days of tapering, during which the training load is gradually reduced to ensure players are rested and prepared for the next match. This systematic approach helps in optimizing performance and minimizing the risk of injury, ensuring that players are in peak condition for each game.

In this type of microcycle it is standard practice to label the days following the most recent game as match day plus 1 (MD+1) and match day plus 2 (MD+2). The days leading up to the next match are similarly designated as MD-4, MD-3, MD-2, and MD-1 (Malone *et al.*, 2015). This nomenclature helps in organizing and planning the training schedule, ensuring

that each day is tailored to meet specific recovery, acquisition, and tapering needs. In Figure 5 a typical training week according to what described above is reported.

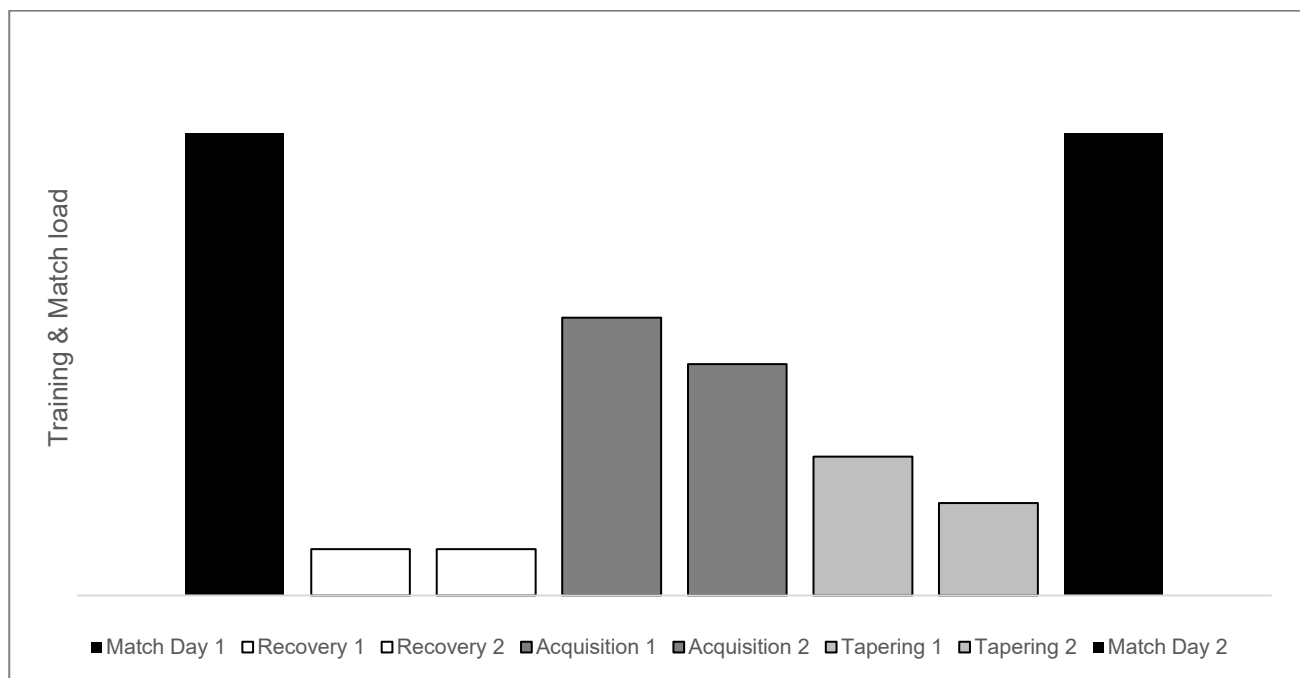


Figure 5: Training & Match Load distribution during a typical week with 1 single match day.

It should be noted that the planning strategy described is typical in Italy and similar countries, but it may differ in contexts where a weekday off is commonly accepted by default, usually at MD+2 or MD-3.

When players have to play only one match per week, managing their training load is relatively straightforward, regardless of whether they play in the match or remain on the bench. However, the situation becomes more complex when there are two games in one week, as illustrated in Figure 6. In such scenarios, the training and recovery schedules must be meticulously planned to ensure players are adequately prepared for both matches. This involves balancing the need for recovery with the necessity of maintaining fitness and readiness. For starting players, who experience higher physical demands during matches, the focus is on optimizing recovery while still incorporating sufficient training stimuli. For non-starting players, the challenge is to provide enough high-intensity training to keep them match-ready, despite fewer opportunities to play. Practitioners need to take into account the varying needs of both groups of players and ensuring that all players of the roster can perform at their best in both games. However, before delving into the complexities of periods with two games per week that we discuss deeply in Chapter 1.5, it is essential to clearly define who the starting and non-starting players are.

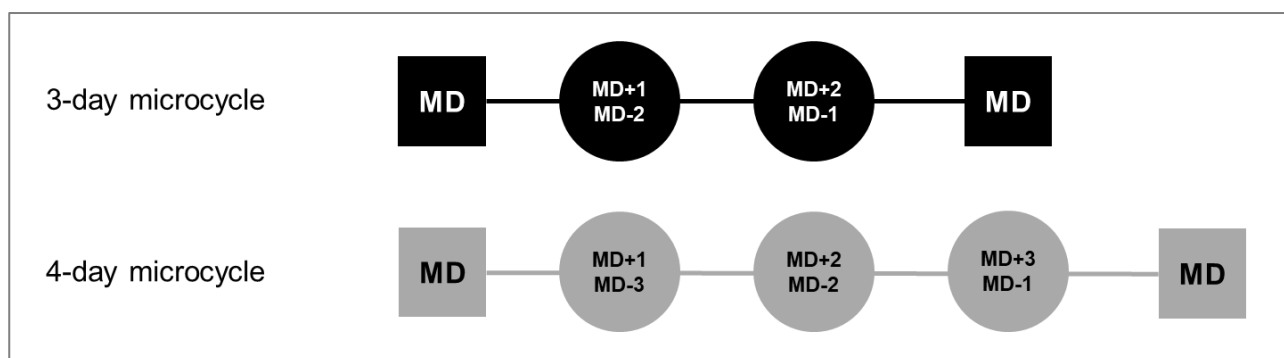


Figure 6: 3-day and 4-day microcycles.

1.4 Defining starting and non-starting players

Starting players, often referred to as starters, are those selected to begin the match on the field. These players typically experience higher physical demands during the game, including greater distances covered and more high-intensity activities. Non-starting players, or non-starters, include those who begin the match on the bench and may or may not be substituted into the game. Non-starters generally have lower or null physical demands on match day but still require appropriate training loads to maintain their fitness and readiness for future matches.

During a football match, starting players generally cover distances ranging from 10 to 13 km. This extensive distance includes a variety of high-intensity activities such as sprints, accelerations, decelerations, and changes of direction (Anderson, Orme, Di Michele, Close, Milsom, et al., 2016). Non-starting players need to compensate for their reduced workload with additional training sessions. These sessions can be scheduled immediately after a game or during the subsequent training days, particularly on MD+1 and MD+2, to ensure they maintain an adequate fitness level throughout the season. In practice, the threshold commonly used to differentiate between starting and non-starting players is 60 minutes of playing time. Playing more than 60 minutes imposes a high load on the player, necessitating at least one recovery day to mitigate fatigue. Conversely, playing less than 60 minutes allows for a training session the following day. In this context of individualized training plans, accurately quantifying the total workload - which encompasses both training and match loads - is critically important. This quantification is essential for professional football coaches and sports scientists who aim to achieve optimal physical adaptations and minimize the risk of injury (Thorpe et al., 2015). By carefully monitoring and adjusting the total workload, they

can ensure that all players, regardless of their match participation, maintain peak physical condition and are prepared for the demands of the season.

Recent research conducted over an entire season on English Premier League players has revealed that non-starting players accumulate a similar total exposure time and total distance, considering both match and training time, as starting players. However, non-starters exhibit lower levels of high-speed running compared to their starting counterparts (Anderson, Orme, Di Michele, Close, Milsom, et al., 2016). To address this discrepancy, it is recommended to incorporate additional high-speed activities into the training regimen for non-starters. Nevertheless, increasing the workload, particularly in terms of high-speed running and sprinting, can be challenging during congested fixture periods. This difficulty arises from the uncertainty surrounding player selection and availability. Indeed, within the framework of a 3- or 4-day microcycle (see Figure 6), the day following a match (MD+1) coincides with two days before the subsequent match (MD-2) and three days before the next match (MD-3), respectively. In this context, providing players with an effective training stimulus can be counterproductive if they are selected for the next match and do not adequately recover from the stimulus. Therefore, coaches and sports scientists must meticulously balance the dual objectives of delivering sufficient training stimuli and ensuring players' availability for selection.

1.5 Defining congested fixture periods in football

In contemporary football, the elite teams from various championships, such as Serie A and the Premier League, engage in frequent matches throughout the season to participate in international competitions and national cup tournaments. Consequently, these teams do not limit their play to weekends (one match per week); instead, they often compete multiple times within a week, sometimes playing 2-3 matches over a span of 7-8 days (Julian, Page and Harper, 2021). This scenario is prevalent in top-level football, where congested microcycles constitute 75% of the microcycles throughout an entire season. In Figure 7, the distribution of microcycle lengths over a full season for a professional adult top-level male football team competing in the Italian Serie A is illustrated. As evidenced, 3-day microcycles are more frequent than one might expect, accounting for 34% of the season. When combined with 4-day microcycles, they represent 57% of the season.

This type of "congested fixture season" significantly hinders practitioners' ability to plan training according to the standard microcycle depicted in Figure 5, accounting only for 24%

of the microcycles of a season and which typically involves six training sessions per week with one match. During congested fixture periods, individual players may endure approximately 10 consecutive weeks of an intense schedule, encompassing both domestic and international matches, including commitments with their national teams (Silva *et al.*, 2023). Under these conditions, the number of weekly training sessions is decreased to prioritize physical recovery, particularly in the days immediately following a match, thereby enhancing overall performance (Querido *et al.*, 2022). This approach significantly impacts the training load, such that the weekly load, especially the distance covered at high speed, is predominantly achieved during the matches themselves. (Anderson, Orme, Di Michele, Close, Morgans, *et al.*, 2016).

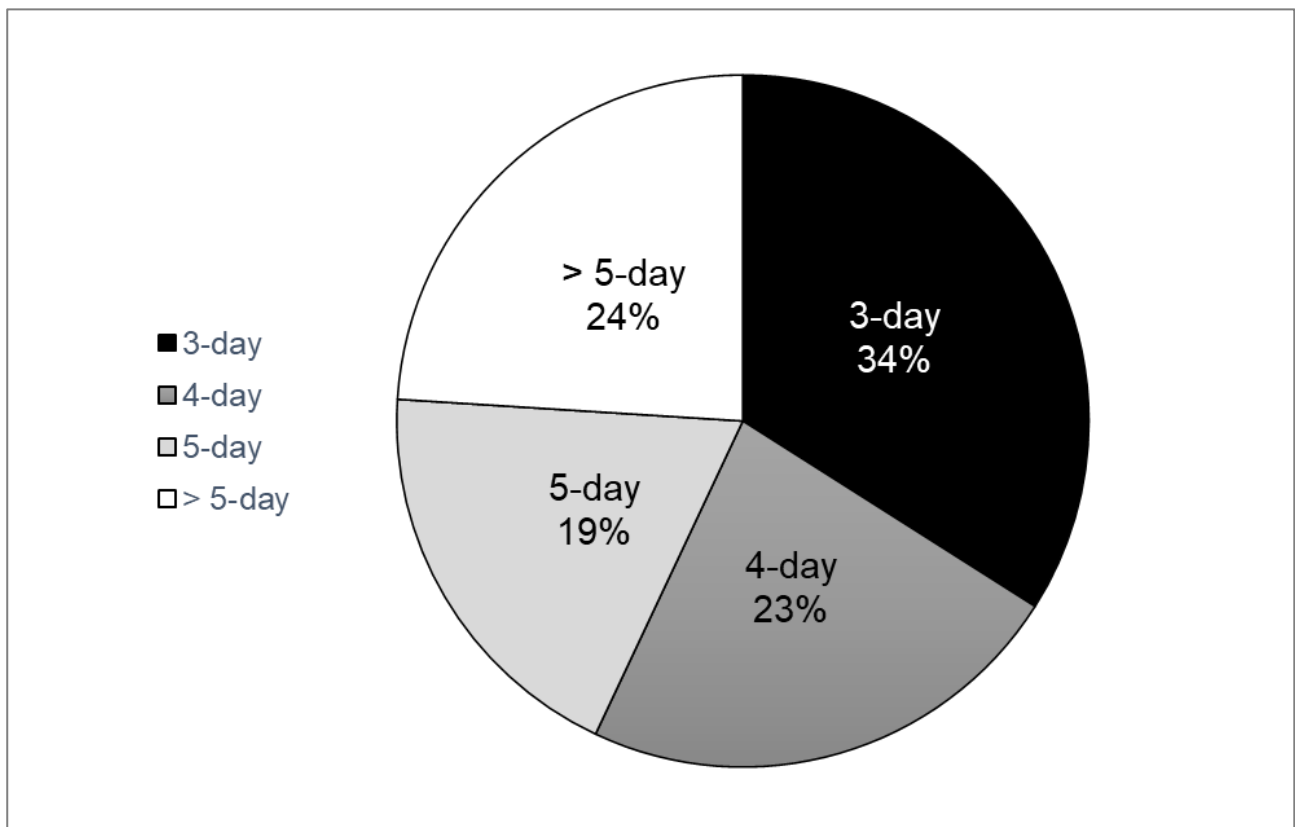


Figure 7: Microcycle length distribution during an entire season of a top-level football team.

To illustrate, within a four-day microcycle, the initial session following a match (MD+1) is the sole opportunity for non-starting players from the previous match day to engage in physical development, occurring 72 hours before the subsequent match day. On MD+2, which is less than 48 hours after the previous match day and 48 hours before the next, starting players are still in the recovery phase from the previous match's exertions and are unable to fully train, while non-starters must begin tapering for the upcoming match day. Finally, MD-1,

occurring less than 72 hours after the previous match day and 24 hours before the next, serves as a tapering session for both starting and non-starting players.

A three-day microcycle, consisting of MD+1, MD-1, and MD, is also feasible and constitutes at least 30% of the microcycles for teams concurrently competing in national championships, cups, and international competitions (FIFPRO, 2022). Under these circumstances, MD+1 remains the only day available for training non-starting players, albeit with a limited load due to the approximately 48-hour window before the next match day. Conversely, MD-1, which occurs less than 48 hours after the previous match day and about 24 hours before the next, may be the only day to prepare starting players and assess their readiness for the forthcoming match. Thus, it is imperative to strike an optimal balance between recovery from the previous game and preparation for the next.

1.6 Defining the most intense periods of the football match

Reporting the match demand using the total values of distance covered and high-intensity activities is insufficient for planning a training session. Coaches can further dissect the match into subunits to be trained, identifying specific tactical situations or critical moments within the match. This approach aids in designing training drills that enhance the performance levels of individual players and, consequently, the team as a whole. Several studies described the total physical demand of a match or its relative demand (i.e., the average demand per minute) to define training targets and design training sessions (Impellizzeri, Marcora and Coutts, 2019; Chaize, Allen and Beato, 2024). However, it was suggested that the average match activities do not fully explain the demands of the game and they cannot be the only reference point for the physical training of the players. Specifically, average values towards training may not expose players to the most intense periods which occur intermittently throughout matches (Delaney *et al.*, 2015). These peak locomotor periods that occur during a game have been reported using different terms such as most intense periods (MIP) (Martín-García, Casamichana, *et al.*, 2018), peak match or physical demand (Whitehead *et al.*, 2018), duration-specific running demands (Duthie *et al.*, 2018), worst case scenario (Novak *et al.*, 2021), most demanding passages (Lino-Mesquita *et al.*, 2024) or other similar lexical alternatives.

In professional football, the MIPs are utilized by practitioners as benchmarks for replicating exercises. This is particularly important when individual repetitions are of short duration, as it helps maintain a high level of physical demand during training (McCall *et al.*, 2020). This

methodology proves beneficial in preparing players for various technical and tactical scenarios that require them to achieve very high intensities and cover significant distances in minimal time, such as during negative and positive transitions (Bortnik, Burger and Rhodes, 2022), very different from the average game demand (Abbott, Brickley and Smeeton, 2018; Riboli, Esposito and Coratella, 2022). In fact, a 5-min peak match demand was reported to be more than twofold for high-speed running distance and three-to sixfold for sprint distance, depending on the playing position, compared with the match average both in elite female (Ramos *et al.*, 2017) and male (Riboli *et al.*, 2021) players. Raising the bar, previous research has reported that relative distance can be over 200 m·min⁻¹ when analysed using short time windows (i.e., 1 min) in USA Major League of Soccer (Calder and Gabbett, 2022), and this game-speed intensity is much higher than the average relative distance (i.e., around 110 m·min⁻¹) reported considering the whole game in English professional football (Beato, Youngs and Costin, 2024; Chaize, Allen and Beato, 2024).

1.7 Conclusion

Football, recognized as the most widely played sport globally, has led to a continuous evolution in training methodologies. Coaches, in their quest for excellence, constantly refine their techniques, focusing on even the minutest details that could provide a competitive edge during matches. Among these various aspects, high-speed running has garnered significant attention over the past decade. This focus is evident not only in academic research but also in practical applications by professionals in the field. The emphasis on high-speed running underscores its perceived importance in enhancing player performance and overall team success.

The substantial number of researchers and practitioners involved in the study of high-speed running in football is beneficial in terms of the volume of data available and reported. However, this abundance can also pose a challenge when there is no established international standard. Currently, there is no universally accepted definition of high-speed running. By synthesizing the various published studies, it is possible to approximate that high-speed running for football players is characterized by velocities exceeding 18-20 km·h⁻¹ for female and male players, respectively. Raising the bar, the threshold for higher velocities, typically referred to as sprint running, is generally defined as speeds above 23-25 km·h⁻¹ for female and male players, respectively.

In this manuscript, for the sake of clarity, the term high-speed running will be used to refer to any running activity that occurs at speeds above $18\text{--}20\text{ km}\cdot\text{h}^{-1}$, unless otherwise specified. This inclusive definition encompasses sprint running as well.

For a football player, and indeed for athletes across various sports, running at high velocities necessitates both adequate space during training sessions and sufficient time for recovery between these sessions. These two variables - space and time - are therefore pivotal in the analysis and optimization of high-speed running. The availability of ample space ensures that athletes can achieve and sustain the required speeds, while appropriate recovery time between single repetitions or sessions is crucial for preventing injuries and maintaining peak performance levels. Consequently, any comprehensive study or training program focused on high-speed running must carefully consider these factors to enhance the effectiveness and safety of the training regimen.

Indeed, each training exercise should be designed to encourage players to achieve high speeds, necessitating the use of large spaces and longer distances. The dimensions of the training pitch alone do not solely determine this; the number of players participating in a drill also plays a crucial role. By dividing the total playing surface by the number of players, one can determine the area each player is responsible for covering. This measurement, referred to as the relative pitch area (RPA), is a critical factor in understanding training demands and it is widely recognized for its impact on the requirements of high-speed running during training sessions. In fact, it highlights the importance of spatial distribution and player density in effectively simulating match conditions and optimizing training outcomes.

On the other side, players require adequate recovery time following high-speed running training sessions or matches, that normally require a player to run a considerable amount of distance at high-speed. This need for recovery can pose significant challenges when there are only a few days between games. At the elite level, football players often contend with two match days per week. Consequently, starting players (those selected to begin the match) typically have only 2-4 days to recover and prepare for the next game. Simultaneously, players who were benched during the match need to experience similar high-speed running stimuli to compensate their lack of playing time. However, providing this exposure is challenging during short competitive microcycles, which offer limited training opportunities due to the brief 2-4 day intervals between games. These dual challenges often result in a polarized high-speed running load on match days, characterized by high weekly high-speed running values for starters and low values for non-starters. This disparity

underscores the difficulty in balancing training demands and recovery periods within the constraints of a rigorous competitive schedule.

Finally, a significant portion of the high-speed running demands in a football match can be concentrated within very brief time intervals. This concentration poses a challenge in understanding the distribution of high-speed running throughout a match and identifying the worst-case scenarios that players must be prepared for. Understanding these peak demands is essential for designing training programs that adequately prepare players for the most intense phases of a match. By replicating these high-intensity periods in training, coaches can ensure that players are better equipped to handle the physical stresses of competitive play, indirectly reducing the risk of an injury occurring.

1.8 Summary and aims of the thesis

Considering the context described by the available literature, in turn determined by practitioners' experiences and needs, it appears fundamental monitoring the workload of a football player. A systematic and individualized approach can help to avoid detraining of non-starting players and overtraining of starting ones, especially during congested fixture periods with reduced training opportunities and recovery days, respectively.

1.8.1 Aims and objectives

1. To date no standardized velocity thresholds exist for classifying high-speed running and sprinting in adult professional female and male football players. The scientific community and practitioners employ various approaches for both absolute and relative velocity thresholds, yet these methods have not been collectively analysed or discussed previously. This lack of a unified approach complicates the aggregation of results from different teams, thereby hindering the development of more robust benchmarks for both match and training demands. Therefore, all the studies about professional adult football players will be systematically analysed to identify potential common criteria to define high-speed and sprint thresholds.
2. For elite level teams playing twice a week, high-speed and sprint running distance appear to be polarized during match days, inducing to find solutions to expose to this kind of stimulus all the players of the roster independently by their playing time. To

date, very few studies have reported data from starting and non-starting players at elite level during congested fixture periods and none of them reported data about the near-to-maximal speed intensity. Therefore, workload differences between starting and non-starting players will be calculated at different speeds, in particular at near-to-maximal velocity.

3. Professional elite level football players have to compete more than once a week, but very few studies have described this particular scenario identified by microcycles with four or five days and none has explored the worst scenario of the three-days microcycle. Therefore, high-speed running distribution during the most common microcycles in professional elite football with three, four and five days will be defined.
4. It results clear from this review that the average values recorded during a match can help to modulate the load across the training days and define training drills, but higher benchmarks have to be looked for to prepare all the players to the most demanding passages of the match. To date, most intense periods have been described for elite players, but only considering time windows longer than 1 minute. Therefore, shorter most intense periods of the match will be calculated and analysed to define the maximum quantity of high-speed running a top player has to run in a portion of the match.

1.8.2 Research questions

To address the gaps in knowledge identified in the aims, four intermediate research questions were formulated:

1. Which high-speed running thresholds are most appropriate for describing the training and performance of football players? (Chapter 2)
This question seeks to establish the specific velocity thresholds that best capture the demands of high-speed running in female and male adult football players, providing a standardized framework for both training and performance analysis.
2. Is there a difference in high-speed running load between starting and non-starting players, particularly during congested fixture periods? (Chapter 4)
This question aims to investigate whether starting players experience different high-speed running loads compared to non-starting players, especially during periods with

a high density of matches. Understanding these differences can inform tailored training and recovery strategies.

3. What is the distribution of high-speed running during different congested fixture microcycles? (Chapter 5)

This question focuses on analysing how high-speed running is distributed across various microcycles within congested fixture periods. The goal is to identify patterns and optimize training schedules to manage player load effectively.

4. What are the maximum intensity periods during matches for an élite Italian adult team? (Chapter 6)

This question seeks to pinpoint the most demanding periods of high-speed running during matches, in particular for time windows shorter than one minute. By identifying these peak intensity phases, players can be better prepared for the highest physical demands they will face in competition.

1.8.3 Main thesis hypothesis

Given the growing and sustained interest in the subject of high-speed running in football, the aim of this thesis is to provide a comprehensive description of its dynamics within an élite adult football team and to elucidate the specific patterns, demands, and implications of high-speed running in this context, offering valuable insights into how elite football players manage and optimize their performance through targeted training and recovery strategies. By focusing on an élite adult team, the thesis sought to contribute to the broader understanding of high-speed running, informing both academic research and practical applications in the field of sports science.

In order to do this, the main hypothesis for this thesis are that (1) non starting players are less taxed compared to starting players, especially at very high running velocity, (2) very short congested fixture microcycles exacerbate this gap and, (3) most intense periods need to be trained specifically since completely different from average match values.

This is presented graphically below in Figure 8, and these hypotheses will be examined in the experimental chapters of this thesis.

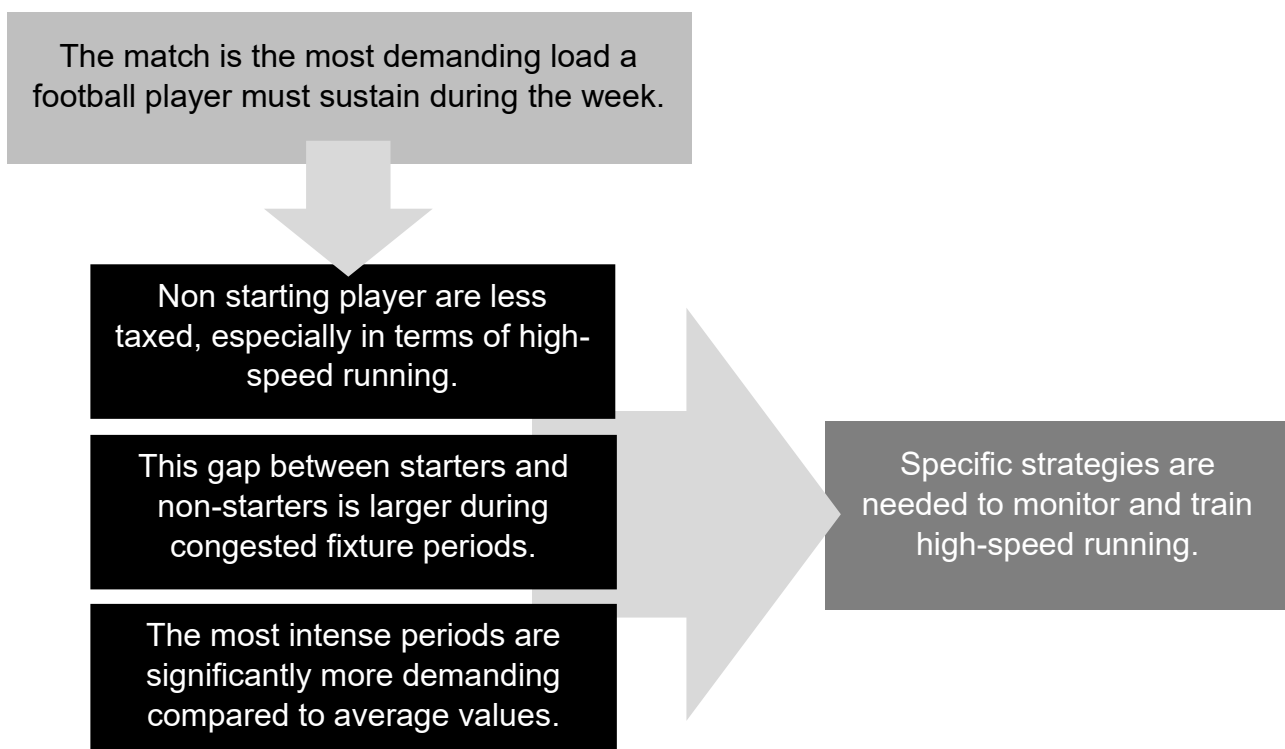


Figure 8: Graphical representation of thesis hypothesis.

Chapter 2: Systematic review of the topic

Aspects of this chapter have been published in the following paper: Gualtieri A, Rampinini E, Dello Iacono A, Beato M. High-speed running and sprinting in professional adult soccer: Current thresholds definition, match demands and training strategies. A systematic review. *Front Sports Act Living*. 2023 Feb 13;5:1116293. doi: 10.3389/fspor.2023.1116293.

2.1 Introduction

In this chapter which high-speed running and sprinting thresholds are most appropriate for describing the training and performance of football players are systematically analysed.

Football is a team-based sport characterized by an intermittent activity profile with high-intensity activities such as accelerations, decelerations, changes of direction, sprinting, jumping, and tackling interspersed by low-intensity phases of passive (i.e., standing) and active recovery (e.g., walking, jogging) (Stolen *et al.*, 2005; Reynolds *et al.*, 2021). The match play intensity in male football has considerably increased over the last 15 years, especially due to the greater high-speed running and sprint locomotive demands. High speed running, in this case the distance covered at velocity between 19.8 km·h⁻¹ and 25.1 km·h⁻¹, increased around 29%, and sprint, in this case distance covered at velocity above 25.1 km·h⁻¹, increased around 50%. High-speed running and sprint running account for ~7-11% and ~1-3% relatively to the total distance covered during a match, respectively (Barnes *et al.*, 2014; Reynolds *et al.*, 2021; Lago-Peñas *et al.*, 2022). Similarly, intense running in female football has increased across various playing positions by approximately 16-32% from the 2015 to the 2019 *Fédération Internationale de Football Association* World Cup (FIFA, 2019).

In the lines here above the entry speed considered to define both high-speed running and sprinting were specified. In fact, to define high-speed running or sprinting an entry speed has to be defined. These two entry speeds, that consequently define two speed thresholds, can be absolute or relative. In the first case, a velocity, usually reported using km·h⁻¹ or m·s⁻¹ as unit of measurement, is defined as cut off, while in the second scenario a percentage value is used to define the thresholds. This percentage value is relative to the maximum velocity achievable by every single player, that represents the 100%. Both absolute and relative thresholds can be useful for practitioners, as illustrated in the next lines.

The evolution of football matches intensity implies that players should be adequately prepared to cope with the physical demands of the game. Furthermore, high-speed running and sprint activities are also considered as key determinants for successful performance

(Carling, Le Gall and Dupont, 2012). To illustrate, straight sprinting has been identified as the single most frequent locomotive action preceding goal situations, performed by either the scoring player or the assisting one (Faude, Koch and Meyer, 2012; Martínez-Hernández, Quinn and Jones, 2022). Moreover, there is evidence highlighting significant positive associations between high-speed running and sprint distances covered by players in specific positions (e.g., wide midfielders and forwards) and the number of matches won by their team (Chmura *et al.*, 2018). Accordingly, the ability to sustain high-speed running and sprinting can be considered a key characteristic for football players to compete at the professional level (Chmura *et al.*, 2017). Therefore, developing players' capacity to perform high-speed running and sprinting is paramount for the coaching staff and sport science departments in professional football. On the other hand, even if the demand is increasing, there is no evidence that producing more high-speed or sprinting distance leads to the victory: preparing players to cope with the higher and higher game demand without deceiving them with the hope of an easy victory thanks to an improved sprinting capacity could be the most appropriate approach to be adopted by coaches.

With the performance model in mind and moving to the training, the use of individual relative thresholds has been proposed as an alternative approach to arbitrary velocity thresholds selection for better quantifying external load measures in football (Beato, Drust and Iacono, 2021), i.e. how much distance, high-speed running, sprinting players have to perform during training or games. For example, when comparing in Chapter 4 external load between starting and non-starting players during a 21-day congested fixture period of a Serie A team, significant between-group differences for sprint distance emerged only when individualized thresholds were used. In that case, 80 % of the individual peak velocity was used to define sprinting velocity. This may suggest that the selection of velocity thresholds should account for the individual maximal velocity to accurately quantify sprint distance outcomes during training and matches. Nevertheless, given that only preliminary evidence is available on this topic, further research is warranted to investigate the effectiveness of using individual relative thresholds in football.

The monitoring of high-speed running and sprinting distance has been traditionally used to inform training practices with the aim to physically prepare football players to the match demands. However, some training contents and drills are unable to elicit high-speed running or sprinting: summarizing the pertaining literature and outcomes across different types of exercises can allow coaches to make evidence-informed decisions when planning training sessions aimed at ensuring adequate high-speed running and sprint distances exposure.

Therefore, in the next paragraphs the evidence on velocity thresholds used to classify high-speed running and sprinting in adult professional female and male soccer players will be reported; the existing evidence about the use of individualized thresholds will be examined; the high-speed running and sprinting demand during football matches and training will be described; and the available evidence about the relationship between high-speed running and injuries will be discussed.

Once these questions are addressed, it will facilitate a comprehensive understanding of high-speed running and sprinting in football. This will also elucidate the existing knowledge gaps that the experimental studies in Chapters 4, 5, and 6 aim to bridge. These chapters offer an in-depth examination of high-speed running in football players, beginning with a week-long period and culminating in Chapter 6 with an analysis of the most intense 10 seconds during a match.

2.2 Methods

To analyse systematically the literature about high-speed running and sprinting in football, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA) statement was consulted. As a consequence, prior to the start of this systematic review the relative checklist was completed (Page *et al.*, 2021). The review methods were established prior to the conduct of the review, including review question, search strategy and inclusion/exclusion criteria. No significant deviations from the a priori protocol was made. The assessment of the risk of bias was not performed because of the complexity of judging the quality of observational studies: this decision has been taken considering what previously reported by other authors that deepened the topic (Lang and Kleijnen, 2010).

2.2.1 Review questions

Four review questions were stated before starting with the systematic search of the literature:

1. What absolute and relative velocity thresholds are utilized to classify high-speed running and sprinting in adult professional female and male soccer players?
2. What are the demands of high-speed running and sprinting during football matches?
3. What are the demands of high-speed running and sprinting during football training sessions?
4. Is there a relationship between high-speed running and the incidence of injuries?

2.2.2 Search methods for identification of studies

To answer the four questions reported in the previous paragraph, the same systematic search was performed in PubMed (MEDLINE), Web of Science and SPORTDiscus (EBSCO) until October 2022 with no restriction for year of publication. The following search strategy adapted for each database was used: (('football' OR 'soccer') AND ('adult' OR 'senior')) AND (('high speed' OR 'sprint') AND ('running' OR 'distance' OR 'effort')) AND (((('match' OR 'game') AND ('demand' OR 'request')) OR ('training' OR 'session'))).

Table 1: Systematic review search strategy

Variable	Search terms
Population	('football' OR 'soccer') AND ('adult' OR 'senior')
Load	('high speed' OR 'sprint') AND ('running' OR 'distance' OR 'effort' OR 'velocity')
Variable	((('match' OR 'game') AND ('demand' OR 'request')) OR ('training' OR 'session'))
Final search	Combination of the three groups: 'Population' AND 'Load' AND 'Variable'

In addition, manual searching, and reference checking have been performed by three independent reviewers to search other relevant reports.

2.2.3 Inclusion and exclusion criteria

Studies were included if they met the following criteria.

- The study was original research article.
- the study was published in English and in a peer-reviewed journal.
- The research design was either an observational study, an intervention study including a control group or with a crossover design.
- Participants were professional football players of any football code and any sex.
- The study reported high-speed running or sprint distances outcomes, defined according to arbitrary or individualized velocity thresholds and collected during official matches or training sessions.
- The study reported any high-speed running related injury mechanism, incidence, or prevalence.

Contrariwise, manuscripts were excluded from the review in any of the following cases.

- The subjects played at a lower level of the third national league, but only if not defined as professional players.
- Metrics reported did not include high-speed running and sprinting values.
- Data came from manual coding.

2.2.4 Data collection and analysis

My self and another independent researcher independently assessed titles and abstracts of all identified articles, which were downloaded into a web app for systematic reviews (rayyan.qcri.org, Hamad Bin Khalifa University, Qatar) (Ouzzani *et al.*, 2016). A third independent reviewer was consulted to settle conflict.

2.2.5 Data extraction

Me and the other reviewer independently extracted data from all relevant articles by reading the articles in full. Key areas of interest were elucidated, and the information extracted included:

- Study population, i.e. sample size, gender, football code, competition level and Club's name when available.
- Dataset dimension, i.e. number of training sessions or weeks, number of games, number of seasons included in the study.
- High-speed and sprint running metrics, adopted absolute and/or individualized thresholds.
- Details from the study relevant for the systematic review, i.e. main findings and average training or match load values.

2.3 Results

2.3.1 Search results

The systematic search through the 3 databases (i.e., Pubmed, Web of Science, SPORTDiscus) produced 830 records, which were screened using a web app for systematic reviews (rayyan.qcri.org, Hamad Bin Khalifa University, Qatar) (Ouzzani *et al.*, 2016) to remove any duplications. The summary of the systematic search was as follows:

- **704** results on Pubmed
- **76** results on Web of Science
- **50** results on SPORTDiscus

After removing duplicates ($n = 32$), to enable simultaneous screening against the inclusion–exclusion criteria, titles and abstracts were screened to remove articles that were clearly not relevant. At this stage, 733 records were excluded. The full texts of the remaining 65 articles were then accessed for complete screening with 19 studies being excluded as did not meet the inclusion criteria. Seven additional studies were found through other sources, 3 from personal archives and 4 following references screening of the 65 articles accessed. Independent screening results were then combined, and any disagreements was resolved by consensus discussion with supervisors. After the final screening, 53 studies were included in this systematic review. The PRISMA flow diagram for the description of the overall process is reported in Figure 9.

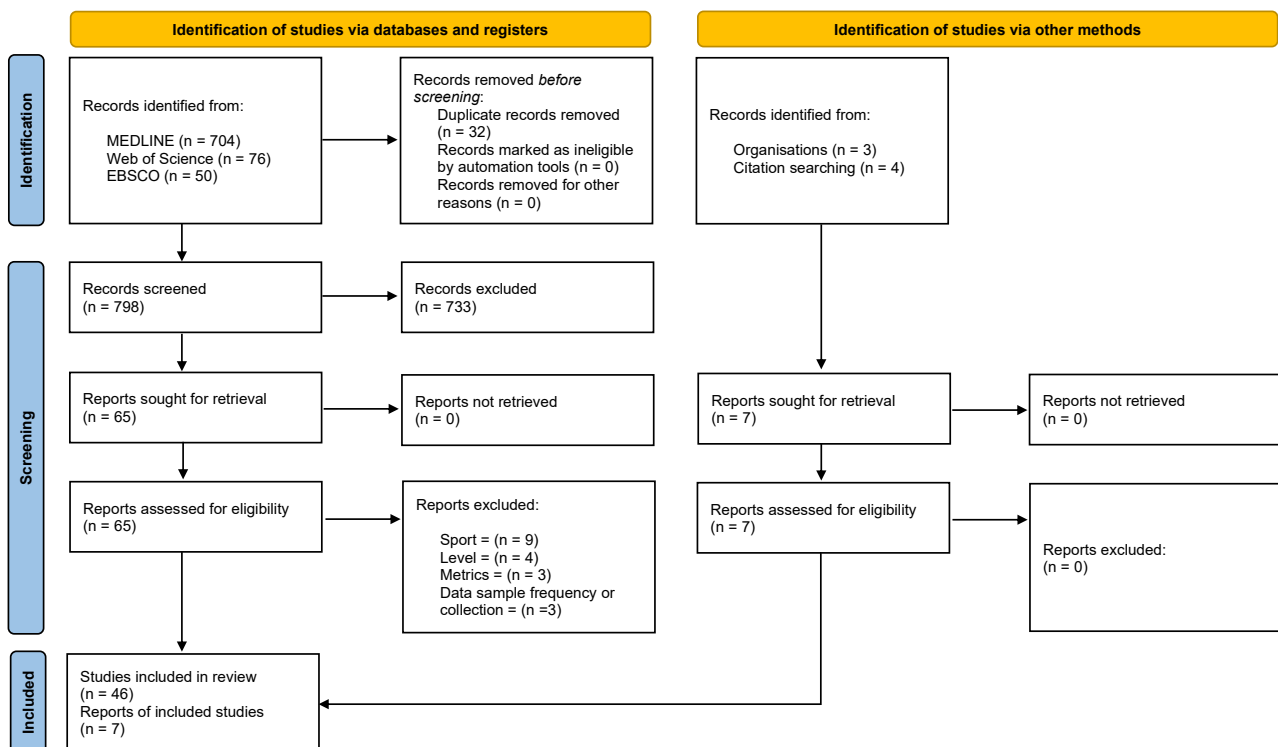


Figure 9: PRISMA flow diagram for the description of the overall process for the systematic review.

2.3.2 Descriptive characteristics of the included studies

After final screening, 1 longitudinal observational study, 2 reviews, and 50 observational studies were included in the systematic review. Data regarding sample size, gender, age, load metrics and results about match and training demand as well as high-speed running related injuries were extracted, verified for accuracy, and reported in Table 2, Table 3 and Table 4.

Seven studies were carried out with female players, 43 with male players and 1 with both female and male players. These studies were carried out between 2013 and 2022 and comprised a total of 1897 participants, divided as follows: 97 adult females and 1800 adult males. The total number of analysed games was 442 for females and 2098 for males. The asymmetry between the number of players and the number of games is due to the different objects of the studies. The male sample considers both training monitoring and matches, while the female sample includes only data collected during matches. The total number of pre-season and in-season weeks was 287 overall. The total number of single drills analysed was 209. The key outcomes of the selected studies in this systematic review included velocity thresholds definition, match demands and training outcomes in terms of high-speed running and sprint distance, and high-speed running related injuries.

Table 2: High-speed running in women and men & absolute VS relative thresholds.

Study	Subjects	Metrics	Details
(Bradley and Vescovi, 2015)	Female football players	HSR threshold Sprint threshold Vmax	Female VS male football players: Vmax ~10% lower, V@VO_{2max} ~15% lower, final V@Yo-Yo ~12% lower. A generic HSR thresholds for female could be at 15-16 km/h. To set an individual threshold for HSR you can use V@VO_{2max} or the final V@Yo-Yo. In female it changes with age till >24 yrs. To assess Vmax a 30-40m sprint test is needed. In female Vmax tends to plateau at 16 yrs.
(Mara <i>et al.</i> , 2017)	12 elite female players from the Australian national league (W-League) 7 games	HSR = 12.24 - 19.0 km/h Sprint >19 km/h High Speed Runs and Sprints (n)	Match demand: HSR = 2452 ± 636 m; Sprint = 615 ± 258 m; high-speed runs = 376; sprints = 70. A large proportion of high-speed runs (81–84%) and sprints (71–78%) were performed over distances less than 10 m, with 14 seconds between high-speed runs and 87 seconds between sprints. The characteristics of high-speed runs and sprints differed between repeat and nonrepeat efforts, and the activity profiles of players varied according to positional groups and period of the match.
(Baumgart, Freiwald and Hoppe, 2018)	14 adult female players 115 U12-13-14-15-17-19-23 and PRO male players from a 1st division German Bundesliga club	30m linear sprint with 5-10-20m split times	Sprint mechanical properties differ according to gender and age in top-level German football players. An increase in sprint mechanical properties was found from U12 to U17. Sprint mechanical properties of females were similar to those of U14 and U15 male players.
(Scott and Lovell, 2018)	22 International women's football players	HSR >12.67 km/h (HRDP) VHSR > 17.82 km/h (MAS)	In this approach, each players running speed corresponding to HRDP, together with their MAS determined from the VAM-EVAL, were used as the entry-points to the HSR and VHSR zones. Individualised speed thresholds for external load monitoring were not able to better quantify the dose-response of Football training during a 21-day training camp in players representing the highest level of women's football. Quantifying the external load using players' peak sprinting speed demonstrated a lower capacity to determine the dose-response of training, with consistently lower associations with heart rate and RPE.

(Massard, Eggers and Lovell, 2018)	23 semi-professional Australian male football players	Peak speed (PS) in 40-m sprint test and match	Maximal sprint speed testing may be unnecessary for PS determination in football players. Instead, tracking PS via 10 Hz GPS over a series of matches is a suitable alternative, even during preseason “non-competitive” matches. Absolute PS was faster in matches ($31.4 \pm 1.5 \text{ km} \cdot \text{h}^{-1}$) versus measures in a 40m sprint test measured using timing gate ($+0.80$; 90% CI: 0.13–1.47 km/h; likely small effect) and GPS ($+1.14$; 90% CI: 0.47–$1.81 \text{ km} \cdot \text{h}^{-1}$; likely moderate effect).
(Kyprianou <i>et al.</i> , 2019)	12 male youth football players (U17)	Peak speed in 40-m sprint test, sprint training, match, LSG, MSG, SSG	To assess Vmax a 40m sprint test is needed. Percentage differences Vpeak when compared with the sprint test were as follows: -41% (SSG), -27% (MSG), -21% (LSG), -3% (sprints), and -9% (matches).
(Park, Scott and Lovell, 2019)	27 international female players 52 international matches	HSR: $\geq 12.5 \text{ km/h}$ VHSR: $\geq 19 \text{ km/h}$ Sprint $\geq 22.5 \text{ km/h}$	PS in elite women = $29.0 \pm 1.5 \text{ km/h}$ k-means clustering and Gaussian mixture modelling were not appropriate for football given the limited instances in which players move at velocities associated with sprinting, which are often considered key physical performance indicators. A spectral Clustering technique with application of a $\beta = 0.1$ smoothing factor derived new thresholds featuring both logical validity and analysis rigor. Similar analyses may be warranted to determine appropriate velocity zones for other sports and youth populations.
(Rago <i>et al.</i> , 2019)	13 Italian Serie B football players	MSR = arbitrary 14.4 – 19.8 km/h or individualised 80–99% MAS HSR = 19.9 – 25.1 km/h or 100% MAS – 29% ASR Sprint = $\geq 25.2 \text{ km/h}$ or $\geq 30\%$ ASR	Perceptual responses (RPE) were moderately correlated to MSR and HSR quantified using the arbitrary method ($p < 0.05$; $r = 0.53$ to 0.59). However, the magnitude of correlations tended to increase when the individualised method was used ($p < 0.05$; $r = 0.58$ to 0.67). Distance covered by sprinting was moderately correlated to perceptual responses only when the individualised method was used ($p < 0.05$; 0.55 [0.05; 0.83] and 0.53 [0.02; 0.82]). The magnitude of the relationships between external training load (ETL) and RPE parameters appears to slightly strengthen when ETL are adjusted to individual fitness capacities, with special emphasis on cardiorespiratory fitness (MAS).
(Ramos <i>et al.</i> , 2019)	U17 (n=14), U20 (n=14) and adult (n=17) international women football players	High intensity (HID) = 15.6 – 20 km/h Sprint $> 20 \text{ km/h}$	Likely to almost certainly differences among all age brackets for the HID and sprint were found (adult > U20 > U17, ES varying from 0.41 [0.23–1.06] to 3.69 [2.63–4.76]), except for the comparison between U17 and U20 for sprint where the differences were rated as unclear. HID: adult (756m) > U20 (688m) > U17 (485m). Sprint: adult (307m) > U20 (223m) $\approx$ U17 (192m).
(O'Connor <i>et al.</i> , 2020)	53 pro male Australian rules footballers	ABS sprint $> 24.9 \text{ km/h}$ REL sprint $\geq 75\%$, $\geq 80\%$, $\geq 85\%$, $\geq 90\%$, $\geq 95\%$,	Very low and very high 4-week cumulative sprint loads $\geq 80\%$ individual Vmax resulted in higher incidence rate ratios (2.54–3.29), than ABS thresholds (1.18–1.58).

(Scott, Norris and Lovell, 2020)	36 elite female players from National Women's Soccer League (NWSL, USA) 408 match observations (11±6 per player)	HSR: ≥12.5 km/h or 60% vIFT (50% PS) VHSR: ≥19 km/h or 80% vIFT (65% PS) Sprint ≥22.5 km/h or 30% ASR (80% PS)	Subjective ratings of fatigue and wellness are not sensitive to substantial within-player changes in match physical performance. HSR, VHSR, and SPR thresholds customized for individual players athletic qualities did not improve the dose-response relationship between external load and wellness ratings. PS in elite women = 30.5 ± 1.8 km/h (mean of 5 different roles). Match demand (ABS): HSR = 2401 ± 454 m; VHSR = 398 ± 143 m; sprint = 122 ± 69 m.
----------------------------------	---	--	---

Table 3: High-speed running during training and match.

Study	Subjects	Metrics	Details
(Mugglestone <i>et al.</i> , 2013)	20 semipro football players 50 games	HSR >15 km/h Sprint > 21 km/h (meters & number) 1 st vs 2 nd half (1 Hz GPS)	HSR was reduced in the second half (1st half vs 2nd half: 837±294 vs 797±289 m; p = 0.03). The number of sprints decreased over time, but between halves there were no differences in the distance sprinted (1st half vs 2nd half: 159±100 vs 161±93 m; p = 0.79) or in the number of sprints (1st half vs 2nd half: 11±6 vs 11±6; p = 0.68). Large correlations between temperature and number of sprints (1st half 0–5 min: r = 0.638, p < 0.001; 2nd half 0–15 min: r = 0.616, p < 0.001) and temperature and total distance covered (1st half 0–5 min: r = - 0.767, p < 0.001; 2nd half 0–15 min: r = 0.763, p < 0.001) in the first 5 min of each half. Semipro in this study performed 1/3 of HSR in a 5 min period compared with the top-class.
(Scott <i>et al.</i> , 2013)	15 professional football players 97 individual training sessions	HSR >14.4 km/h VHSR >19.8 km/h	Absolute and % of total distance values recorded during training: HSR = 544 ± 255m (12.0 ± 3.8%), VHSR = 132 ± 101m (2.8 ± 1.9%). For ranges see the table below.
(Silva <i>et al.</i> , 2013)	13 professional players from the Portuguese championship 8 matches during 4 time points of the season Manual coding	HSR = 18 – 30 km/h Sprint >30 km/h	Match demand: HSR distance = 420 ± 107m (Aug), 380 ± 56m (Oct), 430 ± 54m (Jan), 661 ± 193m (Mar). Sprint distance = 98 ± 28m (Aug), 96 ± 25m (Oct), 111 ± 33m (Jan), 206 ± 78m (Mar). Alterations in game physical parameters of professional football players occur during the season and training status is related to a greater ability to maintain HI-related performance variables during the match. Players covered greater total and HI distances in the last quarter of the season. The amount of HI performed in the last 15-minute period of each half, which is indicative of the ability to maintain performance during the game was higher in the last quarter of the season.

(Wehbe, Hartwig and Duncan, 2014)	19 elite male adult football players from Australian-league (A-League) soccer (Sydney Football Club) 8 preseason matches	HSR > 19.7 to ≤ 25.1 km/h Sprint > 25.1 Putting together thresholds: HIR >14.3 km/h VHIR > 19.7 km/h	Positional comparison: midfielders covered 28% more HIR distance than defenders. Match half comparison: HIR and VHIR decreased from the first to the second half by 10 and 11%, respectively. Match status analysis: when the team was winning, average speed was 4% lower than when the team was drawing ($p \leq 0.05$, $d = 0.32$). Pre- and post-goal analysis: scoring or conceding goals did not appear to affect HIR. In the 5-minute intervals before and after a goal was scored, 5-minute HIR distance was 140 and 128 m, respectively ($p = 0.464$). In the 5-minute intervals before and after a goal was conceded, 5-minute HIR distance was 144 and 110 m, respectively ($p = 0.015$). Average and peak 5-minute HIR distance during the whole match was 123 and 237 m, respectively. Spanish league players covered less distance at high intensity (>19.1 km/h) and more distance at low intensity (<14.1 km/h) when their team was winning compared with when their team was losing (Lago 2010).
(Malone <i>et al.</i> , 2015)	30 professional players from English Premier League (Liverpool) 6 preseason weeks 36 in-season weeks 3 microcycles	HSD > 19.8 km/h	Higher total distances covered in the early stages of the competitive season and the highest HR response occurring at the midpoint of the season. HID 1-week in-season microcycles (daily means): early-season = 243 ± 229m, mid-season = 225 ± 213m, late-season = 146 ± 104m. Wide midfielders covered a higher amount of HSD across the different microcycles than central defenders (94 [43–145] m, ES = 0.47 [0.22–0.73], small). Periodization of training load was typically confined to MD-1 (regardless of mesocycle), whereas no differences were apparent during MD-2 to MD-5.
(Anderson, Orme, Di Michele, Close, Morgans, <i>et al.</i> , 2016)	12 English Premier League players 10 training sessions + 6 games (1-, 2-, 3-game weeks)	HSR = 19.8 - 25.1 km/h Sprint >25.1 km/h	The majority of distance during specific training sessions was completed in the low-to moderate speed zones, whereas the distance completed in high-intensity zones were largely completed in the game itself. HSR: match demand = 706 m; training stimulus = 156 m (1-game week), 192 m (2-game week), 81 m (3-game week). Sprinting: match demand = 295 m; training stimulus = 8 m (1-game week), 16 m (2-game week), 7 m (3-game week).

(Carling <i>et al.</i> , 2016)	12 French League 1 players 31 games	HSR = 19.8 - 25.2 km/h Sprint >25.2 km/h Total HSR (THSR, ≥ 19.8 km/h);	Math demand: HSR = 587 ± 133 m; Sprint = 184 ± 87 m; THSR = 770 ± 206 .
(Kobal <i>et al.</i> , 2016)	PRO vs U20 vs U17	10-20 m sprint time Squat 1RM, CMJ/SJ height, Yo-Yo IRTL1	10 and 20m sprint time is not different between U17, U20 and PRO: due to importance of sprinting in football, it is strongly recommended that fitness coaches develop more effective strategies to improve speed ability in PRO.
(Chmura <i>et al.</i> , 2017)	340 international football players from 32 teams 905 single observations during 2014 World Cup	HIR = 19.9 – 25.2 km/h (% of TD) N° of sprints >25.2 km/h	The mean distance covered by players at high intensity was $8.83 \pm 2.11\%$. It was significantly longer between the quarter-finals and the semi-finals ($p \leq 0.01$). In the semi-finals the percentage values of TD covered at HI were the greatest. Individually, the greatest percentage achieved was 17% by 2 midfielders. The mean number of sprints performed was 33.25 ± 10.67, 1 every 173 s . The greatest number of performed sprints was 68, 1 every 82 s, in a semi-final match. <i>Winning a football championship requires players to run longer mean total distances and longer distances at high intensity during a single match.</i>
(Miñano-Espin <i>et al.</i> , 2017)	149 Real Madrid games: data from Real Madrid and opposing teams' players	HIR = 21.1 - 24.0 km/h Sprint >24 km/h High Speed Runs and Sprints (n)	Match demand: HIR distance = 269 m Real Madrid vs 285 m opposing team; Sprint distance = 245 m vs 248 m; High Intensity Runs = 11; Sprints = 20. Players from Real Madrid covered shorter distances in HIR and Sprint and executed less sprints than players from the opposing team. No differences were revealed in the HIR and Sprint distances or the number on high intensity runs and sprints performed by players from Real Madrid depending on the quality of the opposition .
(Abbott, Brickley and Smeeton, 2018)	46 U23 Premiere League 2 professional players (Brighton and Hove Albion) 22 matches 39 LSG, MSG, SSG	VHSR = 100% MAS – 30% ASR Sprint >30% ASR Mean and 1-min peak values	Despite eliciting significantly higher average total distances compared with competition, LSGs produced significantly lower peak total distance relative to the competition. For VHSR and sprinting, LSGs elicited similar average intensities to competition; however, peak intensities were significantly lower than competition. VHSR and sprinting distances increased with game format , with LSGs ($> 7v7$) producing the highest intensities. Only LSGs were able to replicate competitive demands, with SSGs and MSGs significantly below competitive values for all positions.

(Baptista <i>et al.</i> , 2018)	18 professional football players (Tromsø Idrettslag) 23 official matches	HIR ≥ 19.8 km/h Sprint ≥ 25.2 km/h Number of HIR and sprint efforts of various length (1-5, 6-10, 11-15, 16-20, 21-25, 26-30, 31-35, 36-40, 41-45, 46-50m) CoD counts	CB had the lowest values of all positions in both variables but especially pronounced in Sprint (1 m/min) when compared with CF (2.5 m/min). HIR analysis: CF presented higher values in 26-30 m than all the other positions, while distances of 36-40 and 46-50 m were covered more times by FB. CB were the players with lowest values in these longer distances (36-40 and 46-50). Sprint analysis: CB, FB, CM and WM performed higher number of 1-5 m sprints , while CF covered higher number of 6-10 m sprints . <i>The most common distance covered in HIR for CB, CM, WM and CF was 1-5 m, but for full-backs was 6-10 m.</i>
(Casamichana, Bradley and Castellano, 2018)	20 amateur adult football players 4 different SSG 5v5+GK: 25x40, 25x66, 50x40, 50x66	13.0 – 17.9 km/h 18.0 – 20.9 km/h >21 km/h	(1) short narrow pitch (SN; 40 × 25 m), (2) short wide pitch (SW; 66 × 25 m), (3) long narrow pitch (LN; 40 × 50 m), and (4) long wide pitch (LW; 66 × 50 m). <i>Coaches could design SSGs on short pitches if the neuromuscular load (accelerations, decelerations and change of direction) needs to be increased and design SSGs on longer pitches if the cardiovascular (heart rate) and mechanical load (distance covered and peak speed) needs to be elevated.</i>
(Martín-García, Gómez Díaz, <i>et al.</i> , 2018)	24 professional football players (Barcelona 2nd team) 37 matches + 42 training weeks (1 game per week)	HSR >19.8 km/h Sprint > 25.2 km/h	When comparing starters and non-starters at MD+1 , thanks to the SSG approach used in players with limited game time, non-starters demonstrated greater external loads for TD, HMLD, AMP, ACC, and DEC, but not for HSR or SPR. In youth football, Ade <i>et al.</i> found that running-based drills elevated HSR and SPR compared with SSG drills, but the latter produced more ACC and DEC. Thus, implementing a mixed strategy of SSG and running-based drills could provide the best training stimulus for non-starters. The session that produced the greatest HSR (43%) and SPR (45%) distances relative to competition was MD-4. HSR and SPR distances are the metrics illustrating the most variability within the microcycle (>80%), which is consistent with the variability found in SSG formats (60–140%) (2) but lower than competition variability (20–30%) (14,16).

(Martín-García, Casamichana, <i>et al.</i> , 2018)	23 professional football players (Barcelona 2nd team) 37 official matches	HSR > 19.8 Sprint >25.2 km/h 1', 3', 5' and 10' MIP using TD, HMLD e AMP as the criterion variables	HSR: FB covered the greatest distance, reaching values of 47.2 ± 24.0 m/min in the 1' period. 1' MIP demand using TD as the criterion variable (positions' average): TD = 191.6 ± 19.7 , HSR = 38.3 ± 23.1 , Sprint = 10.6 ± 15.6 , ACC > $3\text{m/s}^2 = 2.8 \pm 1.6$, DEC < $-3\text{m/s}^2 = 3.5 \pm 1.6$ 1' MIP demand using HMLD as the criterion variable (positions' average): TD = 173.5 ± 26.0 , HSR = 49.9 ± 19.8, Sprint = 16.6 ± 17.4 , ACC > $3\text{m/s}^2 = 3.5 \pm 1.7$, DEC < $-3\text{m/s}^2 = 3.6 \pm 1.7$
(Soroka, 2018)	599 players who played in 2010 World Cup	HIR = 19.9 – 25.2 km/h Sprint > 25.2 km/h	The largest amount of HIR and Sprint distance was found in midfielders , which did not correspond to studies carried out on players of the Premier League and Primera Division in 2006-2007 (strikers covered the largest sprint distance) (Carling 2008).
(Vieira <i>et al.</i> , 2018)	40 Brazilian professional football players 59 official matches	HIA: ≥ 15 km/h (events) MSS (1 Hz GPS)	Individualized data analysis revealed that during national leagues the players presented reduced HIA when played congested than non-congested periods.
(Dalen <i>et al.</i> , 2019)	26 male football players from an elite Norwegian league team 18 games and 56 SSGs (28 4vs4 + 28 6vs6)	HIR >19.8 km/h Sprint >25.2 km/h	HIR (m/min) in match peak (5 mins most demanding period), match mean, 4v4 and 6v6 = 19 ± 3.5 , 8.3 ± 2.1 , 2.7 ± 0.9 , 3.7 ± 2.1 . Sprint = 8.8 ± 4 , 1.7 ± 0.7 , 0.1 ± 0.1 , 0.2 ± 0.5 . The smaller pitch used for SSGs may lead to a different work pattern from match play, which is supported by the relatively low HIR and sprint distances observed during SSGs in this study. 4 vs 4 games are a good method of training acceleration and player load tolerance, but SSGs do not represent a good method of training HIR .
(Clemente, Sarmiento, <i>et al.</i> , 2019)	23 professional football players (Portuguese Second League) 5v5+GK in 40x31m (124 m ²) 6v6+GK in 45x32m (120 m ²) 9v9+GK in 70x50m (194 m ²)	Running = 14 – 20 km/h Sprinting >20 km/h	Greater values for sprinting distance were found in the full match compared to 5vs5+GK (d = 3.673, strong effect), 6vs6+GK (d = 2.606, moderate effect) and 9vs9 +GK (d = 1.903, moderate effect) sided games. MSG are not appropriate for simulating the sprinting conditions of official full matches. LSG (9vs9+GK) simulate official full matches more accurately than the other sided-games that were studied (5vs5+GK and 6vs6+GK).
(Jones <i>et al.</i> , 2019)	37 professional male football players (English Football League One) 79 matches partitioned in 3 fixture congestion scenario	HID = 19.9 – 25.2 km/h Sprint > 25.2 km/h	The Linear Mixed Model did not identify significant interactions between position, fixture congestion scenario and time period (p = 0.549), position and fixture congestion scenario (p = 0.481), nor fixture congestion scenario and time period (p = 0.162).

(Casamichana <i>et al.</i> , 2019)	23 professional football players (Barcelona 2nd team) 37 official matches	TD, HMLD, AMP 1', 3', 5' and 10' MIP	The differences between the first and second half are trivial or unclear when short time windows are considered (e.g., 1 and 3 min), but they increase as the rolling duration increased, reaching the greatest difference between halves in the complete half (45 min).
(Clemente, Rabbani, <i>et al.</i> , 2019)	27 professional football players (Sporting Lisbona) 22 training weeks (with 3-4-5 training sessions + 1 game)	RD = 14.0 – 19.9 km/h HSR = 20.0 – 24.9 km/h Sprint > 25.0 km/h Training/Match ratio (TMr)	It was observed that specific variables (e.g., HSR distance and sprinting distance) were associated with substantially lower ratios than other variables. The TMr for RD and HSR distance were 1.2±0.7 and 1.1±0.8, respectively, in 3-days week and 2.3±1.3 and 2.3±1.5, respectively, in 5-days week. This suggests that the number of training sessions tend to emphasize the stimuli of overall distance and that the demand of three days of training is very similar to the demand of one match. Some determinant external load measures (e.g., HSR or sprinting) are clearly undertrained comparing with more prevalent measures (e.g., TD, ACC or DEC): SSG increase the frequency of ACC/DEC while decreasing opportunities to perform HSR or sprinting.
(Hills <i>et al.</i> , 2019)	17 Championship football players (Hull City Tigers) 13 matches (35 single observations)	MSR > 14.4 ≤ 19.8 km/h HSR > 19.8 ≤ 25.2 Sprint > 25.2	Relative TD (+13.4 m/min) and HSR (+0.4 m/min) distances covered during rewarm-ups increased with proximity to pitch-entry. Very few HSR and no sprint distance were performed during each warmup or rewarm-up bout. Substitutes covered greater TD (+67 to +93 m) and HSR (+14 to +33 m) distances during the first five min of match-play versus all subsequent epochs.
(Modric <i>et al.</i> , 2019)	101 professional football players from Croatian Soccer League (6 th of 10) 14 matches	RD = 14.4 – 19.7 km/h HSR = 19.8 – 25.1 km/h Sprint > 25.2 km/h InStat technical index	Math demand: HSR = 462 ± 160 m; Sprint = 156 ± 97 m. Association between the running performance of players involved in certain playing positions and overall game performance (InStat index). Specifically, it seems that CD distance in the running zone and number of high-intensity accelerations, FB number of decelerations, and FW sprinting distance are crucial physical requirements of team success.
(Oliveira <i>et al.</i> , 2019)	19 elite football players participating in UEFA Champions League. 39 weeks + 50 matches	HSD > 19 km/h Hooper Index	Although there are some significant differences between mesocycles, there was minor variation across the season for the internal and external TL variables used. MD-1 presented a reduction of external TL during in-season match-day-minus training comparison

(Asian-Clemente <i>et al.</i> , 2020)	17 U19 professional football players from an elite Spanish first division football club 4 SSGs (5c5c5+2) in 1 single 35x35m pitch or in 2 28.5x28.5m contiguous pitches	HSD = 18 – 21 km/h VHSD >21 km/h	VHSD (m/min): 2.5 ± 1.8 in 35x35m, 12.8 ± 6.3 using 2 contiguous 28.5x28.5 pitches, 4.6 ± 2.3 in official matches. When football is played in smaller relative areas than those used for official games, the ACC and DEC will be increased. Similarly, forcing players to change spaces quickly during SSGs promotes greater running activity, with higher HSD and VHSD covered per player. Although most of the running demands during matches were simulated with the proposed SSGs, it may be necessary to design other types of tasks to train for peak speed and distance covered at sprint speed.
(Kelly <i>et al.</i> , 2020)	26 English Premier League players (Manchester United) 1 season	HSD >14.4 km/h VHSD = 19.8 – 25.2 km/h	HSD was greater 3 days before a game (G-3) vs G-1 (95% CI, 140 to 336 m) while VHSD was greater on G-3 and G-2 than G-1 (95% CI range, 8 to 62 m; p < 0.001). HSD was similar between mesocycles during the whole season suggesting that training schedules employed in elite football may be highly repetitive likely reflecting the nature of the competition demands.
(Altmann <i>et al.</i> , 2021)	German Bundesliga male players (n = 25) Match observations (n = 163)	HID = 17.0 – 23.99 km·h⁻¹ Sprint ≥24.0 km·h⁻¹	CM showed both the largest total (11.66 ± 0.92 km, ES = 0.68–1.86) and HID (1.57 ± 0.83 km, ES = 0.08–0.84) compared to all other positions, WM demonstrated the largest sprinting distance (0.42 ± 0.14 km, ES = 0.34–2.39). Some professional football players will likely incur differences in the composition of physical match performance when switching positions and therefore should pay special consideration for such differences in the training and recovery process of these players.
(Oliva-Lozano, Fortes, <i>et al.</i> , 2022)	Spanish LaLiga male players (n = 277) Match observations (n = 1252)	Maximal Intensity Sprint: when an acceleration occurred from 14 km·h⁻¹ and the player got to exceed 30 km·h⁻¹ for 0.2 s.	Professional football players need to be prepared for maximal intensity sprints in the first period of the match as well as maximal intensity sprints under high fatigue conditions given the frequency of sprints in the last period of the match. Training drills should be designed with a special focus on non-linear sprints without possession of the ball, based on the main tactical purpose of each position (e.g., CD: interceptions; CM: recovery runs; FB, WM and FW: run the channel).

Table 4: High-speed running and injuries.

Study	Subjects	Metrics	Details
(Small <i>et al.</i> , 2009)	9 semi-professional football players	SAFT 90: sprint time every 15' of a 90' simulated game 3D kinematic data	Acute fatigue effect during game: significant time dependent increase was observed in sprint time during the SAFT 90 with a corresponding significant decrease in stride length. Analysis of the kinematic sprint data revealed significantly reduced combined maximal hip flexion and knee extension angle, indicating reduced hamstring length, between pre-exercise and halftime and pre-exercise and full-time. Exercise simulating the physiological and mechanical demands of football match play produced a time dependent alteration in sprinting kinematics/technique that may have implications for the increased predisposition to hamstring strain injury during the latter stages of football match-play.
(Duhig <i>et al.</i> , 2016)	51 professional Australian Football players 2 seasons	GPS data + sRPE	Higher than 'typical' HSR session means (i.e. Z-score >0) were associated with a greater likelihood of HIS. Trivial differences were observed between injured and uninjured groups for standardised s-RPE, TD, ACC and DEC. Exposing players to large and rapid increases in HSR distances above their 2-yearly session average increased the odds of HSI. However, reducing HSR in week -1 may offset HSI risk. It is not the absolute HSR distance the problem, but the large and rapid increases: this is why it is important to monitor changes in each player's HSR.
(Malone <i>et al.</i> , 2016)	37 elite Gaelic footballers 1 season 91 injuries	GPS data + sRPE	Players who produced over 95% maximal velocity on at least one occasion within training environments had lower risk of injury compared to the reference group of 85% maximal velocity on at least one occasion. Higher chronic sRPE-TL (≥ 4750 AU) allowed players to tolerate increased distances (between 90 to 120 m) and exposures to maximal velocity (between 10 to 15 exposures), with these exposures having a protective effect compared to lower exposures.
(van den Tillaar, Solheim and Bencke, 2017)	12 adult sports students	SM, ST and BFIh sEMG during 7 hamstring exercises + sprint	Maximal EMG activity of the different hamstring exercises was on average between 40-65% (ST), 18-40% (BFIh) and 40-75% (SM) compared with the max EMG activity in sprints, which were considered as 100%. Nordic hamstring exercises with its variation together with the laying kick activates the hamstrings at high levels and at angles similar to the joint angles at which peak hamstring activation occurs during sprinting (at least for the hip angle, but the knee joint angle was not specific to the angle at which highest activation occurred during the sprint).

(Colby <i>et al.</i> , 2018)	60 professional Australian Football players 3 seasons	GPS data + sRPE	Exposure to a very low sprint chronic load condition in the previous week was associated with a 3-fold increase in injury risk, identifying 50% of injuries in this cohort. Preventive strategies should ensure AF players attain >150 m of sprint volume per week (2 sessions exposed to >85% max velocity) to maintain a minimum workload for competitive demands.
(Jaspers <i>et al.</i> , 2018)	35 professional football players 2 seasons, 64 overuse injuries	GPS data + sRPE HSR > 20 km/h Cumulative 1-2-3-4 wks loads, ACWR 1:4 coupled	Likely harmful effects were observed for HSR: for a medium 1-weekly HSR (634-1028 m , OR: 1.56, 90% CI: 0.99–2.46), and for a high ACWR 1:4 coupled for HSR (>1.18 , OR: 1.71, 90% CI: 0.90–3.26). A high ACWR for HSR should be avoided. External load indicators may be more relevant to monitor than RPE multiplied by duration to minimize injury risk.
(Malone <i>et al.</i> , 2018)	37 professional football players (Benfica) 48 weeks	HSR >14.4 km/h Sprint > 19.8 km/h	When HSR and SR distances are considered independently of aerobic fitness and previous training load history, a U-shaped association exists for distance completed at these speeds and subsequent injury risk. Players with higher aerobic fitness were able to complete increased weekly HSR and SR distances with a reduced injury risk. Higher 21-day chronic sRPE-TL (≥ 2584 AU) allow exposure to greater volumes of HSR and SR, which in turn offers a protective effect against injury. 1-week safer zone: HSR = 700-750m, SR = 200-350m. Absolute weekly change safer zone: HSR < 100m, SR < 50m 3:21 acute:chronic workload ratio safer zone: HSR < 0.85, SR = 0.71-0.85
(Tokutake <i>et al.</i> , 2018)	61 male track and field athletes 1 season	Hip and knee strength, gluteus maximus and biceps femoris muscle thickness, hip and knee joint ROM, previous hamstring injury	Previously injured athletes had a significantly higher injury rate than uninjured athletes. Passive hip ROM (flexion and extension) tended to be larger in the injured than control group. The incidence of HSI was 2.88/1000. NO significant differences in the injury occurrence ratio among short sprinters (100 or 200 m: 8/18 [44.4%]), long sprinters (400 or 800 m: 5/10 [50.0%]), hurdlers (110 or 400 mH: 1/9 [11.1%]), long jumpers (long jump or triple jump: 3/15 [20.0%]), and decathletes (decathlon: 1/9 [11.1%]) ($p > 0.05$).

(Buckthorpe <i>et al.</i> , 2019)	Educational review from Southampton Football Club	Muscle architecture Running kinematics Core stability Cardiovascular fitness HSR loads	Rather than implement a single modal intervention, a holistic approach considering the complex interaction of multiple risk factors in HSI is encouraged, alongside a five-point strategy not wholly evidence based: (1) strengthen the hamstring muscles in the gym and sprinting, (2) optimise the training balance (ACWR) monitoring and ensuring optimal recovery, (3) implement a lumbopelvic hip stability program to control anterior pelvic tilt during terminal swing phase, (4) develop players' cardiovascular fitness to cope with the movement demands without adverse fatigue and its associated negative consequences, (5) incorporate a focus on movement quality.
(Hegyi <i>et al.</i> , 2019)	13 healthy recreational football and Gaelic football players	EMG activity and MTU lengths at slow (45% of Vmax), moderate (60%) and fast (75%) steady speed on treadmill	Peak BFIh and ST EMG amplitudes were observed in late swing (from maximum hip flexion angle to ipsilateral foot strike) at fast speed ($6.78 \pm 0.39 \text{ m} \cdot \text{s}^{-1}$) in all muscle regions (proximal, middle, distal): $115 \pm 13\%$ and $121 \pm 18\%$ MVIC. Speed-MTU length interactions were found in late stance (from maximum knee angle in stance to toe-off), maximum lengths only increased from slow to moderate speed, BFIh MTU was significantly longer than ST MTU across the entire stride at all speeds. Conclusions: large increases in hamstring EMG activity were accompanied by relatively small increases in maximum MTU lengths in the late swing and early stance phase, indicating higher hamstring stiffness at higher speeds.
(Kenneally-Dabrowski <i>et al.</i> , 2019)	Review	BFIh musculotendon mechanics and muscle excitation and how they relate to late swing/early stance HSR injuries	In professional football, 57%-72% of all hamstring injuries occurs during HSR, and in nearly all these injuries (up to 94%), the primary injury site is the BFIh musculotendon complex. The large eccentric contraction characterized by peak musculotendon strain and negative work during late swing phase is widely suggested to be potentially injurious. Direct evidence still lacks, but the majority of the literature suggests that the most likely timing of injury is the late swing phase.
(McGrath <i>et al.</i> , 2020)	33 elite rugby league players Retrospective cohort study with pre-season and in-season testing	Single-leg NHE peak force and 3D motion analysis BFIh fascicle length Dist >80% & >90% Vmax in the last 28 & 56 days	The most important contributor to variability in fascicle length is running volume (measured in meters) >80% PS (30%). The others contributors are: peak NHE force output (27%), elapsed time under load at long lengths (17%), peak running velocity (13%), previous injury (8%) and age (5%). Categories of contributors: velocity = 43%, strength-related variables = 44%, non-modifiable risk factors = 13%. Weakly mean D>80% = 77m, D>90% = 14m. These findings give practitioners the option to monitor alternative variables (instead of fascicle length itself) and be able to approximate (around 90%) of the impact it may have on fascicle adaptations in elite athletes.

(Whiteley <i>et al.</i> , 2020)	15 highest level professional football codes 22 injuries	5 games HSR prior and subsequent to HSI	On return to play, 7 of the 15 players showed a sustained absolute reduction in preinjury HSR distance, 7 showed no change, and 1 player showed an increase. Persisting deficits in match HSR may exist for many players after HSI.
---------------------------------	---	---	---

2.4 Discussion

2.4.1 Defining “absolute” thresholds: high, very high and sprint running distance

The primary finding of the systematic review regarding the definition of thresholds for high-speed running is the lack of consensus within the football literature. Additionally, the terminology used to describe the concept of high-speed running is not uniform; terms such as high-intensity distance, high-speed distance, and very high-speed running distance are used interchangeably to convey the same meaning. Therefore, the general situation is not encouraging, but it only serves to stimulate the need to precisely define each intensity of running, both for male and female football players. The initial attempt to address this issue involved graphically representing the distribution of these thresholds. Accordingly, Figure 10 illustrates the range of velocity thresholds reported in studies on professional adult female and male football players included in this review. Specifically, the entry velocities for high-speed running are typically set between $12.2 \text{ km}\cdot\text{h}^{-1}$ and $15.6 \text{ km}\cdot\text{h}^{-1}$ for females, and between $14.4 \text{ km}\cdot\text{h}^{-1}$ and $21.1 \text{ km}\cdot\text{h}^{-1}$ for males. The most common high-speed running entry velocity seems to be $12.5 \text{ km}\cdot\text{h}^{-1}$ and $19.8 \text{ km}\cdot\text{h}^{-1}$ for female and male, respectively. Similarly, the entry velocity for sprint distance is typically set between $17.8 \text{ km}\cdot\text{h}^{-1}$ and $22.5 \text{ km}\cdot\text{h}^{-1}$ for females, and between $19.8 \text{ km}\cdot\text{h}^{-1}$ and $30 \text{ km}\cdot\text{h}^{-1}$ for males. As with high-speed running, certain common entry velocities for sprint running can be identified, such as $22.5 \text{ km}\cdot\text{h}^{-1}$ for female players and $25.2 \text{ km}\cdot\text{h}^{-1}$ for male players. This clearly demonstrates the significant variability in velocity thresholds for the same external load metrics commonly used among football scientists and practitioners.

A review of the retrieved papers also revealed a few studies that employed three distinct thresholds to categorize different intensities of high-speed running in female football: high-speed running, very high-speed running (VHSR), and sprint running velocity (Park, Scott and Lovell, 2019; Scott, Norris and Lovell, 2020). This approach highlights the nuanced differentiation in running intensities, which can provide more precise insights into the physical demands placed on female football players. Specifically, Park et al. developed an approach based on logical validity and analysis rigor by using a spectral clustering technique with application of a $\beta = 0.1$ smoothing factor to compute the exact velocity thresholds for the analysis of external load data collected from international female football players. The authors were able to define velocity thresholds as follows: $\text{HSR} \geq 12.5 \text{ km}\cdot\text{h}^{-1}$, $\text{VHSR} \geq 19 \text{ km}\cdot\text{h}^{-1}$, $\text{sprint} \geq 22.5 \text{ km}\cdot\text{h}^{-1}$ (Park, Scott and Lovell, 2019).

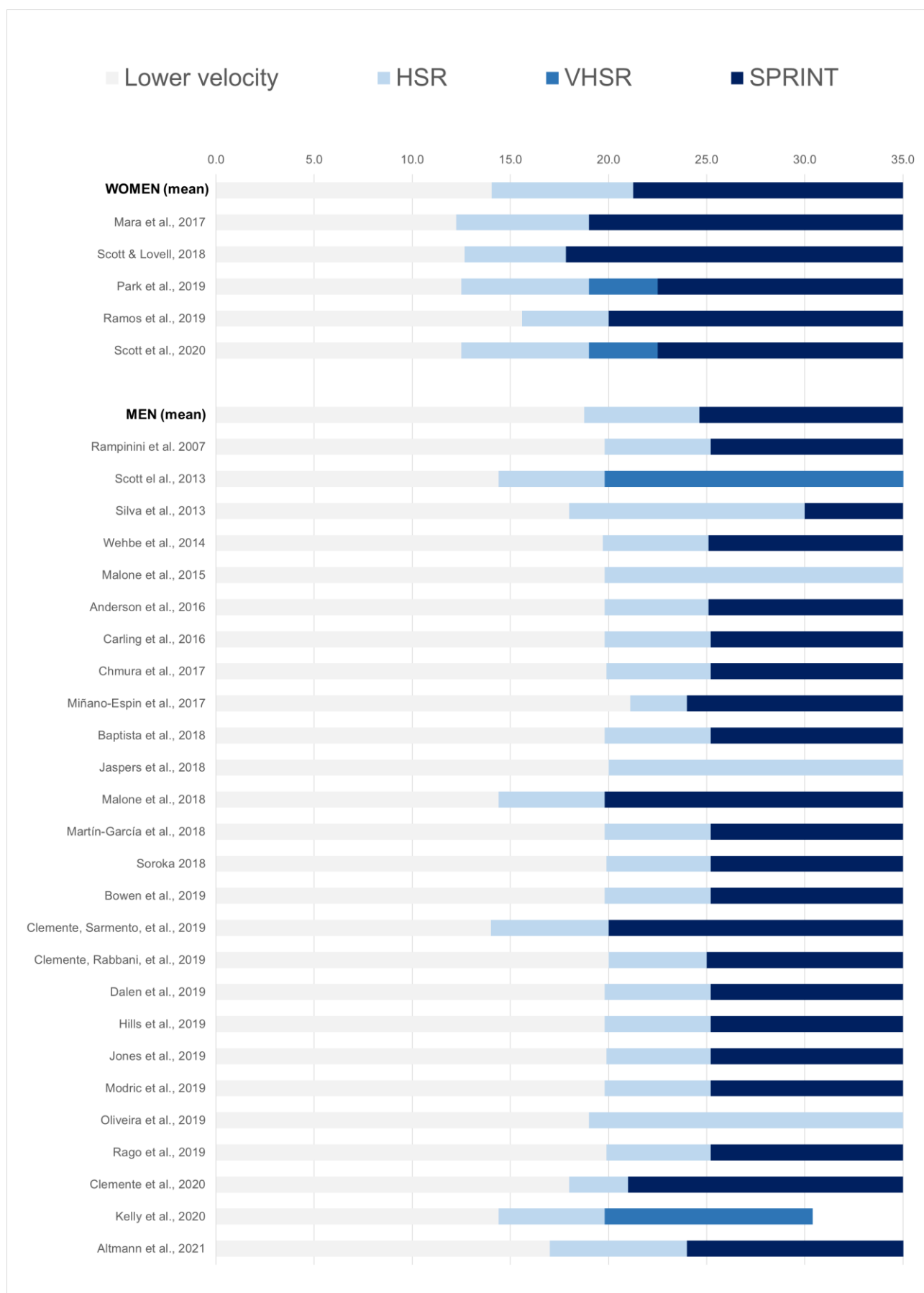


Figure 10: High-speed running (HSR), very high-speed running (VHSR) and sprint thresholds for elite adult female and male football players expressed in $\text{km}\cdot\text{h}^{-1}$.

Scott et al. reported the use of the same thresholds based upon the final outcomes of an intermittent test. They adopted the 30:15 intermittent fitness test (vIFT), that involves alternating 30-second shuttle runs with 15-second walking recovery periods. The test starts at $8 \text{ km}\cdot\text{h}^{-1}$, increasing by $0.5 \text{ km}\cdot\text{h}^{-1}$ every 30 seconds. Athletes run between two lines 40 meters apart, guided by audio beeps that shorten intervals as the test progresses, increasing intensity. Based on the peak velocity achieved by players during the 30-15 IFT, which corresponds to the last completed stage, the velocity thresholds were defined as follows: high-speed running (HSR) at $\geq 12.5 \text{ km}\cdot\text{h}^{-1}$ or 60% of vIFT (approximately 50% of peak velocity), very high-speed running (VHSR) at $\geq 19 \text{ km}\cdot\text{h}^{-1}$ or 80% of vIFT (approximately 65% of peak velocity), and sprinting at $\geq 22.5 \text{ km}\cdot\text{h}^{-1}$ or roughly 80% of peak velocity (Scott, Norris and Lovell, 2020).

The convergent findings from the studies by Park et al. and Scott et al. appear to support the robustness of the proposed velocity thresholds for adult female football players. However, it is important to note that a definitive conclusion cannot yet be drawn. Further research is needed to validate these thresholds comprehensively.

Similar to the approach reported above, data mining modelling was proposed to define standard definitions and thresholds for male players by other authors (Dwyer and Gabbett, 2012). The actual average distribution of velocities was calculated and series of Gaussian normal curves representing four velocity ranges was computed for best fit. The intersecting points for each Gaussian curve were used to determine the velocity range for each of the following locomotive activities: walking, jogging, running and sprinting. The entry velocity for sprinting was determined at $21.35 \text{ km}\cdot\text{h}^{-1}$. While the conceptual operationalization and the robustness of this approach appear rigorous, the threshold definition emerging from this study could be questioned due to the very low sample analysed (5 games of 5 players in a professional Australian A-League team), low sample frequency of the GPS units utilized (i.e., 1 Hz), and the lack of evidence suggesting that the velocities within each zone follow a Gaussian distribution (Dwyer and Gabbett, 2012). No other attempts to establish the rational for the use of “absolute” thresholds on male players were conducted using sufficiently rigorous methods.

Therefore, based on the current literature, although these approaches sound promising, the definitions of the thresholds for high-speed and sprint running are still arbitrary (Abt and Lovell, 2009; Cummins, Orr and Connor, 2013) with no consensus in the football literature (see Figure 10).

In addition to the lack of agreement on absolute thresholds to be used, practitioners have to consider that the physical performance level of football players continuously improves. For these reasons, it seems desirable for sports scientists to have the capacity to adjust the velocity thresholds and to reprocess the collected data, especially when comparing or sharing data with clubs and federations adopting different numerical references. This approach seems a viable and practical solution at least until consensus on the definition of standard velocity thresholds is achieved. The establishment of an international standard, adopted by practitioners and manufacturers, could significantly enhance data exchange between clubs and national teams, thereby increasing the value of velocity monitoring in football. Technology providers should continue to allow practitioners to set their absolute thresholds, which is essential for comparisons with historical data owned by the club. However, they should also begin to offer default international standardized thresholds to facilitate data sharing with other clubs or national teams. A practical starting point would be the adoption of FIFA's preferred velocity thresholds: 19 km·h⁻¹ and 20 km·h⁻¹ for high-speed running (female and male entry velocities, respectively), and 23 km·h⁻¹ and 25 km·h⁻¹ for sprint running.

Even if international standards are established, practitioners must remain aware of the limitations in accuracy and reliability between different tracking technologies, i.e. variations between EPTS brands. Therefore, caution is necessary when comparing data from different clubs that use different devices. This awareness is crucial to ensure the validity and reliability of the comparisons made (Thornton *et al.*, 2019).

2.4.2 Relative velocity thresholds

The use of individualized thresholds quantifying internal load measures like heart rate and maximum oxygen consumption can facilitate training prescription and monitoring by setting relative work intensities corresponding to individual physiological targets (Castagna *et al.*, 2013). For example, coaches and sport scientists can tailor the training plans based on well-defined physiological parameters such as VO_{2max}, maximum heart rate and onset of blood lactate accumulation (OBLA) (Helgerud *et al.*, 2001). Working with percentage values of maximal heart rate allows for more precise stimulus administration, as absolute values can vary significantly between individuals. For instance, a 25-year-old football player has a theoretical maximal heart rate of 195 bpm, calculated using the FOX's equation (220 minus age) (Fox, Naughton and Haskell, 1971). However, in practice, the maximal heart rate rarely

matches this theoretical value and must be measured using an incremental running test. Once the actual maximal heart rate is determined, individual thresholds can be set, enabling precise monitoring of metabolic intensities regardless of absolute values. This approach ensures that high-intensity sessions achieve significant time spent above 90% of maximal heart rate for all players, regardless of whether they have high or low maximal heart rates. Conversely, using only absolute thresholds can lead to undertraining in players with higher-than-theoretical maximal heart rates and overstimulation in those who do not reach the theoretical maximal heart rate.

What has just been described above could also be used for the evaluation of individual external load parameters such as running velocity. The rationale of implementing relative thresholds for velocity parameters is justified by the assumption that absolute thresholds fail to account for the players' individual physical capacities, and therefore, they could result in an inappropriate assessment of the players' external load performed during training (Gualtieri *et al.*, 2020) and matches (Abt and Lovell, 2009), especially for high-speed and sprint running. Practitioners should consider that players have specific physical characteristics that should be accounted for during the monitoring of training and matches, with peak velocity being one of those. Thus, the use of relative individual thresholds would allow for more precise programming of the training load, which could help to design the appropriate dose of high-speed running and sprinting distance, preventing the implementation of unattainable velocities that could potentially be injurious (Jastrzębski and Radzimiński, 2015), or not fast enough to elicit the desired adaptation (van den Tillaar, Solheim and Bencke, 2017; McGrath *et al.*, 2020).

Previous research has tried to individualize specific velocity thresholds based on physiological or performance parameters using some performance tests, which have been summarized in the following lines.

Individual high-speed running velocity has been defined as:

- the velocity corresponding to the maximal oxygen consumption (Maximal Aerobic Speed, MAS) both for women (Bradley and Vescovi, 2015) and men (Rago *et al.*, 2019), assessed through a gas analysis during an incremental ramp test or the final velocity reached during the Yo-Yo IRT1 (Krustrup *et al.*, 2003; Castagna *et al.*, 2006);
- the velocity corresponding to the Heart Rate Deflection Point (HRDP) determined from an incremental field test, the VAM-EVAL (a modified version of the Montreal Track test), in women (Scott and Lovell, 2018) or from an incremental field test in men (Jastrzębski and Radzimiński, 2015).

Individual sprint running velocity has been defined as:

- 80-85% of maximal velocity reached in a > 30 m sprint test by female players (Bradley and Vescovi, 2015);
- 80% of maximal velocity reached in a 40 m sprint test by male players (Jastrzębski and Radzimiński, 2015);
- >80%, >85% and >90% of the highest running speed measured during either top-speed training sessions or matches (Buchheit *et al.*, 2020).
- the velocity corresponding to the MAS determined from the VAM-EVAL test in female players (Scott and Lovell, 2018);
- $\geq 30\%$ of the Anaerobic Speed Reserve (ASR), calculated as the maximal sprint speed (MSS) – MAS in male players (Rago *et al.*, 2019).

For further details about VAM-EVAL, maximal sprint speed and anaerobic speed reserve definition, please refer to the article of Buchheit and Laursen (Buchheit and Laursen, 2013) and Sandford *et al.* (Sandford, Laursen and Buchheit, 2021).

Nevertheless, the validity criteria underpinning the determination of individual velocity thresholds using physiological parameters collected during continuous test protocols rather than external load proxies fail to consider the intermittent and repeated accelerative profile of football described in Chapter 1 (Schimpchen, Gopaladesikan and Meyer, 2021), and as such seems inappropriate or at least inaccurate.

In contrast with the physiological approaches reported above, another common method to define relative thresholds from measures of external load is the percentage of the individual peak velocity, measured as the maximal velocity attainable during an all-out effort (Kyprianou *et al.*, 2019). Following this rationale, the entry velocity for sprint running was established at 80-85% of the peak velocity achieved in a minimum 30-meter sprint test for female players (Bradley and Vescovi, 2015) and at 80% of peak velocity reached in a 40-meter sprint test in male players (Jastrzębski and Radzimiński, 2015). In another study, sprint threshold was set either at >80%, >85% or >90% of the highest running velocity measured during either training sessions or matches (Buchheit *et al.*, 2020). To date, the most reliable and simplest procedure to determine the peak velocity is through GNSS systems during a 40-meter sprint test (Bradley and Vescovi, 2015; Kyprianou *et al.*, 2019; Beato, Drust and Iacono, 2021). Alternatively, when dedicated all-out tests are not feasible, peak velocity can be tracked and determined from official matches (Massard, Eggers and Lovell, 2018). However, this approach has limitations, as players may not always reach their

maximal velocities during matches due to contextual constraints and specific positional demands (Kyprianou *et al.*, 2019; Beato, Drust and Iacono, 2021). Therefore, while useful, this method should be applied with caution, considering the peak speed recorded in at least three distinct matches and to supplement this data with other assessments whenever possible. In official matches some between-gender differences were observed for sprint velocities with $30.5 \pm 1.8 \text{ km}\cdot\text{h}^{-1}$ (mean of 5 different roles) (Scott, Norris and Lovell, 2020) and $32.0 \pm 1.0 \text{ km}\cdot\text{h}^{-1}$ (mean of 3 different roles) (Rampinini *et al.*, 2007) for female and male players, respectively. In consideration of the accuracy and reliability of tracking devices (Beato *et al.*, 2018) now easily affordable and widely available, it would be reasonable to conduct an all-out 40-meter sprint test at the beginning of a training session, following a standardized warm-up procedure. This approach is valid, ecologically sound, and time-efficient for determining each player's peak velocity. Consequently, individual velocity thresholds can be accurately defined based on the results of this test.

Although the number of studies supporting the concurrent validity of individualized thresholds is limited, there is still some evidence. Specifically, previous research has reported associations between internal load and high-speed running demands. Specifically, the perceptual responses collected using the RPE (Rating of Perceived Exertion) validated by Borg (widely described in Chapter 3) provided by football players in the Italian Serie B at the end of matches were found to be moderately correlated ($r = 0.53$ to 0.59) with the high-speed running distance covered. This distance was expressed using absolute velocity thresholds ranging from 14.4 to $19.8 \text{ km}\cdot\text{h}^{-1}$ and above $19.8 \text{ km}\cdot\text{h}^{-1}$. This correlation underscores the relationship between perceived exertion and the physical demands quantified by these velocity thresholds (Rago *et al.*, 2019). Notably, the strength of the correlations tended to increase, albeit not significantly, when individualized velocity thresholds were used ($r = 0.58$ to 0.67) (Rago *et al.*, 2019). Moreover, the distance covered by sprinting was moderately correlated to RPE only when individualized thresholds were applied ($r = 0.55$) (Rago *et al.*, 2019).

In contrast, the use of individualized velocity thresholds were not able to better quantify the dose-response of female football players during a 21-day training camp (Scott and Lovell, 2018). The study indicated that using players' peak sprinting velocity to quantify external load showed a lower capacity to determine the dose-response of training. This method consistently exhibited weaker associations with heart rate and RPE compared to other metrics (Scott and Lovell, 2018). In another study, high-speed running and sprinting thresholds customized for individual female players athletic qualities did not improve the

dose-response relationship between external load and wellness ratings (Scott, Norris and Lovell, 2020). In summary, the individualization of velocity parameters based on players' individual fitness level (i.e., MAS or peak velocity) only marginally improves (trivial or small magnitude of the change) relationships between external and internal training load parameters (Scott and Lovell, 2018; Rago *et al.*, 2019; Scott, Norris and Lovell, 2020). Based on the evidence presented thus far, it is clear that internal and external training load parameters are distinct constructs, regardless of whether absolute or relative thresholds are used. Therefore, practitioners should monitor both types of parameters, as one cannot be inferred from the other. This comprehensive approach ensures a more accurate assessment of the training load and its impact on athletes.

The current evidence does not permit definitive conclusions regarding the use of individualized velocity thresholds in football. From a practitioner's perspective, while individualized thresholds offer the advantage of more precise quantification of individual external load, they may hinder comparisons between players, training sessions, and matches, or over time when players' individual velocity thresholds change (Schober and Schwarte, 2018). This duality highlights the need for a balanced approach, considering both the benefits of individualized metrics and the practical challenges they present.

Thus, based on the present systematic review, either absolute or relative velocity thresholds seem appropriate to monitor high-speed running and sprinting exposure in professional football players. While absolute values are suitable to make between-player comparisons, relative thresholds are preferable for the individualization of the high-velocity aspects of the external training load. However, more research is needed on this topic before recommending the use of one over the other.

2.4.3 High-speed running and sprinting during official matches

One of the limitations stemming from the absence of an international standard for defining high-speed running and sprinting velocity thresholds is the challenge of aggregating data from different populations. Nevertheless, an attempt has been made to provide an overview of high-speed running in football. Table 5 summarizes the high-speed running and sprinting distance outcomes, along with the associated velocity thresholds, during matches among professional adult female and male football players. This summary aims to provide a comprehensive perspective despite the variability in definitions and measurements across the studies included in this systematic review. The following lines report the average values,

aggregating only the data recorded using overlapping thresholds. This approach helps to present a clearer and easier picture of high-speed running and sprinting distances during matches among professional adult female and male football players.

High-speed running ($> 15.6 \text{ km}\cdot\text{h}^{-1}$) and sprint ($> 20 \text{ km}\cdot\text{h}^{-1}$) demands in professional female football were around 1000 m (range: 911-1063 m, $10.1\text{-}11.8 \text{ m}\cdot\text{min}^{-1}$) and 270 m (range: 223-307 m, $2.5\text{-}3.4 \text{ m}\cdot\text{min}^{-1}$), respectively. In professional male football players, the analogous outcomes for HSR ($> 19.8 \text{ km}\cdot\text{h}^{-1}$) and sprint ($> 25.1 \text{ km}\cdot\text{h}^{-1}$) demands were around 760 m (range: 618-1001 m, $6.9\text{-}11.1 \text{ m}\cdot\text{min}^{-1}$) and 200 m (range: 153-295 m, $1.7\text{-}3.3 \text{ m}\cdot\text{min}^{-1}$). It is important to note the significantly different absolute values defining the two velocity thresholds. Specifically, the sprint thresholds for female players are comparable to the high-speed running thresholds for male players.

Table 5: High-speed running (HSR) and sprint match demands for elite adult female and male football players. Data are grouped by HSR zone to facilitate between-studies comparison. Bold values were considered for mean match demand calculation reported in the text.

Studies	Subjects		HSR		Sprint
Mara et al. 2017	Women – Elite Australian	$12.2\text{-}19 \text{ km}\cdot\text{h}^{-1}$	2452 m	$>19 \text{ km}\cdot\text{h}^{-1}$	615 m
Scott et al. 2020	Women – Elite USA	$\geq 12.5 \text{ km}\cdot\text{h}^{-1}$	2401 m	$\geq 22.5 \text{ km}\cdot\text{h}^{-1}$	122 m
Ramos et al. 2019	Women – Adult	$15.6\text{-}20 \text{ km}\cdot\text{h}^{-1}$	756 m	$>20 \text{ km}\cdot\text{h}^{-1}$	307 m
Ramos et al. 2019	Women – U20	$15.6\text{-}20 \text{ km}\cdot\text{h}^{-1}$	688 m	$>20 \text{ km}\cdot\text{h}^{-1}$	223 m
Anderson et al. 2016	Men – Premier League	$19.8\text{-}25.1 \text{ km}\cdot\text{h}^{-1}$	706 m	$>25.1 \text{ km}\cdot\text{h}^{-1}$	295 m
Modric et al. 2019	Men – Elite Croatian	$19.8\text{-}25.1 \text{ km}\cdot\text{h}^{-1}$	462 m	$>25.1 \text{ km}\cdot\text{h}^{-1}$	156 m
Carling et al. 2016	Men – League 1	$19.8\text{-}25.2 \text{ km}\cdot\text{h}^{-1}$	587 m	$>25.2 \text{ km}\cdot\text{h}^{-1}$	184 m
Kelly et al. 2020	Men – Premier League	$19.8\text{-}25.2 \text{ km}\cdot\text{h}^{-1}$	620 m	-	-
Miñano-Espin et al. 2017	Men – La Liga	$21.1\text{-}24.0 \text{ km}\cdot\text{h}^{-1}$	277 m	$>24 \text{ km}\cdot\text{h}^{-1}$	247 m
Wehbe et al. 2014	Men – Elite Australian	$>19.7 \text{ km}\cdot\text{h}^{-1}$	645 m	-	-
Baptista et al. 2018	Men – Elite Norwegian	$\geq 19.8 \text{ km}\cdot\text{h}^{-1}$	744 m		
Rampinini et al. 2007	Men – League 1	$>19.8 \text{ km}\cdot\text{h}^{-1}$	821 m	-	-
Stevens et al. 2017	Men – Eredivisie	$>19.8 \text{ km}\cdot\text{h}^{-1}$	738 m		
Dalen et al. 2019	Men – Elite Norwegian	$>19.8 \text{ km}\cdot\text{h}^{-1}$	747 m	$>25.2 \text{ km}\cdot\text{h}^{-1}$	153 m
Clemente et al. 2019	Men – Dutch and Spanish 2 nd Division	$>20 \text{ km}\cdot\text{h}^{-1}$	730 m		
Asian-Clemente et al. 2020	Men – U19 elite Spanish	$>21 \text{ km}\cdot\text{h}^{-1}$	414 m	-	-
Altmann et al. 2021	Men – Bundesliga	$17.0\text{-}23.99 \text{ km}\cdot\text{h}^{-1}$	1340 m	$\geq 24 \text{ km}\cdot\text{h}^{-1}$	495 m

Shifting the focus from "how much?" to "how" high-speed running is performed, it is observed that female football players execute a significant proportion of high-speed runs (12.24 - 19.0

km·h⁻¹) and sprints (>19.0 km·h⁻¹) over distances shorter than 10 meters. Specifically, 81 to 84% of high-speed runs and 71 to 78% of sprints fall within this distance range. The average recovery time between high-speed runs is 14 seconds, while the recovery time between sprints is 87 seconds, corresponding to work-to-rest ratios of 1:7 and 1:43, respectively (Mara *et al.*, 2017). Similarly, for professional male players, the most common distance covered in high-speed running (≥ 19.8 km·h⁻¹) is between 1 and 5 meters. An exception to this are full backs, who typically cover high-speed running distances averaging between 6 and 10 meters. This distinction highlights the positional differences in high-speed running demands within male football players (Baptista *et al.*, 2018).

Practitioners need to consider that the between-match variability for high-speed running (19.8-25.2 km·h⁻¹) and sprint (>25.2 km·h⁻¹) distance is notably high and is mainly affected by the positional playing role (Carling *et al.*, 2016; Altmann *et al.*, 2021). Higher variability has been reported for central players (midfielders and defenders) while lower variability for wide midfielders and attackers (Gregson *et al.*, 2010; Carling *et al.*, 2016; Trewin *et al.*, 2018). For example, the CV for female players ranged between 28% and 41% for high-speed running (>16.3 km·h⁻¹) and between 35% and 65% for sprint (>20.0 km·h⁻¹) distance (Trewin *et al.*, 2018). In male professional players, the CV for high-speed running and sprint distance ranges between 16% and 18% and between 31% and 37% respectively (Gregson *et al.*, 2010; Carling *et al.*, 2016). Moreover, the characteristics of high-speed running and sprints differ between positional roles and period of the match (Mara *et al.*, 2017). In the 2010 World Cup, the largest amount of high-speed running (19.9-25.2 km·h⁻¹) and sprint (>25.2 km·h⁻¹) distance was observed in midfielders (Soroka, 2018), which did not completely reflect the outcomes of previous studies conducted in the English Premier League and Spanish Primera Division in 2006-2007, where strikers were found to cover the largest sprint distances (Carling *et al.*, 2008). In addition, practitioners should consider that the main tactical purpose of each playing position influence how the player has to perform maximal intensity sprints: interceptions for central defenders, recovery runs, closing down and pressing for midfielders, running in the channel to receive or exploit space, break into the box, or run-in-behind for wide-midfielders and forwards (Oliva-Lozano, Fortes, *et al.*, 2022).

Another influential factor is the quality of the opponents. In fact, contextual analysis of the physical demands during matches indicates that high-speed running and sprinting are affected by the quality of the opposition, with higher values of high-speed running and sprinting reported during matches played against stronger opponents compared to weaker

ones (Rampinini *et al.*, 2007). This suggests that players tend to exert more effort and cover greater distances at higher intensities when facing more challenging competitions.

To further contextualize these findings, it is essential to interpret them in relation to the game's outcome. Notably, regardless of the opponents' skill level, football players appear to engage in significantly less high-intensity activity (21.1-24.0 km/h) when they are winning, compared to when they are losing or when the score is balanced (Miñano-Espin *et al.*, 2017). This phenomenon may primarily explain why no significant differences were observed in the distances covered by players of an elite team such as Real Madrid (which won approximately 70% of the total matches played during the examined period), regardless of the strength of the opposing team (Miñano-Espin *et al.*, 2017).

Another common scenario in professional football and worthy of consideration pertains to fixture congestion. This very common condition among elite teams is more deeply described in Chapter 1 and will be analysed in Chapter 4 and Chapter 5. From preliminary results, it seems that playing many consecutive games does not affect the amount of high-speed running (19.9-25.2 km·h⁻¹) covered during the consecutive matches (Jones *et al.*, 2019), although the flawed methodological approach to quantify high-speed running exposure across studies investigating this area precludes to make definitive conclusions (Julian, Page and Harper, 2021).

Relying solely on average match demands as a reference could lead to misguided strategies for physically preparing players during training. The concept of the most intense period of the match, introduced in Chapter 1, will be thoroughly examined in Chapter 6. For instance, during the 2014 World Cup, the mean high-speed running distance (19.9-25.2 km·h⁻¹) covered across all positions was $8.8 \pm 2.1\%$ of the total distance, with midfielders reaching the highest value of approximately 17% (Chmura *et al.*, 2017). Interestingly, focusing on the most intense periods of the game can provide valuable insights for training prescription. For instance, in Australian-league football, the mean high-speed running distance (defined as distance run at a velocity >14.3 km·h⁻¹) was 24.6 m·min⁻¹, while the peak high-speed running distance over 5-minute epochs was 47.4 m/min (Wehbe, Hartwig and Duncan, 2014). This indicates that the high-speed running distance was twice as much during the 5-minute epochs compared to the average value for the entire match. In discussing other findings, Norwegian players exhibited high-speed running (>19.8 km·h⁻¹) and sprinting (>25.2 km·h⁻¹) distances of 19 ± 3.5 m·min⁻¹ and 8.8 ± 4 m·min⁻¹, respectively, during the most demanding 5-minute epochs. In contrast, the match mean values reported in the same study were 8.3 ± 2.1 m·min⁻¹ for high-speed running and 1.7 ± 0.7 m·min⁻¹ for sprinting (Dalen *et al.*, 2019).

In the Spanish La Liga, analysing high-metabolic demands by using 1-min epochs revealed 49.9 ± 19.8 and 16.6 ± 17.4 m·min⁻¹ for high-speed running (>19.8 km·h⁻¹) and sprinting (>25.2 km·h⁻¹), respectively (Martín-García, Casamichana, *et al.*, 2018). In view of these reference values, it seems reasonable to consider higher benchmark values to not underestimate the real exercise intensity during matches or when planning the prescription of training drills aiming at exposing football players to high-speed running and sprint distances. However, practitioners should consider that the “most intense period” is a complex and composite construct reflecting an extreme internal response elicited via various combinations of physical and contextual factors. To note, these demands do not occur concurrently during the game and similarly for all metrics and players (Novak *et al.*, 2021), thus a more accurate analysis of “maximal intensity period” requires a case-by-case approach.

2.4.4 High-speed running and sprinting during training

High-speed running and sprinting distances exhibit the greatest variability across days during the weekly training microcycle, ranging between 60 and 120%. The variability is notably higher compared to that observed in official matches, which ranges between 20 and 30% (Martín-García, Gómez Díaz, *et al.*, 2018). This variability is likely a consequence of weekly planning that requires day-by-day load modulation, which can differ significantly between coaching staffs and is influenced by national football culture. Additionally, the inherently fluctuating and unpredictable nature of game-based drills, such as small- and large-sided games or ball possession exercises, which are prevalent in modern football, further contributes to this variability. Small- and large-sided games are actual matches played with goalkeepers, where the primary objective is to score goals. Conversely, ball possession games focus on maintaining control of the ball, with points typically awarded for completing a minimum number of passes without interruption by the opponent. Training variability may partially arise from the specific and differing positional demands that are intensified during game-based training drills. Therefore, it is advisable to implement game-based drills in conjunction with other training forms to mitigate the substantial variability in high-speed running and sprinting. Additionally, monitoring individual high-speed running and sprinting cumulative distances and frequencies is essential to ensure effective load management strategies, particularly to prevent detraining in players who are less or not physically taxed during games.

Knowledge of the match physical demand allows for the development of appropriate prescription of the training load as to adequately prepare individual players. Summaries from studies involving elite (Stevens et al., 2017; Baptista et al., 2019; Clemente, Rabbani, et al., 2019; Oliveira et al., 2019) and sub-elite professional players (Martín-García, Gómez Díaz, et al., 2018; Clemente, Owen, et al., 2019) revealed that the training-to-match ratios for total distance and accelerations tend to vary from approximately 1 to 4 arbitrary units (AU). This indicates that, within one week of training, players were exposed to 1 to 4 times the match load. However, the ratios for high-speed running and sprinting distance were relatively lower and clearly under-attained during the training week compared to other measures such as total distance and accelerations (see Table 6 and Table 7). For high-speed running the training to match ratio was reported to vary between 0.2 AU and 2.3 AU, while for sprinting the values ranged from 0.03 AU (i.e., none or trivial sprinting exposure during training) to 1.3 AU. Notably, these ratios represent average team values and exhibit considerable variability, at least among teams competing in Europe, while comparable data from non-European teams are still lacking. Given the substantial inter-individual variability observed for the same external load metrics, these ratios should be interpreted with caution and should not be regarded as definitive benchmarks.

Table 6: Training/Match ratio (T/M ratio) for high-speed running (HSR) in adult male football players. Only data referred to weeks within 4 or 5 training days + 1 match day are reported. Data are grouped by HSR zone to facilitate between-studies comparison.

Reference	Subjects	HSR weekly load			T/M ratio
		Thresholds	Training	Match	
Anderson et al. 2016	Men - Premier League	19.8-25.1 $km \cdot h^{-1}$	156	706	0.2
Kelly et al. 2020	Men - Premier League	19.8-25.2 $km \cdot h^{-1}$	987	620	1.6
Clemente, Rabbani et al. 2019	Men - Elite Portuguese	20-24.9 $km \cdot h^{-1}$	-	-	2.3
Stevens et al. 2017	Men - Eredivisie	>19.8 $km \cdot h^{-1}$	811	738	1.1
Martin Garcia et al. 2018	Men - La Liga - Reserve	>19.8 $km \cdot h^{-1}$	726	440	1.7
Baptista et al. 2018	Men - Elite Norwegian	$\geq 19.8 km \cdot h^{-1}$	460	744	0.6
Clemente, Owen et al. 2019	Men - Dutch and Spanish 2nd Division	>20 $km \cdot h^{-1}$	1342	730	1.8

Table 7: Training/Match ratio (T/M ratio) for sprint in adult male football players. Only data referred to weeks within 4 or 5 training days + 1 match day are reported. Data are grouped by HSR zone to facilitate between-studies comparison.

Reference	Subjects	Sprint weekly load			
		Thresholds	Training	Match	T/M ratio
Anderson et al. 2016	Men - Premier League	$>25.1 \text{ km}\cdot\text{h}^{-1}$	8	295	0.03
Kelly et al. 2020	Men - Premier League				
Clemente, Rabbani et al. 2019	Men - Elite Portuguese				
Stevens et al. 2017	Men - Eredivisie				
Martin Garcia et al. 2018	Men - La Liga - Reserve	$>25.2 \text{ km}\cdot\text{h}^{-1}$	131	100	1.3
Baptista et al. 2018	Men - Elite Norwegian	$\geq 25.2 \text{ km}\cdot\text{h}^{-1}$	69	144	0.5
Clemente, Owen et al. 2019	Men - Dutch and Spanish 2nd Division				

In light of current evidence, particular attention should be directed towards non-starting players. Recent studies conducted in the Italian Serie A and the English Premier League have revealed that non-starting players are exposed to significantly lower high-speed running and sprinting distances compared to starting players (Anderson, Orme, Di Michele, Close, Milsom, *et al.*, 2016; Gualtieri *et al.*, 2020). Accordingly, it seems reasonable that dedicated compensatory drills targeting high-speed running and sprinting should be implemented during training to compensate for the lack of match-related high-speed running and sprint running exposure and to avoid detraining. To design specific sprint training drills, it is crucial to consider playing positions and contextual variables. For instance, as reported in the previous paragraph, defenders typically sprint to intercept the ball, midfielders run to close down and press opponents, and attackers sprint through channels to exploit space and break into the box (Oliva-Lozano, Fortes, *et al.*, 2022).

When football players train on smaller relative areas compared to those used in official matches, the number of accelerations and decelerations increases, but achieving adequate volumes of high-speed running becomes challenging (Dello Iacono *et al.*, 2022). For example, official matches are played on a 105 x 68 m pitch (i.e., 324 m² per player), allowing for a high-speed running distance of 8.4 m·min⁻¹ and a sprinting distance of 2.2 m·min⁻¹. In contrast, during a 4v4 small-sided game on a 39 x 39 m pitch (i.e., 190 m² per player), the high-speed running distance is 2.7 ± 0.9 m·min⁻¹ and the sprinting distance is 0.1 ± 0.1 m·min⁻¹. Similarly, during medium-sided games (6v6) on a 47 x 43 m pitch (i.e., 168 m² per player), the high-speed running distance is 3.7 ± 2.1 m·min⁻¹ and the sprinting distance is 0.2 ± 0.5 m·min⁻¹ (Dalen *et al.*, 2019). Instead, sided-games designed as large formats and

with relative areas per player greater than 225 m² and 300 m² seem adequate to induce high-speed running and sprint distances, respectively, comparable to the analogous match external load outcomes (Riboli *et al.*, 2020). However, it is worth noting that the uncontrolled and unpredictable nature of game-based approaches may still cause large variability across players with the risk of overexposure to some and underexposing to others.

An alternative or complementary training method to sided-games to induce high-speed running and sprinting exposure are running-based drills with linear and non-linear sprints. Again, starting from the performance model defined by the game, strength and conditioning coaches should consider that the mean sprint (>30 km·h⁻¹) duration recorded in LaLiga players ranged from 5 to 9 seconds, with a mean distance covered ranging from 30 to 55 m (Oliva-Lozano, Fortes, *et al.*, 2022). Mixing linear sprints and sided-games, Ade and colleagues implemented repeated runs lasting 15 s and performed by young under 19 football players immediately before and after a sided-games bouts to ensure adequate coverage of distances above 19.8 km·h⁻¹ (Ade, Harley and Bradley, 2014; Köklü *et al.*, 2020). In another study conducted on under 19 elite male players, asking players to change zone of the pitch quickly during small sided-games promoted higher high-speed running covered per minute. These authors compared a ball possession drill played in a single pitch (35 x 35 m pitch) to a drill with two contiguous pitches (28.5 x 28.5 m each), and they found that high-speed running was 2.5 ± 1.8 m·min⁻¹ in the single pitch (i.e., 72 m² per player) and 12.8 ± 6.3 m·min⁻¹ using two contiguous pitches, while during official matches was 4.6 ± 2.3 m·min⁻¹ (Asian-Clemente *et al.*, 2020).

Another option to perform high-speed running and sprinting distance is to use isolated running-based drills or adding running phases during sided-games. In this case, high-speed running and sprint running exposure can be accurately prescribed and controlled with a lower degree of uncertainty given that the running intensity is predetermined, fixed, and easily monitored.

More recently, a game profile-based training (GPBT) approach has been proposed to induce relative high-speed running and sprint running distances comparable or greater than matches outcomes in under 19 elite male football players (Dello Iacono, Beato and Unnithan, 2021). A GPBT could be defined as one or more bouts of physical and technical activities (e.g., high-intensity intermittent running, changes of direction, and passes), which replicate the type of movements and physical demands (e.g., internal and external loads) of match-play (Dello Iacono *et al.*, 2021). It was reported that a GPBT was more demanding in terms of distance run above 19 and 25.2 km·h⁻¹ compared with a 5v5 small sided-game in a

42 x 30 m pitch (i.e., 126 m² per player), specifically, 10.2 m·min⁻¹ during GPBT vs 4.6 m·min⁻¹ during small sided-game for high-speed running and 4.2 vs 2.0 m·min⁻¹ for sprinting (Dello Iacono, Beato and Unnithan, 2021). Moreover, beneficial chronic effects on linear sprinting capabilities over 10 m and 20 m were found following a 8-week training period including GPBT, with greater improvements compared to sided-games training in the form of 5-a-side formats. While generalizing such findings to other cohorts warrants caution, the nature of the GPBT drills as fixed running circuits entailing intermittent phases of walking, jogging, running and sprinting may presume that similar outputs can be expected among adult female or male football players as well.

Another aspect to be considered when preparing players for high-speed running and sprint running game demand is sprinting in fatigue condition, since maximal intensity sprints were reported to be more frequent in the first, but also in the last, 15 minutes of the match, regardless of the playing position (Oliva-Lozano, Fortes, *et al.*, 2022). Training high-speed running and sprint running at the end of the training session should therefore be taken into consideration even if a higher risk of musculoskeletal injury is conceivable.

In summary, practitioners are recommended to use a combination of adapted sided-games, GPBT, and running-based drills to ensure adequate high-speed running and sprint running exposure to their players during training. High-speed running and sprinting exposition are particularly important for non-starting players that need to compensate for missing the speed load exposition of the match, which often demands near-to-maximal velocity efforts (Anderson, Orme, Di Michele, Close, Milsom, *et al.*, 2016; Gualtieri *et al.*, 2020).

2.4.5 High-speed running and injuries

High-speed running is usually incorporated into training sessions to acclimate players to the demands of such exertion during matches. This practice not only facilitates achieving victory by overcoming opponents but also mitigates the risk of injury associated with a lack of habituation to high-speed running and repeated sprints during the game. In professional football, in fact, 57% and 72% of all hamstring injuries occurs respectively during running (Woods *et al.*, 2004) and sprinting (Askling, Tengvar and Thorstensson, 2013). The volume of match sprinting activity is considered a risk factor of muscle injury occurrence especially in the minute preceding the injury (Gregson *et al.*, 2020). Nearly all these injuries (up to 94%) interest as the primary injury site the posterior muscles of the thigh, more precisely the biceps femoris long head musculotendon complex (Mueller-Wohlfahrt *et al.*, 2013).

To elucidate why the musculotendinous complex is particularly susceptible to this type of injury, it is essential to introduce the gait cycle and its phases. Without delving too deeply into the subject, the sprinting gait cycle can be divided into four main phases: early stance, late stance, early swing, and late swing. During the early stance phase, the foot maintains contact with the ground and begins to pull back until the late stance phase, when the foot completes its pushing action. Once the foot loses contact with the ground, the flight phase commences, encompassing the early swing phase to the late swing phase, which is the final moment before the foot reestablishes contact with the ground, marking the beginning of the early stance phase once again. The hamstrings are biarticular muscles that lengthen over two joints simultaneously during the latter part of the swing phase of the gait cycle (Stolen *et al.*, 2005). Strains are most likely to occur at this point as the muscles work eccentrically to decelerate the limb and control knee extension (Woods *et al.*, 2004; Kenneally-Dabrowski *et al.*, 2019). Alternatively, injuries may occur during the latter part of the stance phase when the muscle shortens forcefully to extend the hip during take-off, potentially leading to a concentric contraction injury (Small *et al.*, 2009).

Also, the acute fatigue seems to play a role in the hamstring injury occurrence. Exercise simulating the physiological and mechanical demands of football match play produced a time dependent alteration in sprinting kinematics and technique that may have implications for the increased predisposition to hamstring strain injury during the latter stages of football match-play (Small *et al.*, 2009), especially during the last 15 minutes (Gregson *et al.*, 2020). For these reasons, as previously suggested, it may be beneficial to implement training strategies aimed at enhancing fatigue tolerance. This approach could mitigate the effects of

two potential key contributors to hamstring strain injuries: overstriding and abnormal pelvic motion. Consequently, this would provide an indirect benefit in injury prevention (Freeman *et al.*, 2021; Wolski *et al.*, 2021).

The third factor contributing to hamstring strain injuries, in addition to the aforementioned biomechanical reasons and the effects of fatigue, is the overall load produced by the player. In elite Portuguese players (1 season with 37 subjects' study), when high-speed running and sprinting distances were considered independently of aerobic fitness and previous training load history, a U-shaped association was reported for distance completed at these speeds and subsequent injury risk (Malone *et al.*, 2018). In that study, players with higher aerobic fitness were able to complete increased weekly high-speed running and sprinting distances, which in turn offered a protective effect against injury: 1-week (match included) safer zone was reported both for high-speed running (700-750m) and sprint running distance (200-350m) (Malone *et al.*, 2018). Particular attention should be paid to the interpretation of these data since there is large variability between Clubs: each team and each player should look for its "sweet spot".

Similarly, Jaspers *et al.* (Jaspers *et al.*, 2018) observed in 35 professional players over 2 seasons likely harmful effects for a medium 1-weekly high-speed running (634-1028 m, OR: 1.56, 90% CI: 0.99–2.46) and for elevated high-speed running variations. The variations can be calculated using the acute-chronic workload ratio (ACWR), which is simply the ratio between the workload of the most recent week and the weekly mean of the previous weeks (Hulin *et al.*, 2014). The harmful variation identified by Jaspers in 2018 was a 18% increase of high-speed running, that using a 1:4 (weeks) ACWR means a value higher than 1.18 (OR: 1.71, 90% CI: 0.90–3.26). These data support the theory that large and too fast increase of high-speed running should be avoided, considering safer an absolute weekly change < 100m for high-speed running, and < 50m for sprinting or a 3:21 (days) ACWR < 0.85 and between 0.71-0.85 for high-speed running and sprinting respectively (Malone *et al.*, 2018). Also for English Premier League football players (33 players in 3 seasons) an 1:4 ACWR > 2 was associated with 5-7 times the risk of a soft tissue injury than players whose ACWR was lower (Bowen *et al.*, 2019). On the other hand, a 10 weeks study on 15 professional football players reported that spikes in the 1:4 ACWR were not related to a subsequent injury occurrence (Suarez-Arrones *et al.*, 2020). These controversial data remember that care should be taken when applying the findings beyond the studied population and more studies are needed. Moreover, the ACWR construct and most useful ratio are been discussing worldwide and no definitive agreement has been published (Kalkhoven *et al.*, 2021): to date,

the most advisable approach in defining the ratio is adopting an acute and chronic duration reflecting the club typical micro- and meso-cycle, respectively.

2.5 Conclusions on the available literature

The main findings of this systematic literature review are reported below.

1. Non-standard and a wide range of thresholds are employed to monitor high-speed running and sprinting demands among professional football players.
2. Absolute and relative thresholds could be used to analyse or compare performances across players and to monitor training at the individual near-to-maximum velocities, respectively.
3. High-speed running and sprint distances are position-dependent as well as highly variable across the phases of the game.
4. The combination of contextualized game-based and running-based drills should be used to ensure adequate high-speed running and sprinting exposure during training.
5. High-speed running and sprinting distances can be a concurrent cause of muscle injuries (e.g., hamstrings), but if correctly implemented in training such exposition to high-speed can play a protective role, however, further research is needed to clarify the right training dose to implement.

Since there is no consensus on a specific absolute threshold defining high-speed running and sprint in adult female and male football players, and currently an international standard for such velocity thresholds does not exist, practitioners could set as entry velocity for high-speed running and sprinting values included in the range suggested from this review. A second option for practitioners is to use the velocity thresholds adopted by FIFA and UEFA such as $19 \text{ km}\cdot\text{h}^{-1}$ and $23 \text{ km}\cdot\text{h}^{-1}$ for female and $20 \text{ km}\cdot\text{h}^{-1}$ and $25 \text{ km}\cdot\text{h}^{-1}$ for male.

Beyond absolute velocity thresholds, relative thresholds should be considered for specific training sessions where the goal is to reach near to maximal velocity exposure accounting for players' individual physical velocity capacity.

When analysing match demand, practitioners should consider that high-speed running and sprint distances are position dependent as well as highly variable across the phases of the game and between the games: using high-speed running and sprint distance as performance indicators could introduce bias if not contextualized. In any case, players have to be ready for high-speed running and sprinting. To train the high-speed running and

sprinting game demand, practitioners could use a combination of adapted sided-games, game profile-based training, and running-based drills to ensure adequate high-speed running and sprint running exposure to their players during training. Finally, monitoring high-speed running and sprint distances during every single session can allow the practitioner to verify the validity of the training process and optimize physical development, which is necessary to carry out the most demanding phases of the game requiring velocities close to the maximum (e.g., during high-speed counterattack), and, on the other hand, to minimize the injury risk.

Considering the available literature, one limiting factor, especially for research and data sharing between different Clubs and national teams, is the currently lack of a standard defining high-speed and sprint running thresholds in football: that would facilitate multicentric studies involving same level Clubs useful to reach more spreadable and robust conclusions. Lastly, considering that the training information (related to high-speed running and sprint demands) available comes from studies that have mainly enrolled youth players instead of senior players (i.e., first-team players), it is not possible to fully generalize the main findings to adult professional cohorts.

To address these limitations, I designed three original studies focusing on the monitoring of high-speed running and sprint demands during training and matches among adult male professional players. In the following chapters, I aim to fill some of the gaps identified above. In Chapter 4, I analyse the different workloads that starting and non-starting players are exposed to during congested fixture periods. These results inform the approach of Chapter 5, where I describe the shortest microcycles encountered by a top-level football team throughout the majority of the season, considering day-to-day variations. Finally, in Chapter 6, I compare the mean values described in Chapter 5 to the most demanding passages of a match, providing practitioners with an additional benchmark for training sessions or exercises. Each chapter is directly linked to the others, creating a zoom-in process that starts from mesocycle loads and narrows down to a few seconds of a match. This structured approach ensures a comprehensive understanding of the training and match demands in terms of high-speed running. To summarize:

- Chapter 4 aims to assess the internal and external workload of professional Serie A starting and non-starting players during in-season congested fixture periods.
- Chapter 5 aims, firstly, to quantify training and match day (MD) load during three-, four- and five-day microcycles in Italian professional adult football. Secondly, it seeks to compare the effect of microcycle length on the training load during the days before

(MD-1) and after (MD+1) the match, as well as the MD load in the different microcycles.

- Chapter 6 aims, firstly, to quantify and model the game-speed demands of elite football players competing in the Italian Serie A using time windows from 5 seconds to 10 minutes. Secondly, it aims to compare the effect of match location on game-speed outputs, and lastly to examine the effect of playing position on game-speed outputs.

Chapter 3: General methods

3.1 Perceived exertion: the session RPE method

In Chapter 4 and Chapter 5, the perceived exertion of elite adult football players during congested fixture periods have been analysed and reported. At the end of every single training session and match I personally collected their perception using the scale described here below. All the data were manually inserted into a custom-made athlete management system developed by the Club and integrated with the training or match exposure as described below. For the analysis of the data reported in Chapter 4 and 5 the data were exported from the custom-made software and loaded in a dedicated Microsoft Excel-based database.

3.1.1 Psychometric scales to monitor perceived exertion

The Rating of Perceived Exertion (RPE) scale, developed by Gunnar Borg in the 1960s (Borg and Dahlstrom, 1962), is a seminal tool in exercise physiology and monitoring. This scale employs numerical values and verbal descriptors to quantify exercise intensity linearly, correlating with the primary internal load markers of exercise, namely oxygen consumption and heart rate (Borg, 1982). The original scale ranges from 6 (no effort) to 20 (maximal effort), which corresponds to a heart rate range of 60 to 200 beats per minute in a healthy 30-year-old individual. This categorical scale facilitates the comparison of perceived exertion across different individuals. However, it is limited by a "ceiling" effect, as it cannot exceed the maximum value of 20.

3.1.2 CR-10 scale

To overcome the limit of the ceiling effect, the Category Ratio Scale (CR10®) was designed, providing a ratio scale with intensity levels anchored to specific verbal expressions (Borg and Borg, 2001). As displayed in Figure 11 and Figure 12, this scale ranges from 0 (*no effort*) to 10 (*very very hard effort, maximum*), with 10 representing the highest level of perceived exertion ever experienced by an individual, while allowing for values beyond 10 when the effort perceived exceeds the maximal effort ever experienced.

In other words, players accustomed to playing 70-minute matches, the duration of official games for under-15 teams, may perceive the effort required during their first 90-minute games in a higher category as greater than any effort they have previously experienced. In this scenario, the players might report an effort exceeding 10, using values such as 10.5 (slightly higher than the previous maximum effort) or 12 (significantly higher than the previous maximum effort). From that day forward, the match rated with a 12 RPE becomes the new maximum effort benchmark, which is then ranked as 10 on the scale. The CR10® integrates the benefits of both categorical and ratio scales, offering enhanced precision and inter-individual comparability. For these reasons, it is extensively utilized to measure the intensity of exertion in both endurance and team sports. To properly use this scale is important to follow some instructions:

- The perception of effort for the entire training session should be given at the end of the session.
- Before using the scale, one should consider the two extreme situations associated with 0 and 10, respectively. The value 0 corresponds to rest, while 10 corresponds to the highest effort ever experienced.
- The numerical value of effort should be assigned after selecting the adjective. For example, if the effort is 'Moderate,' the value assigned is 3. Intermediate values can be attributed, such as 6.5.
- The highest value on the scale is 10. However, it is possible to assign higher values (11) or even greater.
- It is important that the athletes report the sensation they are actually experiencing and not the expected sensation by either the athlete or the coach. The athlete must be as honest as possible and not overestimate or underestimate the sensation of effort.

CR10 Percezione dello sforzo

0 NESSUNO SFORZO

0.3

0.5 ESTREMAMENTE LEGGERO

1 MOLTO LEGGERO

1.5

2 LEGGERO

2.5

3 MODERATO

4

5 SFORZO FORTE, PESANTE

6

7 MOLTO FORTE, MOLTO PESANTE

8

9

10 FORTISSIMO, PESANTISSIMO

11

• MASSIMO ASSOLUTO

Figure 11: CR10® RPE scales: Italian version

CR10 Perception of Effort

0 NOTHING AT ALL

0.3

0.5 VERY VERY LIGHT

1 VERY LIGHT

1.5

2 FAIRLY LIGHT

2.5

3 MODERATE

4

5 HARD

6

7 VERY HARD

8

9

10 VERY VERY HARD (MAXIMUM)

11

● ABSOLUTE MAXIMUM

Figure 12: CR10® RPE scales: English version

3.1.3 Session-RPE method

In 1995 Carl Foster introduced the session-RPE (sRPE) method to calculate the overall training load of endurance athletes by multiplying the duration of the training session by the perceived intensity (Foster *et al.*, 1995). Subsequently, it was also suggested for team sports such as basketball (Foster *et al.*, 2001) and football (Impellizzeri *et al.*, 2004; Coutts *et al.*, 2009). This approach enables practitioners to obtain a synthetic index that considers both the volume and intensity of the session. However, like any other index, it has the limitation that the same value can be achieved with completely different values of the two factors. Therefore, it is recommended to report the sRPE training load along with at least the session duration, to facilitate easier contextualization and interpretation of the data.

3.1.4 Validity of the method

The construct validity in football has been examined in previous studies comparing the session-RPE method with different heart rate-derived methods previously validated to quantify training load. In fact, heart rate is considered a valid indicator of exercise intensity, also in football (Esposito *et al.*, 2004). Specifically, the correlation between the method known as session-RPE and the workload measured using an heart rate-derived method [Training Impulse by Banister (Banister, Carter and Zarkadas, 1999)] was assessed (Impellizzeri *et al.*, 2004). A significant and substantial relationship between the two methods was found, with all individual correlations ranging from $r = 0.50$ to $r = 0.85$ ($p < 0.01$). In a subsequent study, a correlation was also found with the lactate accumulated during training sessions including small sided football games (Coutts *et al.*, 2009). More recently, a very large correlation was found between sRPE and training impulse – TRIMP – ($r = 0.78$; 95% confidence interval: [0.74-0.82]) also in female football players (Costa *et al.*, 2022).

Adherence to the original instructions provided by the developers is crucial to maintain the validity of these scales. Common errors include modifying the scales, incorporating additional figures or symbols, and using unvalidated translations. The original English and Italian versions of the scales were used for the original studies reported in Chapter 4 and Chapter 5. Both versions are reported in Figure 11 and Figure 12. All the players were informed on the importance of providing accurate data to prevent issues related to overtraining or undertraining and a refresh on how to use the scale properly was set up every 6 months.

3.1.5 Application in the original studies

Once the data were collected from the players, all the information were organized into an Excel-based database designed for our studies, replicating the aforementioned calculations. As illustrated in Figure 13, the minutes of training or game time and the perceived exertion for each player were recorded. Additionally, the team average for each session was calculated. When starting and non-starting players followed different training programs, two separate lines to represent the team averages were utilized.

Name	Date	Exposure (min)	RPE (AU)	sRPE-TL (AU)
Player 1	01/01/2020	57	3	171
Player 2	01/01/2020	40	3.5	140
Player 3	01/01/2020	40	4	160
Player 4	01/01/2020	40	2.5	100
...	...	...	...	...
Team average	01/01/2020	53.9	3.3	175

Figure 13: Part of the database organized to record the sRPE-TL data.

3.2 EPTS: Electronic Performance Tracking Technologies

In Chapters 4, 5, and 6, the external load experienced by elite adult football players during congested fixture periods was analysed and reported. Both Global Navigation Satellite Systems (GNSS) and video tracking systems were employed to monitor training sessions and matches, respectively.

3.2.1 Technology evolution

The advances in wearable micro-technologies – such as Global Navigation Satellite Systems (GNSS) and accelerometers – and video tracking systems has enabled an ever more precise quantification of football training and match loads, in particular those high intensity activities like high-speed running that require highly accurate and precise instruments not available ten years ago.

In the past, low velocity thresholds (i.e., $14.4 \text{ km}\cdot\text{h}^{-1}$ – $15 \text{ km}\cdot\text{h}^{-1}$) were selected to define high-speed running and sprinting. That was due to the low reliability of wearable micro-technologies such as GNSS and video tracking systems devices available at those times, usually sampling at frequencies lower than 5 Hz, (Johnston *et al.*, 2012, 2014; Scott, Scott and Kelly, 2016), that means recording velocity 5 times in a second, in other words every 0.2 seconds. The advances in these tracking systems have enabled a more accurate quantification of football matches and training loads for activities performed at higher velocity (Beato and Jamil, 2018; Beato *et al.*, 2018). At present, the available GNSS technology is deemed valid for measuring distances covered at high-speed running and peak velocity in sports (Beato, Devereux and Stiff, 2018) as well as reliable with excellent inter-unit reliability reported for linear sprint distances (coefficient of variation [CV] = from 1.64% to 2.91%) (Beato and de Keijzer, 2019) and sport specific circuits (Beato *et al.*, 2018). Consequently, tracking technologies are now more commonly used for monitoring high-speed running and sprinting distances during training and competitions in football (Beato, Drust and Iacono, 2021).

3.2.2 Validity of tracking technologies

Nowadays GNSS have excellent validity. Both accuracy and reliability have been tested by FIFA during their electronic performance tracking systems (EPTS) analysis program, with good results at any speed band, high-speed running and sprinting included (Figure 14). Mean speed root mean square difference (RMSD) is nowadays between 0.2 and $0.5 \text{ m}\cdot\text{s}^{-1}$. Similarly, video tracking system demonstrated high accuracy, with mean speed RMSD between 0.2 and $0.4 \text{ m}\cdot\text{s}^{-1}$ (Figure 15).

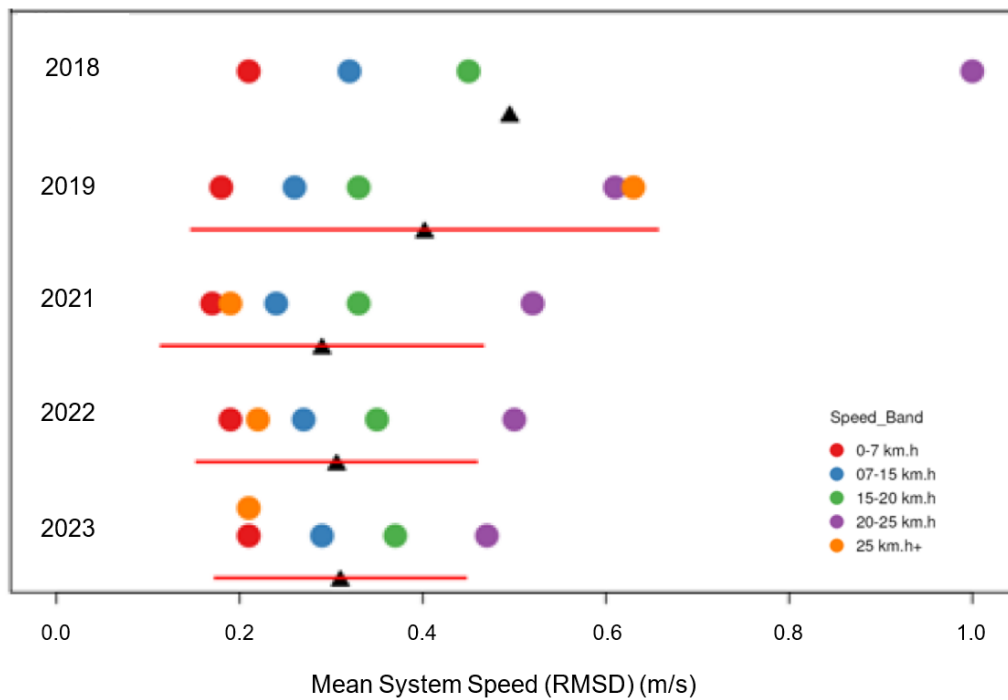


Figure 14: Changes in GNSS speed accuracy since 2018. Mean performance is denoted by the black triangle, with 95% confidence interval shown as a red line. RMSD is root mean square difference, expressed in metres per second (<https://digitalhub.fifa.com/m/189cf989cd172936/original/A-Decade-of-Assessing-EPTS-in-Football-2024.pdf>).

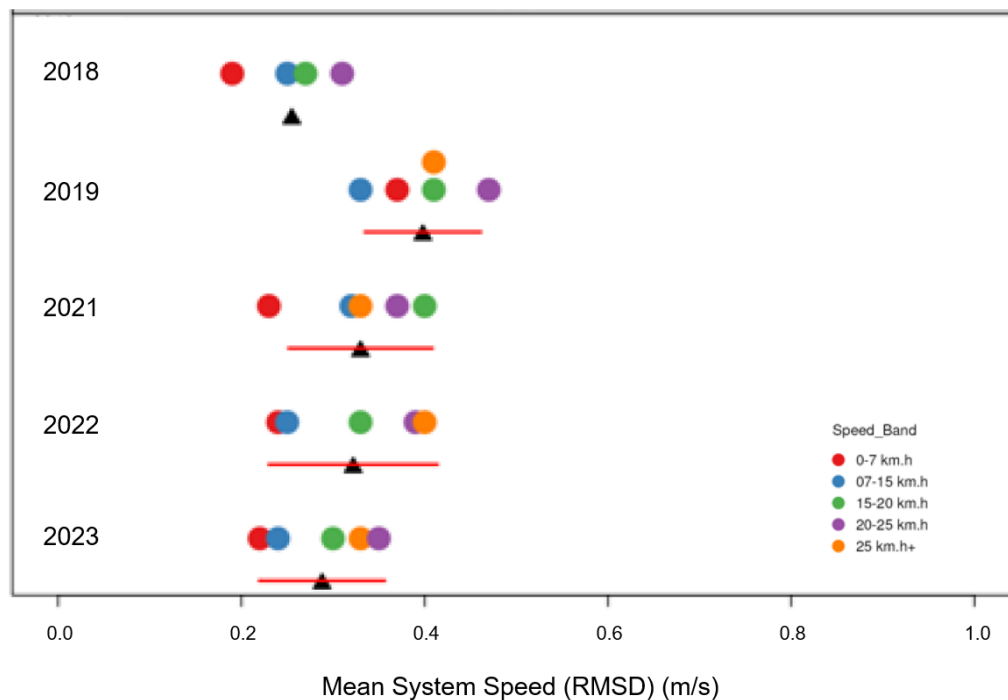


Figure 15: Changes in video tracking speed accuracy since 2018. Mean performance is denoted by the black triangle, with 95% confidence interval shown as a red line. RMSD is root mean square difference, expressed in metres per second (<https://digitalhub.fifa.com/m/189cf989cd172936/original/A-Decade-of-Assessing-EPTS-in-Football-2024.pdf>).

During training, external workload metrics were evaluated by the GNSS system. Previous research reported that Apex units have excellent interunit reliability and a coefficient of variation ranging from 1.64 to 2.91% for the analysis of peak speed during short sprints (between 5 and 30 m) (Beato, Devereux and Stiff, 2018; Beato and de Keijzer, 2019). During intermittent shuttle running all the main metrics generally adopted by practitioners present a low interunit bias and high reliability (ICC) (Beato, Wren and de Keijzer, 2023). Anyway, to avoid any intra-individual variation due to inter-unit bias every player was assigned a single GNSS unit that was never changed during the season.

During matches, external workload metrics were evaluated by the video tracking system. The validity of this type of apparatus and its interchangeability with GNSS for measures of positional tracking metrics to monitoring of training and competitions were previously reported (Taberner *et al.*, 2019).

3.2.3 Application in the original studies

In the original studies reported in Chapter 4, Chapter 5 and Chapter 6 we utilized GNSS Statsports Apex units (STATSports, Northern Ireland) and STATS video tracking system (STATS, USA). Figures of these apparatus are available in Chapter 1 (Figure 2 and Figure 3). During the data acquisition sessions, the Apex units were turned on 15 minutes before the beginning of the data recording to guarantee synchronisation between the Apex units and GNSS (Beato and de Keijzer, 2019). After every single session, GNSS data recorded by the units were downloaded and further analysed with Statsports Software (Apex version 3.0.02011): an example of the software is reported in Figure 16. In this software, data from the GNSS antenna and heart rate sensor are integrated and synchronized, enabling the sport scientist to identify spikes or data leaks. Additionally, specific splits were created to differentiate each drill conducted on the pitch. Finally, a comprehensive drill encompassing the entire session from start to finish was used to determine the total load for the day.



Figure 16: Software for the analysis of GNSS data.

Once the splitting was completed, the data were exported in a *.CSV format and then imported in an Excel-based database designed for the original studies. In Figure 17 some of the columns available were reported to illustrate. Additionally, the team average for each session was calculated. When starting and non-starting players followed different training programs, two separate rows to represent the team averages were calculated.

During matches, external workload metrics were evaluated with the video tracking system. All the process of data collection and elaboration was performed by a company (STATS, USA) that provided a comma separated value (*.CSV) file that was imported in the Excel-based database designed for the original studies and partially reported in Figure 17 to illustrate.

Name	Date	Total Distance	Distance Zone 4 (15-20)	Distance Zone 5 (20-25)	Distance Zone 6 (25-40)	Peak Speed	Number of Accelerations	Number of Decelerations
Player 1	01/01/2020	1504	95	8	0	23.7	26	18
Player 2	01/01/2020	1874	207	39	0	23.4	27	24
Player 3	01/01/2020	1838	89	13	1	25.7	19	12
Player 4	01/01/2020	1826	152	30	0	23.9	41	27
...	01/01/2020	2079	125	25	1	25.3	36	23
Team average	01/01/2020	1781	147	33	0	24.4	31	22

Figure 17: Part of the database organised to record the GNSS and video tracking data.

3.3 MIP: Most intense periods analysis

In Chapter 6, I calculated, analysed, and reported the most intense passages of the match using the rolling average approach described in the following lines. This method allowed for the precise identification of the load corresponding to the most intense periods of the match, which is essential for designing training exercises aimed at stimulating this specific scenario.

3.3.1 Terminology and mathematical approaches

Peak locomotor periods that occur during a match have been reported for many sports. Different terms were used such as most intense periods (Martín-García, Casamichana, *et al.*, 2018), peak match or physical demand (Whitehead *et al.*, 2018), duration-specific running demands (Duthie *et al.*, 2018), worst case scenario (Novak *et al.*, 2021) or other similar lexical alternatives. In the original study reported in Chapter 6, I decided to use Most Intense Periods terminology as suggested in the paper published by Novak *et al.* (Novak *et al.*, 2021).

When looking for the most intense periods, the first thing to do is to define the time window to be indagated. Usually time windows between 1 and 10 minutes are analysed, since larger periods are similar to the average values of the match. Then, two approaches are available. The first one is based on fixed time windows and divides the whole duration in sub-units that never overlap. To illustrate, if looking for the most intense minute of a 90 minute match, with this approach the max values has to be selected from one of the 90 split created. The first split would consider data from the start to minute 1, the second split from minute 1 and minute 2, and so on.

The second approach uses a moving average technique. For example, a 1-minute moving average is calculated over 600 data points (1 minute × 60 seconds × 10 Hz) and moved over the duration of the game activity, i.e. 0–600, 1–601, 2–602, 3–603, etc., and the peak 1-min identified from this (Whitehead *et al.*, 2018).

Previous research showed that mathematical models adopting moving average to assess the relationship between running intensity and duration have shown to be a valid way to quantify football match intensity and account for true periods of maximal player output (Delaney *et al.*, 2018), while using fixed durations lacks sensitivity and might underestimate true running demands up to ~ 25% (Varley, Elias and Aughey, 2012; Fereday *et al.*, 2020). For these reasons in Chapter the second approach described here above was used.

3.3.2 Application in the original study

At the end of each match, a raw speed trace for each player was exported and analysed using customized software (Anaconda Inc, Python, version 3.10.12). Total distance covered, high-speed running distance ($>20 \text{ km}\cdot\text{h}^{-1}$) and sprint distance ($>25 \text{ km}\cdot\text{h}^{-1}$) were calculated. The moving average analysis technique (Varley, Elias and Aughey, 2012) previously described was then applied to each of the output variables, using 15 different durations: 5-10-15-30-60-90 seconds and 2-3-4-5-6-7-8-9-10 minutes. These durations were defined considering the inflection point and the decrease rate of the relationship between movement velocity and duration during football matches previously described (Roecker *et al.*, 2017). To calculate the most intense periods for high-speed running and sprinting distance, the distance covered was calculated considering only the frames where the speed exceeded 20 and $25 \text{ km}\cdot\text{h}^{-1}$, respectively.

Chapter 4: Starting and non-starting players high-speed during congested fixture periods (original study)

This chapter has been published in the following paper: Gualtieri A, Rampinini E, Sassi R, Beato M. Workload Monitoring in Top-level Soccer Players During Congested Fixture Periods. *Int J Sports Med.* 2020 Sep;41(10):677-681. doi: 10.1055/a-1171-1865.

4.1 Introduction and aims

The first aspect I want to describe is the distribution of high-speed running and sprinting during congested fixture periods in an elite adult football team. The systematic review presented in Chapter 2 clearly highlights a lack of data on this scenario. Additionally, it is important to explore the application of different velocity thresholds, both absolute and relative, to determine if any differences or added value exist among them. The optimal approach to investigate this is to identify whether certain thresholds can distinguish between starting and non-starting players more effectively than others. Indeed, starting and non-starting players represent distinctly different populations, engaging in significantly different activities. As reported in Chapter 1 and Chapter 2, during a football game, players who start games (starters) typically cover distances between 10–13 km, performing a variety of intense activities such as sprints, accelerations, decelerations, and changes of direction (Anderson, Orme, Di Michele, Close, Milsom, *et al.*, 2016). Players who do not start games (non-starters) need to compensate for this lack of workload with additional training that can be planned at the end of a game or during the next training session to maintain an adequate fitness level throughout the season. The individual quantification of total workload, which is the combination of training and match load, has critical importance for professional football coaches and sports scientists aiming to obtain physical adaptations and reduce the risk of injury (Thorpe *et al.*, 2015). The most common technology utilized to quantify external workload parameters are global navigation satellite systems described in Chapter 3. Additionally, external workload can be integrated with internal load markers such as rating of perceived exertion (RPE) described in Chapter 3, that might guarantee a better comprehension of the players' workload in football (Thorpe *et al.*, 2015; Beato *et al.*, 2018; Beato and de Keijzer, 2019).

Recent research, conducted over an entire season on English Premier League players, reported that non-starting players have a similar total exposure time and total distance (considering both match and training time), but lower high-speed running and very high-

speed running than starting players (Anderson, Orme, Di Michele, Close, Milsom, *et al.*, 2016). Therefore, in order to compensate for different workload between starting and non-starting players, practitioners should implement additional load during training, in particular with a focus on high-speed activities. However, proposing higher workload, in particular high-speed running and sprint running, may be complicated during congested fixture periods due to uncertainty regarding player selection and availability. In fact, coaches have to manage the workload with the dual purpose of training and ensuring players are available for selection. When only a few days are available, non-starting players cannot engage in heavy training if they aim to be as fresh as possible for selection in the subsequent match. This situation prevents coaches from planning high-load sessions, and if this pattern is repeated over many weeks, it results in players never experiencing high-load sessions. The rationale for this approach is supported by the fact that long-term inadequate or excessive workloads can undermine players' sport-specific physical capacities and increase the likelihood of injury (Thorpe *et al.*, 2017).

To date, information related to in-season internal and external workload in professional top-level football players during congested fixture periods is very limited and none of the previous studies reported data about the near-to-maximal speed intensity. For elite level teams playing twice a week, high-speed and sprint running distance appear to be polarized during match days, inducing to find solutions to expose to this kind of stimulus all the players of the roster independently by their playing time. Therefore, in this original study workload differences between starting and non-starting players is calculated using different velocity thresholds, in particular at near-to-maximal velocity using relative velocity thresholds. The aim of this original study is to assess the internal and external workload of professional Serie A starting and non-starting players during in-season congested fixture periods. The hypothesis is that during congested fixture periods starting players may have higher internal and external workload compared to non-starting players.

4.2 Materials and Methods

4.2.1 Participants

Twenty professional Serie A football players were monitored in this study. The average age at the time of the data collection was 28.4 ± 4.3 years; average body mass was 81.8 ± 6.5 kg; average height was 184.2 ± 5.5 cm; average peak speed was 34.1 ± 1.2 km·h⁻¹, with

80% of peak speed being $27.3 \pm 0.9 \text{ km}\cdot\text{h}^{-1}$. Inclusive criteria were the absence during the whole monitoring period of any medical contraindication, injury or illness, and regular participation in all the team's training sessions. All the players involved in the study received an informed consent and it was accepted. The study was conducted in accordance with the Declaration of Helsinki and the Institutional Ethics Board of the University of Suffolk approved the study.

4.2.2 Experimental Design

External and internal workload data were recorded as part of the daily monitoring routine as reported in Chapter 3. Two congested fixture mesocycles of 21 days (MC1 and MC2), each with 6 matches, were analysed in this chapter. The structure of each of the six microcycles is further described in Chapter 5. The two mesocycles were divided by 2 weeks of the international break, during which players were involved with their national teams: during the last days of the second week, once players returned to the club after the international break, workload was partially individualized. In both mesocycles the training, match, and total workload (sum of training and match load) were calculated.

Starting and non-starting players were categorized based on the match time played with the club during each mesocycle, utilizing a median-split approach as illustrated in Chapter 3. Players were ranked according to their playing time, from those who played the most minutes to those who played the least or no minutes. The first half of the ranked players constituted the starting players group, while the second half defined the non-starting players group.

4.2.3 Procedures

During all the training sessions, Apex 10 Hz GNSS (STATSports, Northern Ireland) units were used to collect data as described in Chapter 3. During matches, external workload metrics were evaluated by a video tracking system (STATS, USA). Reliability of this type of apparatuses is reported in Chapter 3. GNSS and video tracking interchangeability for measures of positional tracking metrics to monitoring of training and competitions were reported in previously published studies (Taberner *et al.*, 2019).

The following external load variables were reported and analysed in this study: exposure time in minutes, total distance measured in metres, relative total distance calculated as the ratio between total distance and the total time of the session, high-speed running and sprint distance. Accordingly to Chapter 2 and Chapter 3, FIFA's preferred velocity thresholds were utilized, specifically distances covered above 20 km·h⁻¹ for high-speed running and distances covered above 25 km·h⁻¹ for sprinting. Additionally, individual very high-speed distances were reported using a threshold of 80% of each player's maximum peak speed, previously recorded by the club using the same GNSS technology and video tracking system for training sessions and matches respectively. Players' internal load was quantified in arbitrary units (AU) using the Borg's CR10-scale for rating of perceived exertion (RPE), whose construct validity in football was illustrated in Chapter 3 and previously reported by other authors (Impellizzeri *et al.*, 2004). Session training load (sRPE-TL) was assessed by multiplying the RPE value by the duration of the training or match, as described in Chapter 3.

4.2.4 Statistical analysis

In the next paragraph, data are presented as mean ± standard deviation (SD). Shapiro-Wilk test was used for checking the normality of the data distribution. Independent t-test comparing starting and non-starting players was used to detect between-groups differences. Statistical significance was set at $p < 0.05$. Estimates of 95% confidence interval (CI) were also calculated. Threshold values for meaningful benefit effects were evaluated based on the smallest worthwhile change (SWC), calculated as 0.2 multiplied by the between-subjects standard deviation. This approach was preferred over the one more suitable for individual subjects' SWC, which requires the individual SD to be multiplied by 0.3. The effect size, calculated as Hedges' g , was interpreted as follows: trivial < 0.2 , small 0.2-0.6, moderate 0.6-1.2, large 1.2-2.0, and very large > 2.0 (Hopkins *et al.*, 2009). Hedges' g was deemed more appropriate than the more common Cohen's d , considering the analysed group comprised fewer than 30 subjects. All the aforementioned statistical analyses were performed using JASP software version 0.10.2 (Amsterdam, Netherlands) for MAC.

4.3 Results

The total workload (sum of training and match load) recorded during the first (MC1) and second (MC2) mesocycle for starting and non-starting are reported in Table 8. In addition, Figure 18 reports the workload subdivision between training sessions and matches for both starting and non-starting players.

Considering training sessions alone, workload values were higher for non-starting players, but during the first mesocycle the differences were not meaningful for sRPE (3.3 vs 3.0 AU, $p = 0.08$), high-speed running (2697 vs 1788 m, $p = 0.08$), sprint distance (498 vs 213 m, $p = 0.12$) and distance run above 80% of individual peak velocity (151 vs 59 m, $p = 0.17$). Contrarywise, in the second mesocycle analysed all the differences were significant apart for the relative distance (72 vs 69 $\text{m}\cdot\text{min}^{-1}$, $p = 0.27$).

On the other hand, considering only workload performed during matches, significantly higher load was found for starting players except for relative distance (MC1: 118 vs 121 $\text{m}\cdot\text{min}^{-1}$, $p = 0.52$; MC2: 114 vs 115 $\text{m}\cdot\text{min}^{-1}$, $p = 0.81$) and sRPE in MC2 (7.7 vs 6.8 AU, $p = 0.109$).

Table 8: Summary of Starters and Non-Starters workload during two 21 days-congested fixture mesocycles.
Data are presented in mean $\pm$ standard deviation (SD). RPE = Rate of Perceived Exertion; AU = Arbitrary Units; sRPE-TL = session Rate of Perceived Exertion Training Load; TD = Total Distance; m = meters; RD = Relative Distance; m.min⁻¹ = meters per minute; D>20 = Total distance above 20 km.h⁻¹; D>25 = Total distance above 25 km.h⁻¹; D>80% Vmax = Total distance above 80% of individual maximum speed; n = number; SWC = smallest worthwhile change calculated as SD*0.2.

Performance metric	Starters Mean $\pm$ SD	Non-starters Mean $\pm$ SD	Delta difference (95% CI)	P-level	Hedges'g	Qualitative assessment	SWC
1st MESOCYCLE							
Playing time (min)	480 $\pm$ 76	151 $\pm$ 99	-329 (-424, -234)	< .001	-3.52	<i>very large</i>	-
Total exposure (min)	1326 $\pm$ 62	1155 $\pm$ 76	-171 (-245, -97)	< .001	-2.33	<i>very large</i>	14
RPE (AU)	4.9 $\pm$ 0.3	3.9 $\pm$ 0.5	-1.1 (-1.5, -0.7)	< .001	-2.54	<i>very large</i>	0.1
sRPE-TL (AU)	6566 $\pm$ 711	4437 $\pm$ 403	-2130 (-2749, -1510)	< .001	-3.49	<i>very large</i>	111
TD (m)	93686 $\pm$ 7929	73492 $\pm$ 4346	-20194 (-27050, -13338)	< .001	-2.99	<i>very large</i>	1227
RD (m.min ⁻¹)	79 $\pm$ 5	75 $\pm$ 5	-3.8 (-8.9, 1.4)	0.138	-0.74	<i>moderate</i>	1.0
D>20 (m)	6363 $\pm$ 1397	4527 $\pm$ 1781	-1836 (-3552, -119)	0.038	-1.09	<i>moderate</i>	318
D>25 (m)	1406 $\pm$ 538	1032 $\pm$ 556	-374 (-960, 213)	0.194	-0.65	<i>moderate</i>	109
D>80% Vmax (m)	1035 $\pm$ 359	658 $\pm$ 392	-376 (-779, 26)	0.065	-0.95	<i>moderate</i>	75
Efforts >80% Vmax (n)	95 $\pm$ 29	45 $\pm$ 27	-50 (-80, -20)	0.003	-1.69	<i>large</i>	6
2nd MESOCYCLE							
Playing time (min)	434 $\pm$ 74	146 $\pm$ 88	-288 (-365, -212)	< .001	-3.41	<i>very large</i>	-
Total exposure (min)	1296 $\pm$ 110	1096 $\pm$ 119	-199 (-307, -92)	0.001	-1.67	<i>large</i>	23
RPE (AU)	4.8 $\pm$ 0.4	4.0 $\pm$ 0.5	-0.9 (-1.3, -0.5)	< .001	-1.98	<i>large</i>	0.1
sRPE-TL (AU)	6283 $\pm$ 865	4347 $\pm$ 719	-1937 (-2684, -1190)	< .001	-2.33	<i>very large</i>	158
TD (m)	85712 $\pm$ 11035	71679 $\pm$ 5541	-14033 (-22237, -5830)	0.002	-1.54	<i>large</i>	1658
RD (m.min ⁻¹)	84 $\pm$ 5	79 $\pm$ 8	-4.7 (-11.2, 1.8)	0.147	-0.65	<i>moderate</i>	1.0
D>20 (m)	5285 $\pm$ 1123	4943 $\pm$ 1200	-342 (-1434, 750)	0.519	-0.28	<i>small</i>	232
D>25 (m)	1175 $\pm$ 403	910 $\pm$ 302	-265 (-599, 70)	0.114	-0.71	<i>moderate</i>	71
D>80% Vmax (m)	843 $\pm$ 331	448 $\pm$ 274	-395 (-681, -109)	0.009	-1.24	<i>large</i>	61
Efforts >80% Vmax (n)	78 $\pm$ 23	37 $\pm$ 20	-41 (-61, -21)	< .001	-1.83	<i>large</i>	4

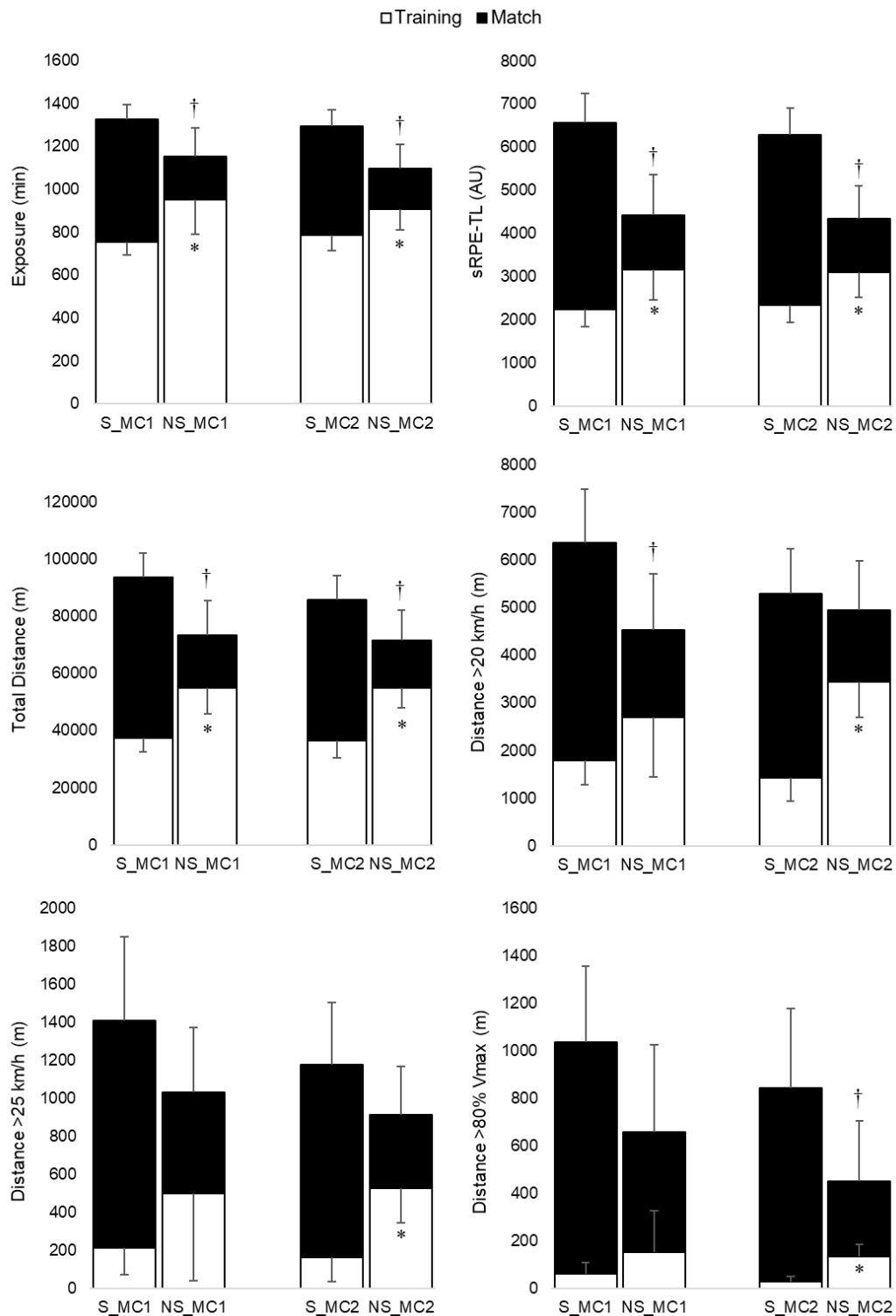


Figure 18: Summary of training and match workload for Starting and Non-Starting players during two 21 days-congested fixture mesocycles.

Data are presented in mean $\pm$ standard deviation (SD). S_MC1 and S_MC2 = Starting players during 1st and 2nd mesocycle respectively; NS_MC1 and NS_MC2 = Non-starting players during 1st and 2nd mesocycle respectively; sRPE-TL = session Rate of Perceived Exertion Training Load; AU = Arbitrary Units; m = meters; Distance >80% Vmax = Total distance above 80% of individual maximum speed; * training load significantly higher than Starting players ($p < .05$); # match load significantly lower than Starting players ($p < .05$); † total workload lower than Starting players.

4.4 Discussion

This study supports the hypothesis presented in the introduction of the present Chapter and addresses the research question posed in Chapter 1. Starting players produce higher internal and external workload compared to non-starters during congested fixture periods when both training and match load are included.

Contrary to previously published data about a seasonal-long analysis (Anderson, Orme, Di Michele, Close, Milsom, *et al.*, 2016), starters accumulated higher total exposure and total distance, but non-significant between groups differences were found for high-speed running in one of the two mesocycles (MC2) and sprint distance in both mesocycles. A definitive explanation for these findings is not possible, however, the training strategies implemented by the club may have partially compensated the differences in workload between starting and non-starting players. Furthermore, these conflicting results may suggest the existence of data variability from team to team, which should not be generalized as Serie A vs. Premier League (Anderson, Orme, Di Michele, Close, Milsom, *et al.*, 2016). Future studies involving multiple teams, all of whom adopt standardized velocity thresholds as discussed in Chapter 2, could further investigate the existing differences between football leagues. However, when distance >80% individual peak velocity was analysed, the differences between the two groups were *moderate* to *large* in both mesocycles. This finding underlines the importance of individualising high-speed running thresholds to optimise football workload analysis. These findings have high relevance in football because of the growing evidence on the importance of high-speed running for performance and injuries prevention purposes (Anderson, Orme, Di Michele, Close, Milsom, *et al.*, 2016; Buckthorpe *et al.*, 2019). Therefore, further attention should be paid, in congested fixture periods, to this training metric for starting and non-starting players.

This study confirms that football matches are a critical training component of the week, where players can perform more high-speed running and football-specific activities, which can be difficult to recreate during a congested fixture micro-cycle (Anderson, Orme, Di Michele, Close, Milsom, *et al.*, 2016; Morgans, Di Michele and Drust, 2018). During the training sessions, coaches may find it difficult to replicate the equivalent match running intensity demands, as well as to compensate for the missing match-load for non-starting players. This is particularly true during congested fixture periods since the available training time may be limited at the end of the game or the day after the game. Moreover, the current research has added evidence of a higher sRPE-TL for starting players, which is not only

explained by the higher exposure time, but also by the impact of the high RPE values recorded during matches that are hardly replicable during training sessions.

The non-significant difference in relative distance is explained by the fact that non-starting players usually perform additional shorter duration high-intensity aerobic training with no high-speed running at the end of the game or during the first available training session, raising average values of relative distance for non-starters in comparison to starters. Moreover, two days after the match, training prescription was differentiated for starters and non-starters, with the objective of reducing high intensity training for starters and properly conditioning non-starters, in line with team objectives and literature recommendations (Morgans, Di Michele and Drust, 2018). In the described mesocycles, the most common strategy utilized to reduce the gap between starters and non-starters occurred between the end of the game and the second day after the match. After the game, low-volume high-intensity aerobic training with no high-speed running was proposed for non-starting players, while the day after the game these players performed a combination of small-sided games and power training in the gym. Two days after the game, following a first part of the session in which low-intensity tactical drills were performed for all the team players, non-starters continued their additional training with technical-tactical high-volume low-intensity drills. Practitioners should take advantage of all the windows of opportunity to train non-starters in the 48 hours following a game. This is particularly important during congested fixture periods to avoid the presence of long de-training periods for non-starters.

A limitation of this study is the sample used, which is relatively small and restricted to a single Italian team. Ideally, sample size determination should rely on an a priori estimation; however, this was not feasible due to the limited availability of top-level football players, an ecological constraint typical of team sports such as football. As previously highlighted, studies involving highly specific populations, such as in this investigation, can still have a substantial impact on real-world practice, even with small sample sizes (Harriss, MacSween and Atkinson, 2019). Nevertheless, the specific cultural context in which the players trained must be considered when interpreting the generalizability of these findings to other clubs or countries.

In conclusion, this original study has reported that starting and non-starting players were exposed to significantly different volumes of internal and external load during mesocycles characterized by congested fixture periods. This difference was mainly ascribable to the different total exposure time of the two groups and to the unique workload demands of the match. Players' individualised thresholds for high-speed running distance (i.e. distance

>80% Vmax) may help to identify the workload needs of non-starting players during congested fixture periods. This external load metric might be necessary for sport scientists and coaches to optimally prepare players for the most demanding phases of the match that will be deeply analysed in Chapter 6 and to avoid de-training for non-starting players. For all the reasons reported, the monitoring of external and internal workload metrics should be utilized to manage the training sessions and to plan compensation drills between starting and non-starting players.

In the next chapter, Chapter 5, the daily workload of the most common congested fixture microcycle is analysed, describing workload alternation in three-, four-, and five-day microcycles, which account for 75% of the total number of microcycles encountered during a season for a top-level team. Specifically, the workload experienced by non-starting players on the day following a match (MD+1) is described and analysed to determine whether the larger window of opportunity to train non-starting players is influenced by the length of the microcycle and how significantly it impacts the overall microcycle workload. Additionally, particular focus is dedicated to high-speed running, considering both absolute and relative thresholds. The latter, as discussed in this chapter, proved useful in identifying workload deficiencies in non-starting players when describing intensities higher than 80% of the maximum velocity.

Chapter 5: High-speed during three-, four- and five-day microcycles (original study)

This chapter has been published in the following paper: Gualtieri A, Vicens-Bordas J, Rampinini E, Ferrari Bravo D, Beato M. Three-, Four-, and Five-Day Microcycles: The Normality in Professional Football. *Int J Sports Physiol Perform*. 2024 Jul 27;19(10):987-995. doi: 10.1123/ijsp.2024-0144.

5.1 Introduction and aims

In nowadays football, the best teams from each championship (e.g., Serie A, Premier League) play frequently during the season to take part in international competitions or national cups. For instance, they do not play only during the weekend (1 match a week), but also during the week (e.g., 2-3 times in 7-8 days) (Julian, Page and Harper, 2021). In these circumstances, the weekly number of training sessions is reduced to facilitate physical recovery, particularly in the days immediately following a game, thereby promoting optimal performance (Querido *et al.*, 2022). Training load is affected by this strategy to the point that the weekly load, especially the distance run at high-speed, is mainly completed during the match itself as reported in Chapter 4 and other studies (Anderson, Orme, Di Michele, Close, Morgans, *et al.*, 2016). This type of “*congested fixture season*” does not allow practitioners to plan training as they would during a standard weekly-based microcycle, which typically includes six training sessions per week with one match. Practice and previous studies have demonstrated that individual players may experience approximately 10 consecutive weeks of a congested calendar, including both domestic and international matches (Silva *et al.*, 2023). In this context, teams’ weekly schedules change during the season, so a standard nomenclature independent by the day of the week is adopted. More precisely, to summarize the detailed discussion in Chapter 3, the training days and their specific aims, such as recovery, development, or tapering, are defined based on their proximity to the previous or next match day (MD). In a traditional microcycle, it is common practice to define the days after the latest game as follow: match day plus 1 (MD+1) and MD+2, where usually the main aim is to promote physical and mental recovery, while MD-4, MD-3, MD-2 and MD-1 for the remaining days before the MD (Malone *et al.*, 2015). However, during congested fixture periods, as described in Chapter 3, the number of days between matches is reduced, resulting in a shorter training week. For example, for a four-day microcycle: MD+1, MD-2, MD-1 and MD.

The periodization of loading across the weekly microcycle is commonly observed in adult players. Previous research reported that training volume gradually decreased during the week as match day approached (Stevens *et al.*, 2017; Martín-García, Gómez Díaz, *et al.*, 2018; Clemente, Owen, *et al.*, 2019; Szigeti *et al.*, 2021). Specifically, in an eight-day microcycle greatest distances and intensities were performed at MD-5 and MD-3, followed by a significant tapering phase at MD-2 and MD-1 in an attempt to reduce the residual fatigue accumulation during the previous days and to optimize MD performance (Clemente, Owen, *et al.*, 2019). A similar trend has been reported by Lopategui *et al.* 2021 in a seven-day microcycle, where a short tapering on MD-2 and MD-1 was planned before the game to recover from the previous loading days, essentials for maintaining or optimizing players' physical performance during the season (Lopategui, Paulis and Escudero, 2021). Furthermore, Fleming *et al.* 2023 reported a similar organization of the training stimulus in six-day microcycles, where MD-4 was the most demanding training session of the week, MD-3 was a day-off and during MD-2 and MD-1 coaches decreased players' load to favour players' readiness (Fleming *et al.*, 2023).

However, this weekly plan cannot be used during congested fixture periods. For example, in a four-day microcycle, the first session after the match (MD+1) is the only available training day where non-starting players who did not play or played only fraction of the previous match can actually perform physical development (72 h before the next match). On MD+2, which is at less than 48 h from the previous MD and 48 h from the next MD, starting players are still recovering from the workload of the previous MD and they cannot actually fully train, while non-starting players needs to start tapering for the next MD and recover from the training session of the previous day. Finally, MD-1 (less than 72 h from the previous MD, and 24h from the next MD) is a tapering session for both starting and non-starting players.

A three-day microcycle composed by MD+1, MD-1, and MD is also possible, and it is not uncommon, as it represents at least 30% of the microcycles for a team as the one described in Chapter 4 competing simultaneously in the national championship, cup, and international competitions (FIFPRO, 2022). In these conditions, MD+1 is the only available day for the coaching staff to train non-starting players, but only contained load can be provided since about 48 h from the next MD are available. On the other hand, MD-1, which is less than 48 hours from the previous MD and approximately 24 hours from the next MD, could be the only day to prepare starting players and assess their readiness before the following match.

Therefore, it is crucial to find the right balance between recovery from the previous game and preparation for the next.

The majority of the studies published in football described the load distribution during regular seven-day microcycles (Martín-García, Gómez Díaz, *et al.*, 2018; Clemente, Rabbani, *et al.*, 2019; Oliveira *et al.*, 2019; de Dios-Álvarez *et al.*, 2021; Guerrero-Calderón *et al.*, 2023; Vardakis *et al.*, 2023), while some papers reported shorter microcycles with six to five days (Akenhead, Harley and Tweddle, 2016; Clemente, Rabbani, *et al.*, 2019; Oliva-Lozano, Gómez-Carmona, *et al.*, 2022; Fleming *et al.*, 2023; Vardakis *et al.*, 2023). However, limited information is currently available about shorter four-day microcycles, particularly for players competing in top-level teams in the Italian Serie A (Djaoui *et al.*, 2022; Oliva Lozano *et al.*, 2023). Furthermore, no studies have reported training load data specifically for scenarios of three-day microcycles (MD+1, MD-1 and MD).

For these reasons, Chapter 5 aimed, firstly, to quantify training and match day load during three-, four-, and five-day microcycles in Italian Serie A professional adult football. Secondly, it aimed to analyse the effect of microcycle length on training load during MD+1 for non-starting players, as well as MD-1 and MD load for the entire team. The hypothesis is that the length of the microcycle do not affect the physical demand of the game, but it influences the training load during MD+1 and MD-1.

5.2 Methods

5.2.1 Subjects

Twenty male professional Serie A football players were monitored in this study for a whole season. The main characteristics were age 28.1 ± 4.7 years; body mass 80.6 ± 5.9 kg; height 183.4 ± 5.1 cm; maximum speed 33.7 ± 1.5 km.h⁻¹; 80% of peak speed 27.1 ± 0.8 km.h⁻¹. The inclusion criteria comprised participation in the official competition. Goalkeepers were excluded from this study, therefore, only outfield players' match data were evaluated. The sample size estimation was calculated using G*power (Düsseldorf, Germany) for a one-way ANOVA fixed effect that indicated a total of 111 individual data points (single days) would be required to detect a *medium* effect ($f = 0.3$), three conditions (3 microcycles) with 80% power and an alpha of 5%. The actual sample size of this study was 1919 individual data

points, with a real power higher than 95%, which reduced the likelihood of type 2 errors (false negative) (Beato, 2022).

As with the other chapters, this study was approved by the Ethics Committee of the University of Suffolk (Ipswich, UK) (project code: RETH19/020). Informed consent to take part in this research was signed by the club. All procedures were conducted according to the Declaration of Helsinki for human studies.

5.2.2 Experimental design

The external training load data was recorded as part of the regular monitoring routine of the club and was only analysed *a posteriori* using a dedicated database as described in Chapter 3. All the data analysed were collected during a single competitive season starting in August and ending in May.

The microcycle length was defined by the number of days available between two subsequent matches, inclusive of the match day itself. A day-off was included as well in the count of the days available. Figure 19 presents the three analysed microcycles and their respective percentages of the total number of microcycles that occurred during the season.

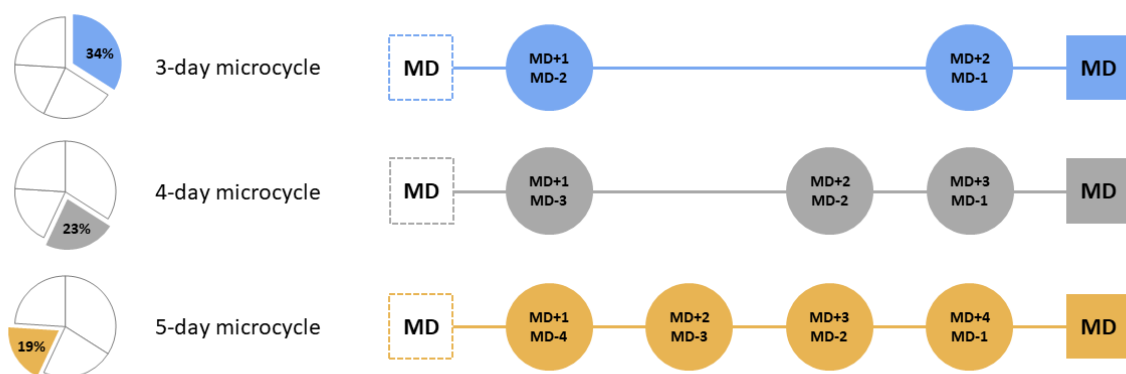


Figure 19: Competitive microcycles analysed and their prevalence during the season.

MD, Match Day. For each training day (circles) the distance in terms of days from both the preceding and succeeding match days has been reported using respectively positive (+) and negative (-) count.

On the day following a match (MD+1), the training load data are exclusively related to the non-starting players to identify any effect of microcycle length on the training outcome, particularly on high-speed running. On MD+1, all the starting players did not train on the

pitch; instead, they performed indoor recovery activities such as cycling, swimming, and stretching. The physical demand of the game reported on MD is the average load produced by all the players involved in the game, regardless of their playing time. Therefore, players were not excluded from the analysis based on their playing time. This decision was made in accordance with the five substitutions rule introduced in 2020, which permits the replacement of up to five players during a match. Prior to the SARS-CoV-2 pandemic and the consequent COVID-19 era, only three substitutions were available for coaches during a match. However, when a congested fixture calendar was required in June and July 2020 to recover the matches missed during the March to May 2020 lockdown period, two additional substitutions were introduced. Since then, the five-substitution rule has become stable and has been adopted by all national federations. From a practical perspective, this rule provides a valuable opportunity to implement partial turnovers for more players during a season. Conversely, from a statistical perspective, this rule increases the variability of team average match load attributable to positional effects. For instance, when only three players are substitutable, the average value of the team is based on the physical demand of seven outfield players, whereas with five substitutions, only five outfield players contribute to the mean. In this scenario, the playing position affects the team average more than before, generating variability that reflects the playing role demand rather than the match demand. To avoid this issue, the total sum of the physical demand sustained by all fifteen outfield players is usually adopted. However, in this study, it would not have been pertinent to the microcycle description due to the different number of players involved during each session or microcycle.

5.2.3 Methodology

As described in Chapter 3, during all the training sessions Apex 10 Hz GNSS (STATSports, Northern Ireland) units were used to collect data. During matches, external workload metrics were evaluated by a video tracking system (STATS, USA). Reliability of this type of apparatuses was reported in Chapter 3. GNSS and video tracking interchangeability for measures of positional tracking metrics to monitoring of training and competitions were previously reported (Taberner *et al.*, 2019).

External load metrics

The total football exposure (EXP) of each training session was quantified and expressed in minutes (mins). GNSS recorded metrics were total distance covered (TD), absolute high-speed running distance (HSR, in this chapter to be considered between 20 and 25 km·h⁻¹) and absolute sprint distance (SD, >25 km·h⁻¹). Additionally, individual sprint distance (D>80% of the individual peak speed) was recorded, as it proved useful in Chapter 4 for identifying deficiencies in training load stimuli for non-starting players. Individual sprint distance was calculated as 80% of the maximum peak velocity of each player previously recorded by the club using the same GNSS technology and video tracking system for training sessions and matches respectively. The number of high-intensity accelerations (ACC, >3 m·s⁻²), and decelerations (DEC, <-3 m·s⁻²) were quantified using GNSS technology (Silva *et al.*, 2022).

Internal load metrics

Players' internal load was quantified in arbitrary units (AU) using the rating of perceived exertion (RPE, Borg's CR10-scale), which construct validity has been reported in Chapter 3. Session training load (sRPE-TL, AU) was assessed multiplying the RPE value by training or match exposure as further explained in Chapter 3.

5.2.4 Statistical Analyses

Data are presented as estimated marginal means (95% confidence intervals) for each dependent variable and were analysed using linear mixed models to account for missing data and repeated measures. Normality of residuals was found for the linear mixed models (LMM). The primary analysis was a LMM, which used the Satterthwaite method to assess if significant differences exist between training days in the different microcycles (three-days, four-days or five-days microcycle as fixed effects) across the dependent variables describing external and internal load (Maullin-Sapey and Nichols, 2021). The degrees of freedom estimation was based on analytical results.

During the secondary analysis, LMM were performed including as fixed effects the day of the week (MD+1, MD-1 and MD) and the type of microcycle (three-days, four-days or five-days), to test for differences and interaction effects. Players were considered as random effect grouping factors in all the analyses. When significant differences were found in the LMM, *post-hoc* tests were performed using Bonferroni corrections for multiple comparisons.

Estimates of 95% confidence intervals (CIs) were calculated and reported in the figures. Effect sizes were calculated from the t and df of the contrast and interpreted using Cohen's d principle as follows: *trivial* < 0.2 , *small* $0.2 - 0.6$, *moderate* $0.6 - 1.2$, *large* $1.2 - 2.0$, *very large* > 2.0 (Hopkins *et al.*, 2009). Unless otherwise stated significance was set at $p < 0.05$ for all tests. Statistical analyses were performed in JAMOV (The Jamovi project [2023], version 2.3, retrieved from <https://www.jamovi.org>).

5.3 Results

5.3.1 Microcycle type

A total number of 18, 12 and 10 of three-, four- and five-day microcycles respectively were analysed, corresponding to 34%, 23% and 19%, respectively, of the total number of microcycles of the competitive season.

The daily mean value was analysed (Table 9, Figure 20 and Figure 21). Three-, four- or five-day microcycles affected most of the variables of interest: high-speed running ($F = 9.04$, $p = 0.00012$), sprint ($F = 13.90$, $p < 0.00001$), individualized sprint $>80\%$ ($F = 20.25$, $p < 0.0001$), accelerations ($F = 10.12$, $p < 0.0001$) and decelerations ($F = 6.01$, $p = 0.0025$). Exposure was found significant ($F = 3.60$, $p = 0.02748$), but the difference between microcycles (*post-hoc*) was trivial. Instead, total distance ($F = 0.691$, $p = 0.501$) and sRPE-TL ($F = 1.03$, $p = 0.358$) were not affected by microcycle type.

Contrasts showed that three- and four-day microcycles had greater daily average high-speed running demands than the five-day microcycle ($p < 0.05$).

Three-day microcycle showed greater sprint and individualized sprint daily demands ($p < 0.001$), but lower accelerations and decelerations ($p < 0.01$), than the four- and five-day microcycles.

Table 9: Differences of daily mean values in different microcycle type.

High-speed running distance (20-25 km·h ⁻¹)						
Microcycle	Difference	SE	t	df	p _{bonferroni}	Cohen's d
Four vs Five	32.358	12.157	2.662	1896.696	0.02352	0.12 <i>trivial</i>
Three vs Five	49.093	11.666	4.208	1909.003	0.00008	0.19 <i>trivial</i>
Three vs Four	16.735	11.796	1.419	1907.728	0.46841	0.06 <i>trivial</i>
Sprint distance (>25 km·h ⁻¹)						
Microcycle	Difference	SE	t	df	p _{bonferroni}	Cohen's d
Four vs Five	11.742	5.783	2.03	1895.936	0.12737	0.09 <i>trivial</i>
Three vs Five	28.968	5.552	5.218	1907.055	< .00001	0.24 <i>small</i>
Three vs Four	17.225	5.613	3.069	1905.786	0.00654	0.14 <i>trivial</i>
Individual sprint distance (>80% individual maximum peak velocity)						
Microcycle	Difference	SE	t	df	p _{bonferroni}	Cohen's d
Four vs Five	5.583	2.245	2.487	1895.925	0.0389	0.11 <i>trivial</i>
Three vs Five	13.584	2.155	6.304	1907.023	< .00001	0.29 <i>small</i>
Three vs Four	8.001	2.179	3.673	1905.754	0.00074	0.17 <i>trivial</i>
Accelerations >3 m·s ⁻²						
Microcycle	Difference	SE	t	df	p _{bonferroni}	Cohen's d
Four vs Five	0.422	1.107	0.381	1895.269	1	0.02 <i>trivial</i>
Three vs Five	-3.89	1.063	-3.66	1905.111	0.00078	-0.17 <i>trivial</i>
Three vs Four	-4.312	1.074	-4.013	1903.895	0.00019	-0.18 <i>trivial</i>
Decelerations <-3 m·s ⁻²						
Microcycle	Difference	SE	t	df	p _{bonferroni}	Cohen's d
Four vs Five	3.93	1.337	2.939	1898.13	0.00999	0.13 <i>trivial</i>
Three vs Five	-0.099	1.282	-0.077	1911.955	1	0.00 <i>trivial</i>
Three vs Four	-4.028	1.297	-3.107	1910.798	0.00575	-0.14 <i>trivial</i>
Exposure time (minutes)						
Microcycle	Difference	SE	t	df	p _{bonferroni}	Cohen's d
Four vs Five	2.979	1.309	2.275	1899.987	0.06902	0.10 <i>trivial</i>
Three vs Five	2.991	1.254	2.384	1914.508	0.05163	0.11 <i>trivial</i>
Three vs Four	0.012	1.269	0.01	1913.676	1	0.00 <i>trivial</i>

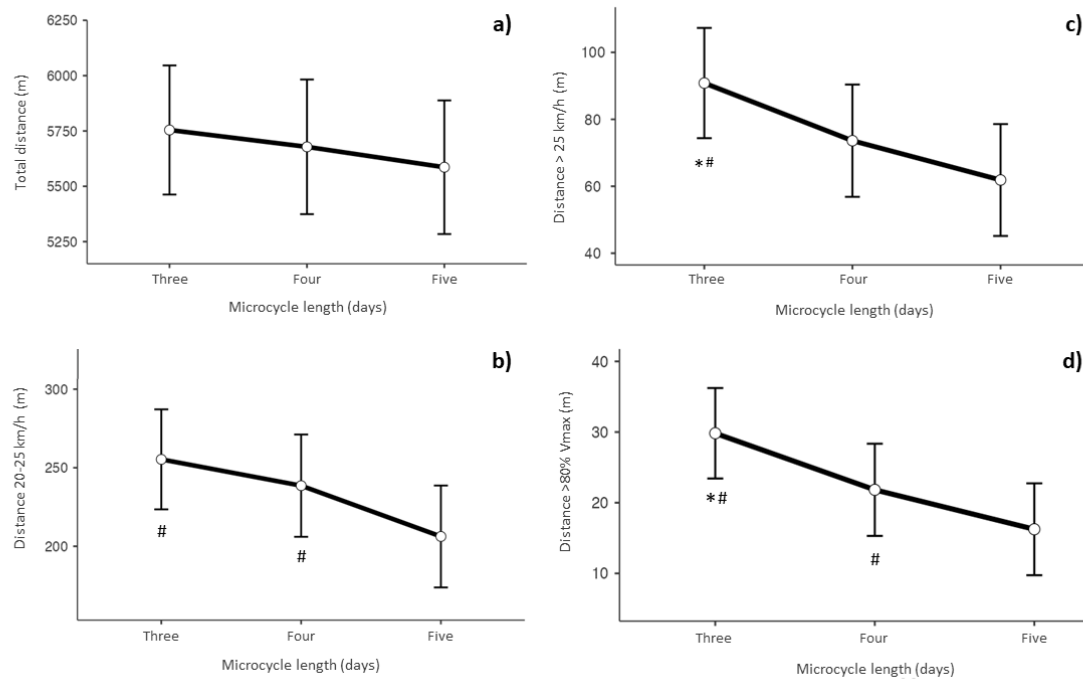


Figure 20: Microcycle type and total distance (a), high-speed running distance (b), sprint distance (c) and individualised sprint distance, i.e. >80% of the individual maximum speed (d). Statistically significant differences ($p < 0.05$) across microcycles length are reported as follows: § significantly higher than three-day microcycles; * significantly higher than four-day microcycles; # significantly higher than five-day microcycles.

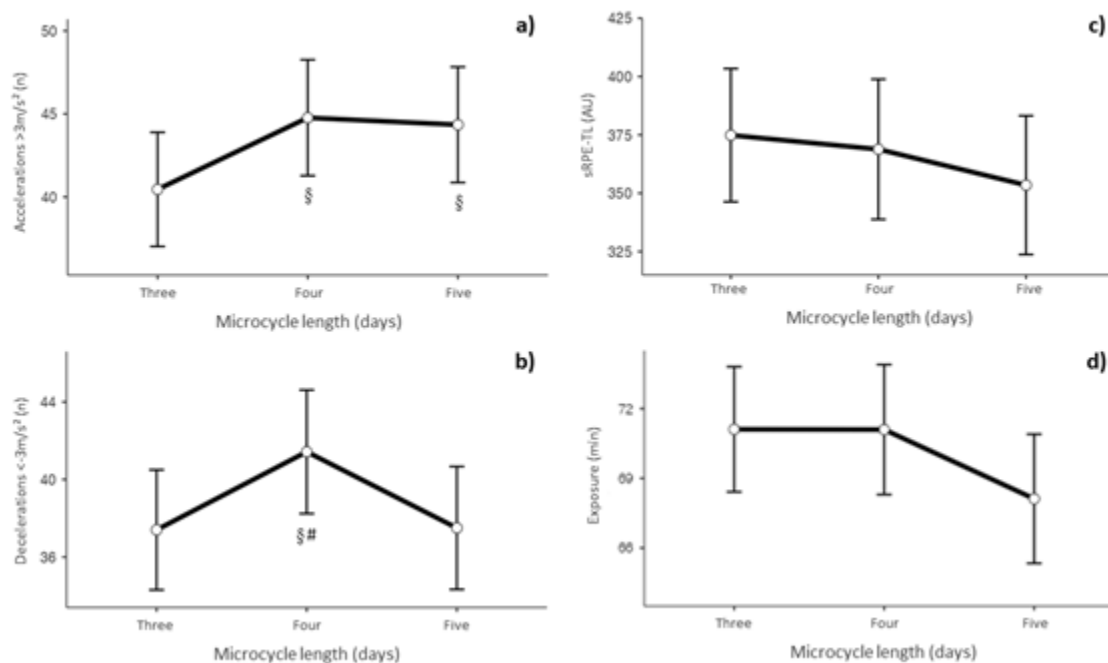


Figure 21: Microcycle type and accelerations (a), decelerations (b), sRPE, session Rating of Perceived Exertion (c) and exposure (d). Statistically significant differences ($p < 0.05$) across microcycles length are reported as follows: § significantly higher than three-day microcycles; * significantly higher than four-day microcycles; # significantly higher than five-day microcycles.

5.3.2 Training day and microcycle type

The training days (MD+1, MD-1) and match day presented differences for all the variables of interest ($p < 0.0001$, Table 10, Figure 22 and Figure 23). There was an interaction effect between training day and microcycle type for sprint ($F = 5.46$, $p = 0.00023$), individualized sprint ($F = 4.51$, $p = 0.00128$), accelerations ($F = 2.24$, $p = 0.06318$) and decelerations ($F = 3.91$, $p = 0.00369$, Table 11).

Contrasts showed, for individualized sprint distance, trivial differences (29 m, $p = 0.018$, $d = 0.18$) at MD+1 in favour to the three-day microcycle compared to the five-day microcycle. Four-day microcycle presented the greater number of accelerations at MD-1, compared to three-day microcycle (-8.5 , $p < 0.00001$, $d = -0.29$); and at MD compared to three- (-11.6 , $p < 0.00001$, $d = -0.36$) and five-day microcycles (-9.3 , $p = 0.00009$, $d = 0.25$). Four-day microcycle presented the greater number of decelerations at MD-1, compared to three-day microcycle (-7.9 , $p = 0.00039$, $d = -0.23$); and at MD compared to three- (-16.4 , $p < 0.00001$, $d = -0.43$) and five-day microcycles (14.2 , $p < 0.00001$, $d = 0.33$).

Table 10: Training days comparison independently by the microcycle.

Total distance						
Split	Difference	SE	t	df	p _{bonferroni}	Cohen's d
MD-1 vs MD	-3681.016	133.125	-27.651	1433.59	< .00001	-1.46 <i>large</i>
MD+1 vs MD	-1589.718	233.989	-6.794	1441.422	< .00001	-0.36 <i>small</i>
MD+1 vs MD-1	2091.298	228.159	9.166	1435.212	< .00001	0.48 <i>small</i>
High-speed running distance (20-25 km·h ⁻¹)						
Split	Difference	SE	t	df	p _{bonferroni}	Cohen's d
MD-1 vs MD	-362.846	9.136	-39.717	1429.858	< .00001	-2.10 <i>very large</i>
MD+1 vs MD	-232.438	16.07	-14.464	1434.773	< .00001	-0.76 <i>medium</i>
MD+1 vs MD-1	130.408	15.659	8.328	1430.661	< .00001	0.44 <i>small</i>
Sprint distance (>25 km·h ⁻¹)						
Split	Difference	SE	t	df	p _{bonferroni}	Cohen's d
MD-1 vs MD	-161.815	4.679	-34.581	1428.934	< .00001	-1.83 <i>large</i>
MD+1 vs MD	-109.224	8.233	-13.267	1432.985	< .00001	-0.70 <i>medium</i>
MD+1 vs MD-1	52.591	8.021	6.557	1429.557	< .00001	0.35 <i>small</i>
Individual sprint distance (>80% individual maximum peak velocity)						
Split	Difference	SE	t	df	p _{bonferroni}	Cohen's d
MD-1 vs MD	-52.429	2.067	-25.368	1429.289	< .00001	-1.34 <i>large</i>
MD+1 vs MD	-33.959	3.636	-9.34	1433.678	< .00001	-0.49 <i>small</i>
MD+1 vs MD-1	18.469	3.543	5.214	1429.981	< .00001	0.28 <i>small</i>

Accelerations >3 m·s ⁻²						
Split	Difference	SE	t	df	p _{bonferroni}	Cohen's d
MD-1 vs MD	-7.737	1.005	-7.695	1429.426	< .00001	-0.41 <i>small</i>
MD+1 vs MD	21.766	1.769	12.305	1433.943	< .00001	0.65 <i>medium</i>
MD+1 vs MD-1	29.503	1.723	17.118	1430.144	< .00001	0.91 <i>medium</i>

Decelerations <-3 m·s ⁻²						
Split	Difference	SE	t	df	p _{bonferroni}	Cohen's d
MD-1 vs MD	-29.67	1.182	-25.103	1431.913	< .00001	-1.33 <i>large</i>
MD+1 vs MD	-7.888	2.078	-3.796	1438.568	0.00046	-0.20 <i>small</i>
MD+1 vs MD-1	21.781	2.026	10.752	1433.153	< .00001	0.57 <i>small</i>

Session Rating of Perceived Exertion (sRPE-TL)						
Split	Difference	SE	t	df	p _{bonferroni}	Cohen's d
MD-1 vs MD	-447.821	13	-34.449	1435.596	< .00001	-1.82 <i>large</i>
MD+1 vs MD	-280.284	22.838	-12.273	1444.449	< .00001	-0.65 <i>medium</i>
MD+1 vs MD-1	167.538	22.278	7.52	1437.692	< .00001	0.40 <i>small</i>

Exposure time (minutes)						
Split	Difference	SE	t	df	p _{bonferroni}	Cohen's d
MD-1 vs MD	-26.487	1.21	-21.895	1433.519	< .00001	-1.16 <i>large</i>
MD+1 vs MD	-24.294	2.126	-11.425	1441.308	< .00001	-0.60 <i>medium</i>
MD+1 vs MD-1	2.193	2.073	1.058	1435.125	0.87112	0.06 <i>small</i>

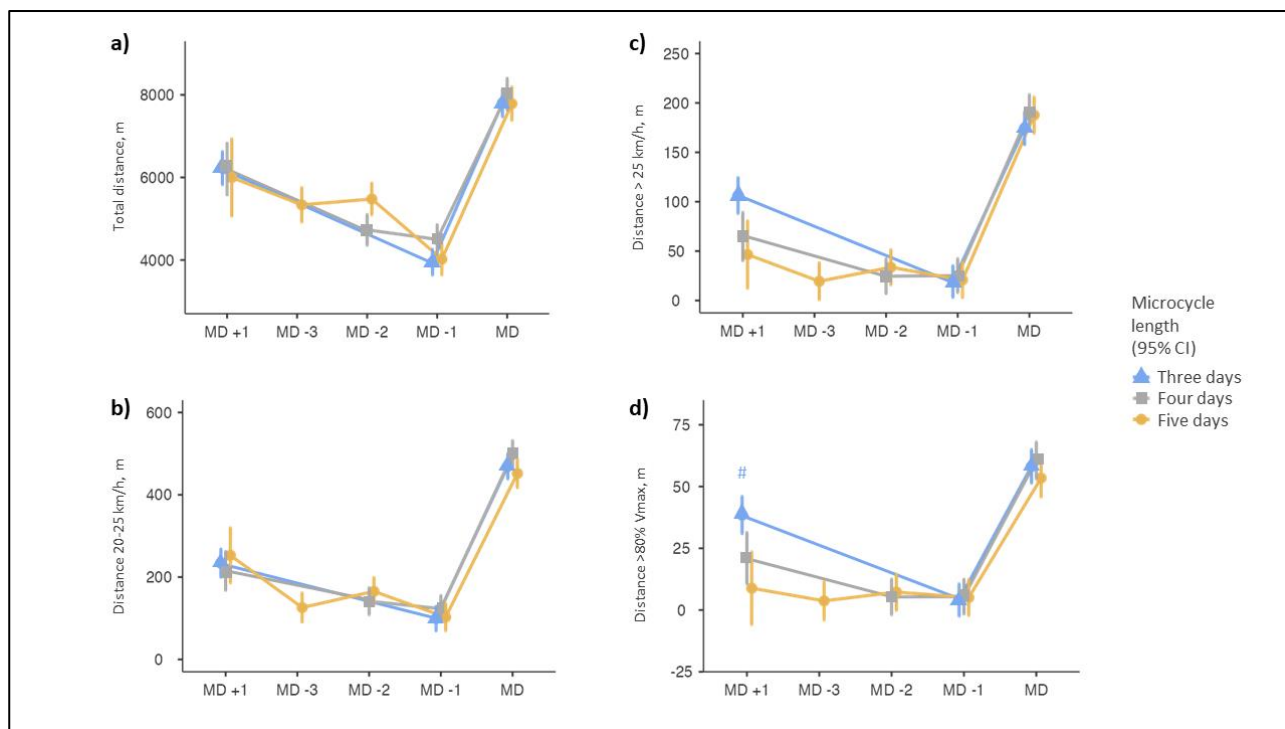


Figure 22: Microcycle type and training day type: total distance (a), high-speed running distance (b), sprint distance (c) and individualised sprint distance, i.e. >80% of the individual maximum speed (d). The load at MD+1 has been produced by non-starting players. Statistically significant differences ($p < 0.05$) across microcycles length are reported as follows: § significantly higher than three-day microcycles; * significantly higher than four-day microcycles; # significantly higher than five-day microcycles. Three-day microcycles data are represented in blue, four-day in grey and five-day in yellow.

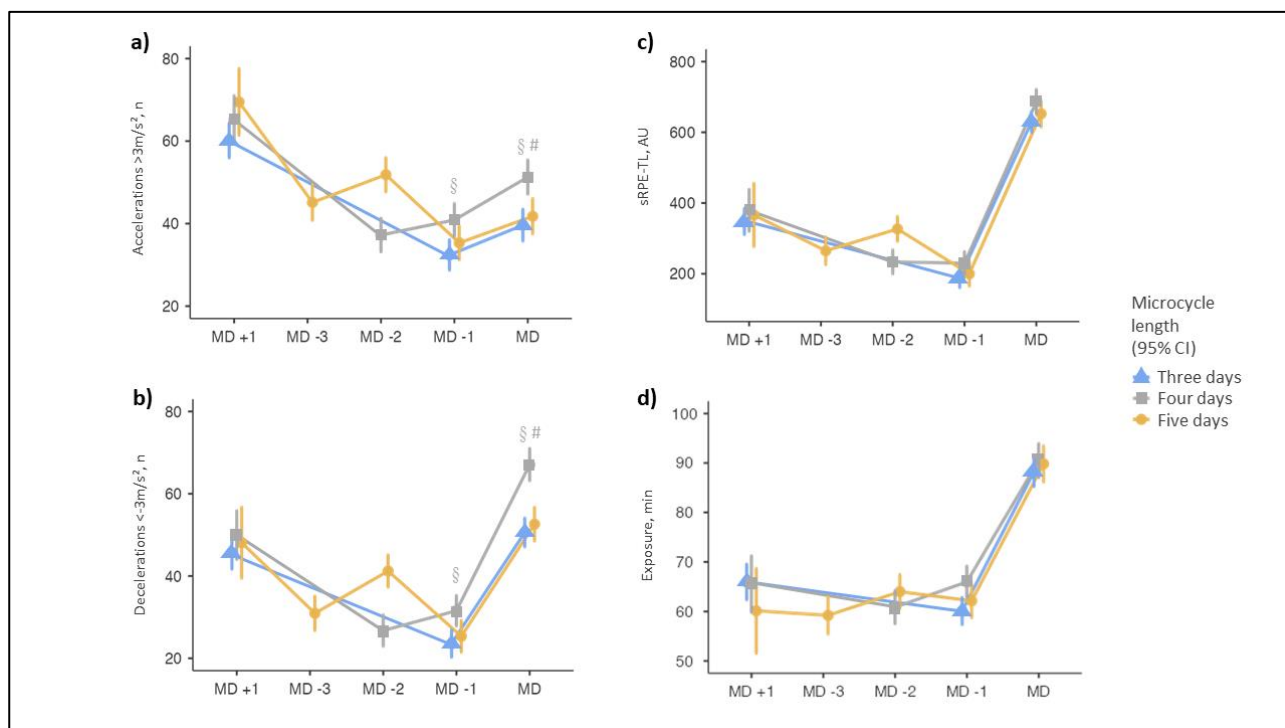


Figure 23: Microcycle type and training day type: accelerations (a), decelerations (b), sRPE, session Rating of Perceived Exertion (c) and exposure (d). The load at MD+1 has been produced by non-starting players. Statistically significant differences ($p < 0.05$) across microcycles length are reported as follows: § significantly higher than three-day microcycles; * significantly higher than four-day microcycles; # significantly higher than five-day microcycles. Three-day microcycles data are represented in blue, four-day in grey and five-day in yellow.

Table 11: Training days comparison in different microcycle types.

Sprint distance (>25 km·h ⁻¹)								
Split	Microcycle	Difference	SE	t	df	p _{bonferroni}	Cohen's d	
MD +1	Three vs Four	41.399	13.111	3.158	1426.857	0.05848	0.17	<i>trivial</i>
	Three vs Five	57.731	18.844	3.064	1428.799	0.0802	0.16	<i>trivial</i>
	Four vs Five	16.332	20.955	0.779	1426.711	1	0.04	<i>trivial</i>
MD -1	Three vs Four	-5.851	7.117	-0.822	1429.072	1	-0.04	<i>trivial</i>
	Three vs Five	-1.732	7.538	-0.23	1428.874	1	-0.01	<i>trivial</i>
	Four vs Five	4.119	8.264	0.498	1425.814	1	0.03	<i>trivial</i>
MD	Three vs Four	-15.705	7.95	-1.975	1430.302	1	-0.10	<i>trivial</i>
	Three vs Five	-13.614	8.353	-1.63	1429.997	1	-0.09	<i>trivial</i>
	Four vs Five	2.091	9.119	0.229	1426.369	1	0.01	<i>trivial</i>
Individual sprint distance (>80% individual maximum peak velocity)								
Split	Microcycle	Difference	SE	t	df	p _{bonferroni}	Cohen's d	
MD +1	Three vs Four	17.47	5.791	3.017	1427.023	0.09359	0.16	<i>trivial</i>
	Three vs Five	28.977	8.323	3.482	1429.122	0.01848	0.18	<i>trivial</i>
	Four vs Five	11.507	9.255	1.243	1426.869	1	0.07	<i>trivial</i>
MD -1	Three vs Four	-1.138	3.143	-0.362	1429.422	1	-0.02	<i>trivial</i>
	Three vs Five	-0.96	3.329	-0.288	1429.202	1	-0.02	<i>trivial</i>
	Four vs Five	0.178	3.65	0.049	1425.897	1	0.00	<i>trivial</i>
MD	Three vs Four	-2.247	3.511	-0.64	1430.744	1	-0.03	<i>trivial</i>
	Three vs Five	4.634	3.689	1.256	1430.404	1	0.07	<i>trivial</i>
	Four vs Five	6.881	4.028	1.709	1426.503	1	0.09	<i>trivial</i>
Accelerations >3 m·s ⁻²								
Split	Microcycle	Difference	SE	t	df	p _{bonferroni}	Cohen's d	
MD +1	Three vs Four	-5.23	2.817	-1.856	1427.087	1	-0.10	<i>trivial</i>
	Three vs Five	-9.748	4.049	-2.407	1429.245	0.58281	-0.13	<i>trivial</i>
	Four vs Five	-4.518	4.503	-1.003	1426.93	1	-0.05	<i>trivial</i>
MD -1	Three vs Four	-8.495	1.529	-5.555	1429.555	< .00001	-0.29	<i>small</i>
	Three vs Five	-2.977	1.62	-1.838	1429.328	1	-0.10	<i>trivial</i>
	Four vs Five	5.519	1.776	3.107	1425.929	0.06927	0.16	<i>trivial</i>
MD	Three vs Four	-11.574	1.708	-6.775	1430.913	< .00001	-0.36	<i>small</i>
	Three vs Five	-2.293	1.795	-1.278	1430.559	1	-0.07	<i>trivial</i>
	Four vs Five	9.281	1.96	4.737	1426.555	0.00009	0.25	<i>small</i>

Table 11 – continues

Decelerations <-3 m·s ⁻²								
Split	Microcycle	Difference	SE	t	df	p _{bonferroni}	Cohen's d	
MD +1	Three vs Four	-4.486	3.313	-1.354	1428.254	1	-0.07	<i>trivial</i>
	Three vs Five	-2.996	4.76	-0.63	1431.411	1	-0.03	<i>trivial</i>
	Four vs Five	1.489	5.294	0.281	1428.053	1	0.01	<i>trivial</i>
MD -1	Three vs Four	-7.942	1.798	-4.418	1431.908	0.00039	-0.23	<i>small</i>
	Three vs Five	-1.837	1.904	-0.965	1431.517	1	-0.05	<i>trivial</i>
	Four vs Five	6.105	2.088	2.923	1426.554	0.12664	0.15	<i>trivial</i>
MD	Three vs Four	-16.378	2.008	-8.158	1433.828	< .00001	-0.43	<i>small</i>
	Three vs Five	-2.167	2.109	-1.027	1433.207	1	-0.05	<i>trivial</i>
	Four vs Five	14.212	2.304	6.168	1427.549	< .00001	0.33	<i>small</i>

5.4 Discussion

This original study aimed, firstly, to quantify training and match day load during three-, four- and five-day microcycles in Italian Serie A professional adult football and secondly to compare the microcycle length on the training load during MD+1 and MD-1 and MD load.

The microcycle length seems to affect the average daily values of most of the variables of interest like high-speed running, sprint and individualized sprint distances, as such the number of accelerations and decelerations. Moreover, the microcycle type affected individualized sprint distance sustained by non-starting players at MD+1, as well accelerations and decelerations at MD-1 and MD for all the players.

The management of recovery and training in a specific congested fixture microcycles plays a key role for the long-term players health, physical development and fitness maintenance (Querido *et al.*, 2022). From the point of view of a starting player, the workload performed during the game becomes critical since there is not much time for training as highlighted in Chapter 4 and other similar studies (Anderson, Orme, Di Michele, Close, Milsom, *et al.*, 2016). On the other hand, from a non-starting player perspective the physical training compensation during the first two sessions of the microcycle is critical. The compensative load is easily achievable during a seven-day microcycle (Oliveira *et al.*, 2023), but almost impossible in the four- or three-day microcycle scenario described above. In a previous study, non-starting players typically had a lower total load than starters during weeks with two matches, with less time spent above 90% of maximum heart rate and covering a shorter high-speed running distance throughout the week, which fell short of the workload equivalent to a full match (Stevens *et al.*, 2017). For these reasons, as previously reported in Chapter

4, managing the load for both starting and non-starting players during a congested fixture mesocycle, which for top clubs can last some months or a whole season, becomes an arduous challenge for practitioners, especially for the most impacting aspects of the physical dimension of training such as high-speed and sprint running. In fact, Chapter 4 clearly demonstrated that such high velocities tend to be polarized during games, making it difficult for non-starting players to bridge the gap during training sessions.

5.4.1 Microcycle type

Microcycle type did not affect significantly the mean volume of the training intended as total distance, exposure time and sRPE training load, but different performance indicators of the intensity were affected by it (Figure 20 and Figure 21). The average high-speed running and sprinting distance was reduced by longer microcycles, in particular by five-day microcycles which caused a reduction of 14-19% and 16-32% respectively. This can be explained by the impact of the non-starting players load at MD+1, the main session for non-starting players to produce high-speed running and sprinting distances in all the microcycles analysed, with very low demands for the other days. The number of accelerations were lower in three-day microcycles when only two days were available to prepare the following match. This can be explained by the coaching staff's more conservative approach during three-day microcycles, particularly with non-starting players on MD+1 and with the entire team on MD-1. In that scenario, the training drills were more focused on organizing team tactics for the upcoming match rather than physical conditioning. This difference in training goals is pivotal, as conditioning a small number of players and preparing the team strategy for a match require completely different training setups. In the first case, small pitches are used, whereas organizing team strategy necessitates a full pitch, and using larger pitches always reduces acceleration demands. (Beato *et al.*, 2023). These data exacerbate the problem of the under-training for non-starting players during congested fixture periods with only two days between games as previously reported in Chapter 4.

The different trend between the microcycles in terms of accelerations and decelerations could be explained by the different type of drills proposed. In fact, match and game-based exercises tend to keep an acceleration-deceleration ratio around 1, while more analytical drills tend to reduce the decelerative demand (Barrett *et al.*, 2020). An example of an analytical drill is represented by the extensive category of technical development exercises. These exercises typically involve the player starting from a stationary position, performing

specific movements such as dribbling the ball to pass or kick it, and then returning to the starting position during the recovery period. As observed, the player remains in possession of the ball throughout the exercise, with no objectives related to being out of possession. The absence of a transition from possession to out of possession, which is characteristic of game-based exercises, allows the player to minimize the number of decelerations, thereby increasing the acceleration-deceleration ratio. In the analysed context, during five-day microcycles, a portion of the sessions was devoted to the technical development of the players. This approach maintained a high accelerative load while imposing a low decelerative demand, as previously explained.

5.4.2 Training day and microcycle type

As reported in other studies, also in this case the daily load decreased when MD approached, with the lower load at MD-1 (Anderson, Orme, Di Michele, Close, Morgans, *et al.*, 2016; Stevens *et al.*, 2017). The length of the microcycle did not significantly affect the load at MD-1, except for accelerations and decelerations, which were lower in a three-day microcycle compared to a four-day microcycle.

On the other side, in all the microcycles MD+1 was the session with the highest training load, which is a desirable outcome as it was generated by non-starting players. In terms of accelerations, the MD+1 training session was more demanding than the match itself. This can be attributed to the low number of players involved during training, as starting players focused on recovery while non-starters engaged in a compensatory session. Consequently, the characteristics of the drills, which preferentially utilized reduced pitch dimensions as detailed in the Methods section of the present chapter, contributed to this increased accelerations demand (Beato *et al.*, 2023; Beato, de Keijzer and Costin, 2023). At MD+1 deceleration demand was lower compared to acceleration demand, which is a different stimulus considering the greater deceleration number compared to acceleration recorded during games (Silva *et al.*, 2022).

Instead, the distance completed at high-speed running and sprinting was largely completed in the game itself, similarly to what previously reported in English Premier League players (Anderson, Orme, Di Michele, Close, Morgans, *et al.*, 2016) and in Chapter 4. In particular, the distance covered at speeds greater than 80% of the individual maximum velocity was notably low on all training days of a five-day microcycle compared to the shorter microcycles. This counterintuitive result can be explained considering the whole season during which

longer microcycles could have been used to favour recovery of starting players. In fact, the fatigue accumulated during chains of three- and four-day microcycles could have been mitigated avoiding single high-load training sessions during five-day microcycles. However, looking at the total volume of high-speed running and sprinting accumulated during the microcycles it becomes clear that the daily average was affected by the number of training days and that a higher absolute high-speed running and sprinting volume was produced when more days were available.

Four-day microcycles were the most demanding scenario in terms of accelerations and decelerations both at MD-1 and MD. These results recorded in Serie A football players are not in line with previous studies showing a higher performance at MD when reducing load at MD-1 (Douchet, Paizis and Babault, 2022). The demand of MD-2 between a four- and five-day microcycle was not compared, which might suggest that a five-day microcycle was more demanding at MD-2 than a four-day microcycle in terms of accelerations. Such fatiguing demands may have influenced the reduced number of accelerations and decelerations during the game at the end of a five-day microcycle compared to a four-day microcycle (Douchet, Paizis and Babault, 2022).

Apart for the number of accelerations and decelerations, the game physical demand was not affected by the microcycle length, but it is important to highlight that only different types of congested periods were compared. In fact, comparing congested and non-congested periods, lower accelerative and decelerative load was reported at MD when more matches were played and less training sessions were available (Djaoui *et al.*, 2022).

This study is not without limitations. As reported in Chapter 4, the sample was limited to a single Italian team observed over one season and therefore influenced by the national context and the specific training philosophy of the coaching staff. Ideally, sample size determination should be based on an a priori estimation; however, this was not feasible due to the specificity of the top-level football players monitored in this study. Consequently, a convenient yet representative sampling method was adopted, as previously recommended by other authors. Observations were conducted throughout an entire season, allowing for the collection of a substantial dataset (Hecksteden, Kellner and Donath, 2022). On the other hand, a key strength of this study is its high ecological validity. Data obtained from a highly specific, elite population can have a strong impact on real-world practice, even when derived from a small sample size (Harriss, MacSween and Atkinson, 2019), particularly for teams competing concurrently in the Italian Serie A and UEFA competitions. A second limitation that should be acknowledged pertains to the use of GNSS for monitoring training sessions

and a video tracking system for monitoring matches. Consequently, some variability between training and games could be attributed to the different monitoring systems employed even if this was not one of the aims of the present original study. A third limitation of this study is the lack of training load quantification for the post-match activities performed by non-starting players immediately at the end of the match when running based training was completed. A dedicated analysis of the training load of starting and non-starting players during various types of congested fixture periods could reveal valuable insights for practitioners. This is particularly relevant for MD+2, a critical training day when starting players need to complete their recovery, while non-starters are ready to train. Further studies could also investigate the impact of positions on training load distribution during different microcycles.

In conclusion, coaches seem to be influenced by shorter microcycles in their training proposal, preferring sessions with a reduced muscle impact when less days are available. This adaptation is managed by reducing the number of drills not focusing on the tactical preparation of the following match such as small-sided games and technical development drills, but not reducing the total exposure of every single session. Regardless of the length of the congested fixture microcycle, the daily load appears to decrease as MD approaches, with the lowest load occurring at MD-1, thereby increasing readiness for the following match day. A five-day microcycle appears to be the shortest period that allows for the alternation of training and recovery days. This alternation is a necessary condition for maintaining players' health and enhancing their performance, which, in turn, contributes to a safe and high-quality sports spectacle.

Practitioners can use present findings to re-think on their training plan during three-, four- and five-day microcycles and to look for any feasible improvement, in particular managing the technical and tactical drills selection. A lower number of accelerations and decelerations can be useful when few days are available to let starting players recover from the previous match and to be as ready as possible for the following one. Similarly, a “longer” five-day microcycle during a congested fixture period can be seen as a recovery opportunity for starting players rather than a “week” to train. On the other side, for non-starting players MD+1 can be a window of opportunity to reach high velocities since they may not have this stimulus the other training days of the week, especially if not exposed to this immediately after the game ends as some form of compensatory training. In Chapter 4 the gap between starting and non-starting players during a congested fixture mesocycle with 6 games in 21

days was reported and, in this Chapter, more detail was researched about the compensatory session for non-starting players in the day after the match.

These results, particularly the data recorded during the three-day microcycles, are being reported for the first time, thereby fulfilling one of the aims outlined in Chapter 1. Analysing this data, football governing bodies should consider increasing the minimum number of days allowed between two official games to allow players more time for recovery. This, in turn, would contribute to higher-quality football events and, hopefully to a lower number of muscle injuries. In this regard, the quality of a football match can be assessed in various ways. When focusing on physical quality, one of the primary indicators of quality is high-speed running, particularly during the most intense phases of the match. These phases were introduced in Chapter 3 and will be analysed in greater detail in Chapter 6.

Chapter 6: The most intense periods during elite football matches (original study)

Aspects of this chapter have been published in the following paper: Gualtieri A, Angonese M, Maddiotto M, Rampinini E, Ferrari Bravo D, Beato M. Analysis of the most intense periods during elite soccer matches: effect of game location and playing position. *Int J Sports Physiol Perform*. Ahead of print.

6.1 Introduction and aims

To summarize the main findings from the previous chapters, Chapter 2 highlighted the utility of individual velocity thresholds, which were further described in Chapters 4 and Chapter 5. In Chapter 4, a workload gap between starting and non-starting players during congested fixture mesocycles was identified, especially at very high-speed running intensity. This gap was further and indirectly elaborated in Chapter 5, with particular attention to the training session on the day after the match, which represents a crucial window of opportunity during congested fixture periods. In this chapter, a more detailed analysis is conducted to define the most intense phases of the match. This is a critical scenario, the most extreme, that non-starting players may not experience for extended periods if not adequately stimulated. Understanding and quantifying such intensity is the first step for practitioners to effectively train it.

As described in previous chapters, football is a physically demanding sport with games lasting at least 90 minutes. Several studies described the total physical demand of a match or its relative demand (i.e., the average demand per minute) to define training targets and design training sessions (Impellizzeri, Marcora and Coutts, 2019; Chaize, Allen and Beato, 2024). However, it was suggested that the average match activities do not fully explain the demands of the game and they cannot be the only reference point for players' preparation. Specifically, average values towards training may not expose players to the most intense periods which occur intermittently throughout matches (Delaney *et al.*, 2015).

As extensively reported in Chapter 3, previous research showed that mathematical models adopting moving average to assess the relationship between running intensity and duration have shown to be a valid way to quantify football match intensity and account for true periods of maximal player output (Delaney *et al.*, 2018), while using fixed durations lacks sensitivity and might underestimate true running demands up to 25% (Varley, Elias and Aughey, 2012; Fereday *et al.*, 2020). The peak locomotor periods that occur during a game have been reported using different terms such as most intense periods (MIP) (Martín-García,

Casamichana, *et al.*, 2018), peak match or physical demand (Whitehead *et al.*, 2018), duration-specific running demands (Duthie *et al.*, 2018), worst case scenario (Novak *et al.*, 2021) or other similar lexical alternatives. In this chapter, I decided to call this analysis “most intense periods” following the paper published by Novak *et al.* (Novak *et al.*, 2021). In that paper, the authors emphasize the importance of defining the most intense period for each individual performance marker, as it is nearly impossible for all markers to peak simultaneously. To illustrate, when the high-speed peak demand occurs, the deceleration demand would be zero. Consequently, the authors recommend avoiding the commonly used term “worst case scenario”, as it implies the simultaneous peak of all performance markers. From a recent Delphi survey, the most intense period in professional football are used by practitioners as benchmarks for exercise replication, especially when the single repetition has a short duration to keep as high as possible the training physical demand (McCall *et al.*, 2020). This approach can be useful to prepare players for all the technical and tactical situations where they have to reach very high intensities to cover high distances in the shortest possible time, really different from the average game demand (Abbott, Brickley and Smeeton, 2018; Riboli, Esposito and Coratella, 2022). An example of this concept is the negative and positive transitions, which are the phases during which a team loses ball possession (negative transition) and the opposing team gains it (positive transition), respectively (Bortnik, Burger and Rhodes, 2022).

Extending the duration of this phase, a 5-min peak match demand was reported to be more than twofold for high-speed running distance and three-to sixfold for sprint distance, depending on the playing position, compared with the match average both in elite female (Ramos *et al.*, 2017) and male (Riboli *et al.*, 2021) players. Raising the bar, previous research has reported that relative distance can be over 200 m·min⁻¹ when analysed using short time windows (i.e., 1 min) in USA Major League of Soccer (Calder and Gabbett, 2022), and this game-speed intensity is much higher than the average relative distance (i.e., around 110 m·min⁻¹) reported considering the whole game in English professional football (Beato, Youngs and Costin, 2024; Chaize, Allen and Beato, 2024). Similarly, in other studies, the average locomotor demand was significantly lower than 1-minute peak demand. Specifically, it accounted for approximately 53-59% of the total distance, around 16-19% of the high-speed running distance, and roughly 6-9% of the sprinting distance (Riboli, Esposito and Coratella, 2022; Oliva-Lozano *et al.*, 2023). This very high game demand was not achieved with small, medium or large-sided games, for this reason other specific training

options must be explored (Abbott, Brickley and Smeeton, 2018; Lacombe *et al.*, 2018; Riboli, Esposito and Coratella, 2023).

Differences across various playing positions during the 1 to 10-minute periods of highest physical demand in professional male football have also been documented (Abbott, Brickley and Smeeton, 2018; Martín-García, Casamichana, *et al.*, 2018; Connor, Mernagh and Beato, 2022; Thoseby *et al.*, 2023). Therefore, playing positions should always be considered when applying the MIP concept. Specifically, central midfielders (CM) reported higher relative distance compared to wide midfielders (WM) (Connor, Mernagh and Beato, 2022) and both CM and WM covered greater total distance and fewer meters sprinting compared to the other playing roles (Martín-García, Casamichana, *et al.*, 2018). Considering the specific tactical behaviour, attacking midfielders covered greater peak total distance than all the other players (Thoseby *et al.*, 2023). In the case of high-speed running, full-backs covered the greatest distance, reaching values of $47.2 \pm 24.0 \text{ m} \cdot \text{min}^{-1}$ when considering the most intense minute of the match (Martín-García, Casamichana, *et al.*, 2018). Similarly, peak high-speed distances were greater for wingers (Thoseby *et al.*, 2023) or WM and forwards (Riboli *et al.*, 2021) than all other positions.

To date, information related to match demand and mathematical models used to evaluate game speed in professional football players is growing since such information may help sports scientists and coaches to adequately prepare football players. Research has mainly studied time epochs of durations from 1 to 10 min (Rico-González *et al.*, 2022; Weaving *et al.*, 2022), but peak durations of crucial attacking and defending activities in elite football last between 20 and 30 sec (Bortnik, Burger and Rhodes, 2022). To date, no shorter than 1 minute duration epochs were analysed for elite football players, causing the lack of more football-specific ways to expose players to maximum physical outputs they achieve in competition. Therefore, the aims of this original study were, firstly, to quantify and model the game-speed demands of elite football players competing in the Italian Serie A using time windows from 5 seconds to 10 minutes, secondly to compare the effect of match location on game-speed outputs, and lastly to examine the effect of playing position on game-speed outputs. The hypothesis was that game speed is affected by the time window being analysed, by the location of the match (home vs. away), and by the players' positional group.

6.2 Methods

6.2.1 Experimental design

A whole season observational longitudinal research design was adopted to establish the relationship between peak running intensity and duration during elite adult football competition. A two-level analysis was conducted to identify peak intensities from a range of locations (home VS away) and positions (center-back [CB], full-back [FB], central midfielder [CM], wide midfielder [WM] and forward [F]).

6.2.2 Subjects

Twenty-four male professional Serie A football players were monitored in this study (age 27.5 ± 4.1 years; body mass 79.3 ± 6.1 kg; height 183.8 ± 3.9 cm; maximum speed 31.0 ± 2.3 km.h⁻¹). The inclusion criteria imposed their participation in at least one 60-minutes official match. Goalkeepers were excluded from this study, therefore, only outfield players' match data were evaluated. Like in the other chapters, the sample size was not estimated a priori but convenience sampling was used in this study, which is a non-probability sampling method where subjects are selected for inclusion in the sample because of factors related to the researcher's access to these subjects, i.e., the players within a specific professional club that represent a unique sample. The actual sample size of this study was 340 single observations. The Ethics Committee of the University of Suffolk (Ipswich, UK) approved this study (project code: RETH19/020). Informed consent to take part in this research was signed by the club. All procedures were conducted according to the Declaration of Helsinki for human studies.

6.2.3 Methodology

During matches, external load metrics were evaluated by a semi-automatic video tracking system (Stats Perform, Chicago, Illinois, USA) as described in Chapter 3. Validity and reliability of this type of apparatus to monitor competitions were previously reported (Buchheit *et al.*, 2014; Taberner *et al.*, 2019) and described in Chapter 3. At the end of each match, a raw speed trace for each player was exported and further analysed using customized software (Anaconda Inc, Python, version 3.10.12). Total distance covered (TD),

high-speed running distance (HSR, $>20 \text{ km}\cdot\text{h}^{-1}$) and sprint distance (SD, $>25 \text{ km}\cdot\text{h}^{-1}$) were calculated. A moving average analysis technique (Varley, Elias and Aughey, 2012) was then applied to each of the output variables, using 15 different durations: 5-10-15-30-60-90 seconds and from 2 to 10 minutes. These durations were defined considering the inflection point and the decrease rate of the relationship between movement velocity and duration during football matches previously described (Roecker *et al.*, 2017). The peak value achieved throughout each match was recorded for each variable for each player as described in Chapter 3. The maximal value across each of the moving average window durations has been then extracted and converted to units of metres per minute ($\text{m}\cdot\text{min}^{-1}$) for further statistical analysis. To calculate the most intense periods for high-speed running and sprint distance, the distance covered was calculated considering only the frames where the speed exceeded 20 and 25 $\text{km}\cdot\text{h}^{-1}$, respectively. To quantify the relationship between moving average duration and running intensity, each of the 3 peak output measures was evaluated relative to the moving average duration, as a power law $y = cx^n$ relationship (Delaney *et al.*, 2018). This resulted in an intercept (c) and slope (n) for each metric (i.e., TD, HSR and SD) for every individual match observation. In addition, team peak values (i.e. the average of all the single player values) for each match were recorded as well as the location to compare home (*team0*) and away (*team1*) games.

6.2.4 Statistical Analyses

Before statistical analyses, the slope and intercept of the speed values were log transformed. All statistical analyses were performed using customized software (R Core Team. R, version 4.3.2). Linear mixed models (lme4 package in R; V 1.1-35.1 and lsmeans package in R; V 2.30.0) were used to determine the magnitude of differences between game location (home VS. away; fixed effects) and players playing roles (CB, FB, CM, WM, and F; fixed effects). The random effects in the models' design were player identification codes, representing mean differences between athletes. The least-squares mean test provided pairwise comparisons of running intensity measures for each game location and playing role, which were further assessed using estimates of 95% confidence intervals (CIs). Unless otherwise stated, significance was set at $p < 0.05$ for all tests.

6.3 Results

All the results for all the durations analysed are reported and expressed in $\text{m}\cdot\text{min}^{-1}$ in Table 12. Total distance varied from $456 \text{ m}\cdot\text{min}^{-1}$ of the most intense 5 seconds (i.e. 38 m in 5 seconds) to $206 \text{ m}\cdot\text{min}^{-1}$ of the most intense minute to $136 \text{ m}\cdot\text{min}^{-1}$ of the most intense 10-minute match fraction. The Power-Law curves are reported in Figure 24. All models demonstrated near perfect fits ($R^2 > 0.97$).

Table 12: Team average $\pm$ standard deviation for total distance, high-speed running distance ($>20 \text{ km}\cdot\text{h}^{-1}$) and sprint distance ($> 25 \text{ km}\cdot\text{h}^{-1}$) of the most intense periods of the game using 5 seconds to 10 minutes moving average time windows and expressed in $\text{m}\cdot\text{min}^{-1}$.

MIP	Total distance ($\text{m}\cdot\text{min}^{-1}$)	High-speed running ($\text{m}\cdot\text{min}^{-1}$)	Sprint running ($\text{m}\cdot\text{min}^{-1}$)
5"	456.0 ± 34.9	456.0 ± 40.0	432.0 ± 115.2
10"	390.0 ± 39.3	348.0 ± 70.2	234.0 ± 102.4
15"	332.0 ± 32.8	240.0 ± 58.5	160.0 ± 70.1
30"	260.0 ± 25.9	130.0 ± 35.6	80.0 ± 35.8
1'	206.0 ± 18.3	74.0 ± 19.5	41.0 ± 18.8
90"	185.0 ± 14.2	54.7 ± 14.3	28.4 ± 12.9
2'	173.5 ± 13.7	45.0 ± 12.5	21.5 ± 10.4
3'	159.2 ± 12.2	36.2 ± 9.8	15.2 ± 7.4
4'	152.5 ± 11.7	29.8 ± 8.2	12.2 ± 5.9
5'	148.0 ± 11.4	26.6 ± 7.4	10.6 ± 5.1
6'	144.6 ± 11.4	24.3 ± 7.0	9.0 ± 4.6
7'	142.2 ± 11.4	22.3 ± 6.5	8.0 ± 4.1
8'	139.3 ± 11.1	21.0 ± 6.1	7.4 ± 3.8
9'	137.3 ± 10.8	20.0 ± 5.9	6.7 ± 3.4
10'	136.2 ± 10.9	19.0 ± 5.6	6.2 ± 3.3

6.3.1 Home vs away games

For all the time windows analysed there were no significant differences observed between home and away matches in terms of total distance covered and high-speed running. However, trivial differences were noted in sprint distance performed by the team, which are slightly higher during home games. Estimate values were -2.54 ($p = 0.1003$), 1.1 ($p = 0.5067$) and 3.98 ($p = 0.0192$) for total distance, high-speed running and sprint distance, respectively.

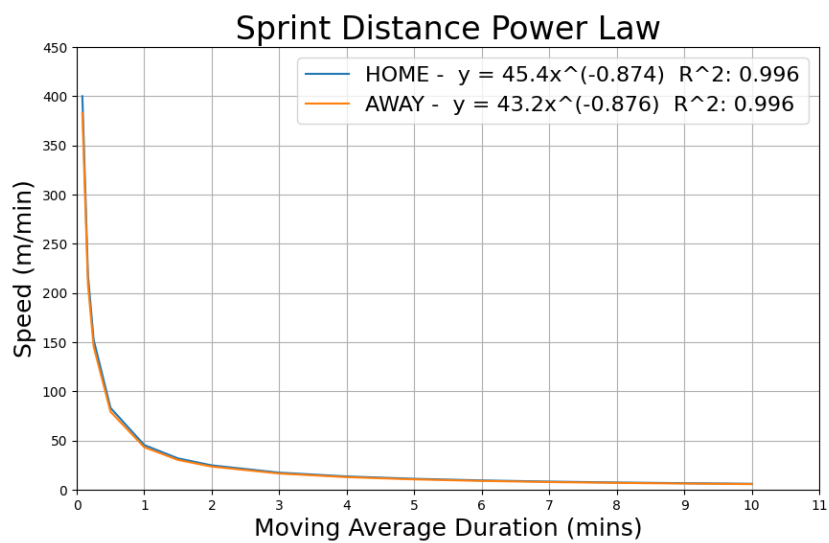
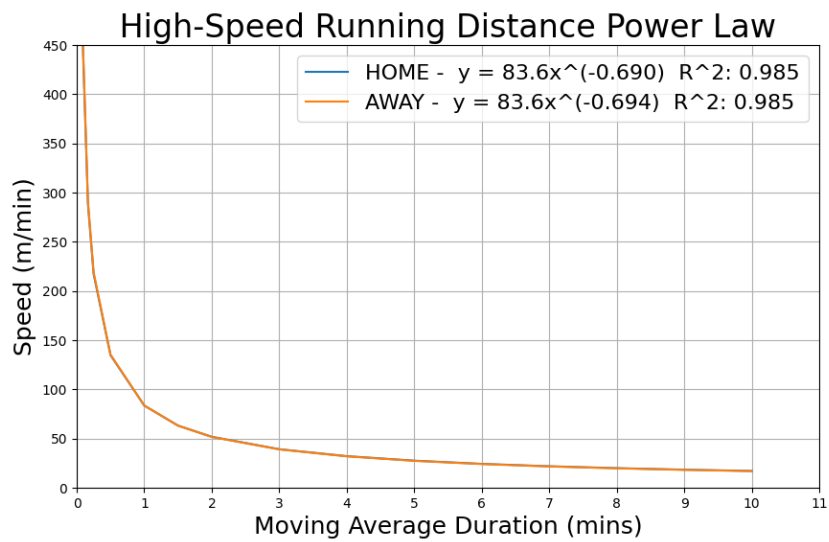
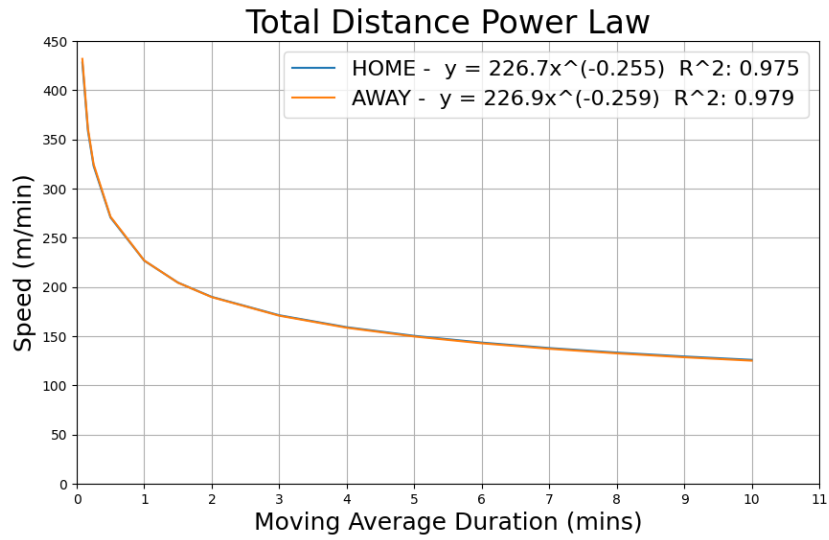


Figure 24: Power law models for home and away matches for (A) total distance, (B) high-speed running distance ($>20 \text{ km}\cdot\text{h}^{-1}$) and (C) sprint distance ($>25 \text{ km}\cdot\text{h}^{-1}$).

6.3.2 Playing roles comparison

The power law curves with the relative slopes and intercepts are reported in Figure 25. Since the differences between roles observed across all time windows from 5 seconds to 10 minutes were consistent, only the differences for the most intense minute are reported (Table 13). In fact, it was previously suggested that short-duration passages (i.e., 1 min) are a more precise approach to establish the MIP of the match, as additional issues (e.g., match stoppages, contextual factors and players fatigue) might influence the MIP over longer time windows (Jiménez *et al.*, 2023).

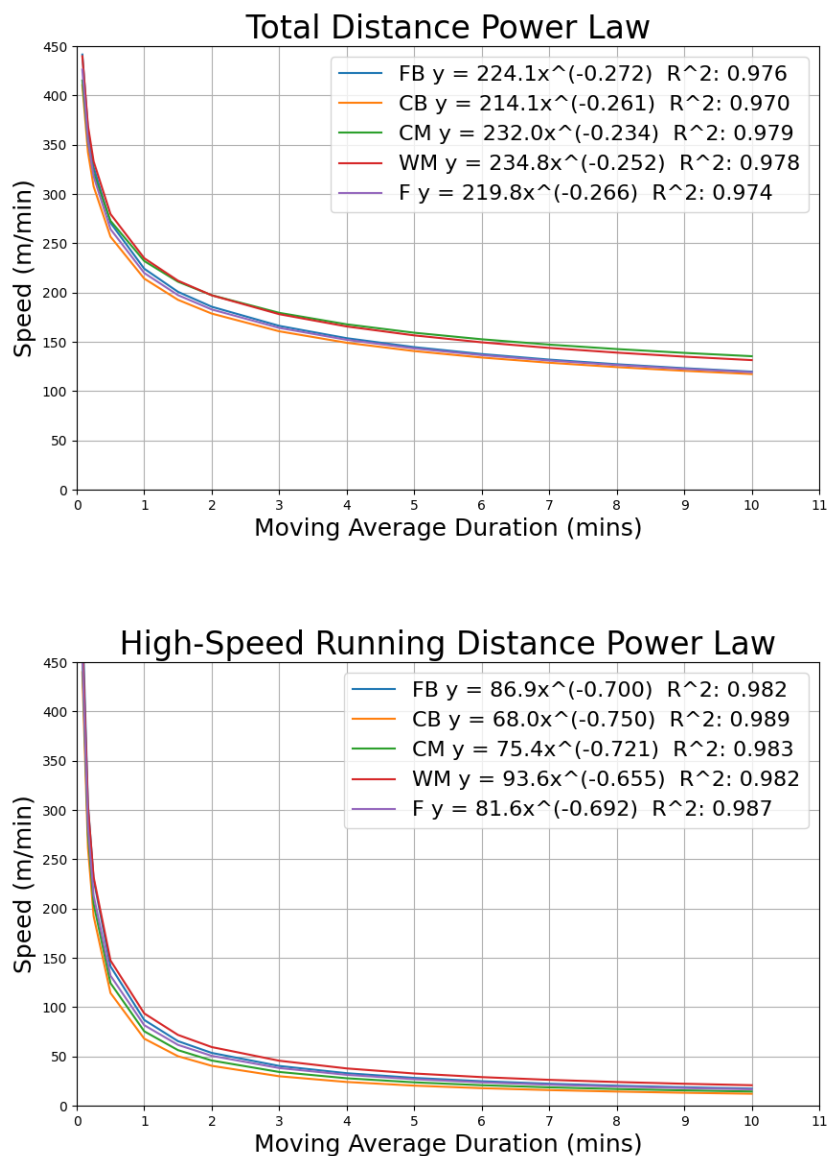


Figure 25: Power law models for (A) total distance, (B) high-speed running distance (>20 km·h⁻¹) and (C) sprint distance (>25 km·h⁻¹) run by full-back (FB), centre-back (CB), central midfielder (CM), wide midfielder (WM) and forward (F).

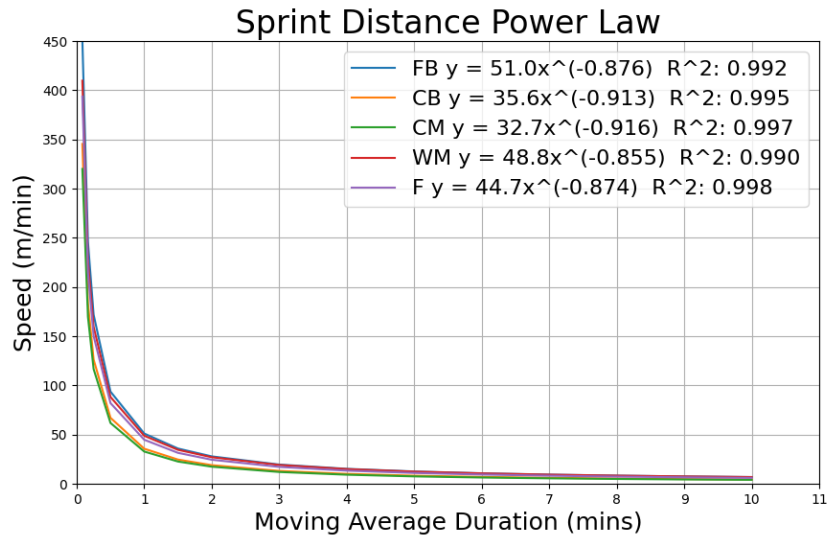


Figure 25 (continues): (C) sprint distance (>25 km·h⁻¹) run by full-back (FB), centre-back (CB), central midfielder (CM), wide midfielder (WM) and forward (F).

Independently by the time window, the highest values for total distance were recorded by CM and WM, significantly different from CB (+19 m, $p = 0.0001$ and +20 m, $p < 0.0001$, respectively), F (+12 m, $p = 0.0082$ and +12 m, $p = 0.0019$) and FB (+13 m, $p = 0.0035$ and + 14 m, $p = 0.0004$). CB performed less high-speed running compared to FB (-12 m, $p = 0.0011$) and WM (-13 m, $p = 0.0079$), while CM values were lower compared to WM (-10 m, $p = 0.0052$). In terms of sprint distance, no significant differences were found between roles, but only a tendency between CB and FB (-63 m, $p = 0.0839$).

Table 13: Most intense minute (60 seconds) between playing roles comparison for full-back (FB), centre-back (CB), central midfielder (CM), wide midfielder (WM) and forward (F). Confidence level used: 0.95.

Total distance (m·min ⁻¹)					
Contrast	Difference	SE	Lower CL	Upper CL	P value
CB-CM	-19.366	4.75	-28.84	-9.897	<0.001
CB-F	-7.664	4.94	-17.54	2.212	0.126
CB-FB	-5.964	3.26	-12.37	0.447	0.068
CB-WM	-19.703	4.16	-27.99	-11.417	<0.001
CM-F	11.702	4.35	3.08	20.324	0.008
CM-FB	13.403	4.47	4.51	22.291	0.004
CM-WM	-0.337	3.18	-6.6	5.928	0.916
F-FB	1.701	4.69	-7.66	11.060	0.718
F-WM	-12.039	3.79	-19.55	-4.533	0.002
FB-WM	-13.740	3.77	-21.21	-6.267	<0.001

High-speed running >20 km·h ⁻¹ (m·min ⁻¹)					
Contrast	Difference	SE	Lower CL	Upper CL	P value
CB-CM	-2.86	5.31	-13.4	7.7	0.592
CB-F	-8.41	5.54	-19.5	2.65	0.134
CB-FB	-11.58	3.53	-18.5	-4.64	0.001
CB-WM	-12.6	4.64	-21.8	-3.38	0.008
CM-F	-5.56	4.81	-15.1	3.94	0.249
CM-FB	-8.72	4.97	-18.6	1.14	0.082
CM-WM	-9.75	3.46	-16.6	-2.93	0.005
F-FB	-3.16	5.25	-13.6	7.29	0.549
F-WM	-4.19	4.18	-12.5	4.09	0.319
FB-WM	-1.02	4.18	-9.3	7.25	0.807

Sprint distance >25 km·h ⁻¹ (m·min ⁻¹)					
Contrast	Difference	SE	Lower CL	Upper CL	P value
CB-CM	-25.613	5.38	-13.26	8.141	0.635
CB-F	-47.031	5.6	-15.9	6.491	0.404
CB-FB	-62.858	3.63	-13.42	0.848	0.084
CB-WM	-62.127	4.71	-15.57	3.145	0.190
CM-F	-21.418	4.9	-11.83	7.546	0.666
CM-FB	-37.245	5.05	-13.75	6.297	0.463
CM-WM	-36.514	3.55	-10.64	3.336	0.305
F-FB	-15.827	5.31	-12.17	9.006	0.767
F-WM	-15.096	4.26	-9.94	6.924	0.724
FB-WM	0.0731	4.25	-8.34	8.489	0.986

6.4 Discussion

The aims of this original study were to quantify the most intense periods of game-speed demand for elite football players competing in the Italian Serie A using time windows from 5 seconds to 10 minutes. In addition, it was compared the effect of match location on most intense periods game-speed outputs, and it was examined the effect of playing position.

During the most intense minute of the match, slightly higher sprint distance was performed during home games. Comparing the most intense minute between the playing positions, central midfielders and wide midfielders run the highest values for total distance, centre-back produced the lowest high-speed running distance value and no significant differences between roles were found in terms of sprint distance.

Comparing the running intensities analysed in the different time windows (Table 12: Team average $\pm$ standard deviation for total distance, high-speed running distance (>20 km·h⁻¹)

and sprint distance ($> 25 \text{ km}\cdot\text{h}^{-1}$) of the most intense periods of the game using 5 seconds to 10 minutes moving average time windows and expressed in $\text{m}\cdot\text{min}^{-1}$. Table 12) it appears that the most intense 5 seconds are run at a speed above $20 \text{ km}\cdot\text{h}^{-1}$ since total distance and high-speed running values are superimposable. Stretching the time window, total distance values decrease slower than high-speed running and sprinting values, confirming that high-speed can be maintained or is requested for reduced time periods during a match. In fact, peak durations of crucial attacking and defending activities in elite football were reported to last between 20 and 30 seconds (Bortnik, Burger and Rhodes, 2022). The different decrease ratio of the curves supports the need of different set durations for exercises targeting the total distance or high-speed running and sprinting distance of the most intense periods. For total distance seems that no differences exist between time windows longer than 5 minutes, while for high-speed running and sprinting distance seems that this breaking point occurs earlier around 2 minutes. Anyway, as previously reported (Roecker *et al.*, 2017), for all the three metrics selected for this study the main differences were detected for time windows lower than 1 minute with values decreasing quickly from 5 to 60 seconds.

Similar to what previously reported for high-speed running in elite women and male football (González-García *et al.*, 2023; Chaize, Allen and Beato, 2024) and total distance in elite male football (Chaize, Allen and Beato, 2024), playing at home seemed to be more demanding in terms of sprint distance in the most intense passages of the game, potentially because of the in favour-crowd effect previously described (Dellagrana, Nunes and Silva, 2023). This information, for instance, can be useful when returning to play after an injury and when planning the first match for a player that sustained a hamstring strain injury. In fact, the lower sprint running capability of injury returning players has been previously reported (Whiteley *et al.*, 2020). For this reason, planning away the first official match after that kind of muscle injury can be advisable when feasible. However, other previous studies have identified no effect between game location and most intense periods (Connor, Mernagh and Beato, 2022) and a previous study reported the most intense period to be more demanding in all the external load variable when playing away matches (Oliva-Lozano *et al.*, 2020). Since the conflictual results, future studies are necessary to examine additional contextual variables (e.g., level of the opponent, total number of fans at the match) which may explain this effect on game most intense periods.

Differences across various playing roles during the most intense periods of the game were found even if differences are minimized in peak-intensity periods compared to match average values (Panduro *et al.*, 2022). Similarly to what previously reported, in the 1 min

MIP the highest values for total distance were recorded by midfielders (Martín-García, Casamichana, *et al.*, 2018), independently if they were central or wide midfielders (Oliva-Lozano *et al.*, 2020). Differently from previous studies (Novak *et al.*, 2021; Connor, Mernagh and Beato, 2022), no significant differences between central and wide midfielders were found, probably because of the different tactical organization (Calder and Gabbett, 2022). For high-speed running can be confirmed that fullbacks and wide midfielders were the most taxed players (Martín-García, Casamichana, *et al.*, 2018; Riboli *et al.*, 2021; Thoseby *et al.*, 2023), especially compared to centre-backs, which performed the lowest high-speed running distance.

In terms of sprint distance, no significant differences were found between roles, but only a tendency between CB and FB. This result let suppose a team behaviour when speed above $25 \text{ km}\cdot\text{h}^{-1}$ are needed during the game, typically during offensive and defensive transition phases that require all the players to produce sprint distance to move quickly in the opposite midfield (Bortnik, Burger and Rhodes, 2022), independently by the goal differential and time of game (Schimpchen, Gopaladesikan and Meyer, 2021). As previously supposed, the rationale for this may be the nature of the most intense periods, that lead all players to act suddenly to try to recover a steady state and avoid the opponent's progression towards a goal scoring opportunity (Oliva-Lozano *et al.*, 2020).

Although adding relevant information regarding elite adult football players MIP, this original study is not without limitations. Firstly, the sample utilized is limited to just one team, however, this was due to the specificity of the top-level football players monitored in this study (Serie A players), therefore a convenience sampling was used and the observations were repeated during a whole season gathering a large dataset (Hecksteden, Kellner and Donath, 2022). Contrariwise, a strength of this study is its high ecological validity; data coming from a very specific population have a very high impact on real-world practice, even with a small sample size (Harriss, MacSween and Atkinson, 2019), but caution is needed when extending conclusions to other competitions such as international competitions or other Championships. A second limitation that should be acknowledged is the univariate approach adopted to describe the most intense periods: the analysis was based on velocity without considering all the other high-taxing actions like jumping, dribbling, accelerating, decelerating or fighting that need a dedicated analysis to detect the relative peak demand during games. Contrariwise, the running demand represent the key performance index of most interest to practitioners to target in training (Novak *et al.*, 2021), especially when using football-specific drills (Weaving *et al.*, 2022). Furthermore, considering in the analysis other

contextual factors beyond the fans support like the tactical situations would provide a more holistic and reliable approach driving to better training proposals.

In conclusion, the quantification of the peak match demands is important to appropriately prepare players for the most intense periods of the game using football-specific drills. During the most intense minute of the match in terms of running demand, slightly higher sprint distance was performed when playing a home match probably because of the crowd support. This should be considered when planning the first match for a player that sustained a hamstring strain injury and for this reason with a lower sprint running capability. Midfielders run the highest values for total distance, centre-back produced the lowest high-speed running distance value and no significant differences between roles were found in terms of sprint distance, probably because of a team behaviour during the most intense phases of the game such as offensive and defensive transition phases. When planning a specific exercise targeting the most intense minute of the match in terms of total distance, a univariate approach based on velocity can help to develop representative training proposal accounting for positional differences. At the same time, when the target is the sprint distance, role differences can be disregarded when using the most intense minute of the game as benchmark. Finally, practitioners need to keep in mind that most intense periods benchmark should be considered exclusively to monitor the physical demand of representative football-specific drills and not for running-based drills.

To connect all the results emerged from the three original studies reported in Chapter 4, Chapter 5 and Chapter 6 a general discussion is reported in the next Chapter.

Chapter 7: General discussion and future directions

7.1 Overview

The preceding Chapter 4, Chapter 5 and Chapter 6 presented the single original studies undertaken with some interconnections related to common approaches adopted. Instead, this chapter aims to synthesize the findings of the studies presented and demonstrate the value of the new results within the broader research landscape. It also seeks to highlight practical recommendations that coaches and sport scientists can implement to enhance player performance and safeguard athlete health, particularly in comparable contexts, such as Italian teams competing in the UEFA Champions League, Europa League, and Conference League. This chapter will examine the intersections between the new findings emerged from the three original studies, and the broader evidence on the topic. Reflections on the importance of this work and the strengths of the studies will be given, and the limitations of the work considered. Recommendations for the application of this research will be described in light of the examined novelty, strengths, and limitations.

Given the growing and sustained interest in the subject of high-speed running in football, the purpose of this thesis was to provide a comprehensive description of its dynamics within an Italian élite adult football team and to elucidate the specific patterns, demands, and implications of high-speed running in this context, offering valuable insights into how elite football players manage and optimize their performance through targeted training and recovery strategies.

In order to reach the goal, the main hypothesis were that (1) non starting players are less taxed compared to starting players, especially at very high running velocity, (2) very short congested fixture microcycles exacerbate this gap and, (3) most intense periods need to be trained specifically since significantly different from average match values.

To verify these hypotheses, Chapter 4, Chapter 5 and Chapter 6 necessitated a preliminary review of the existing literature to investigate the high-speed running thresholds employed to characterize the training and performance of football players. The systematic review presented in Chapter 2 was crucial in establishing the velocity thresholds for data collection in Chapter 4, Chapter 5, and Chapter 6. More importantly, it highlighted the lack of a universally accepted international standard for velocity thresholds among football

practitioners. Additionally, Chapter 2 was instrumental in defining the match and training load that a football player must achieve to perform at the highest level, allowing for comparisons with the results reported in Chapter 4 and Chapter 5. Simultaneously, the most recent evidence regarding the relationship between high-speed running and muscle injuries was compiled, providing practitioners with a robust foundation for constructing their prevention strategies.

Once the most robust markers of high-speed running for football players were defined in Chapter 2, the aims of Chapter 4 were to examine the differences in high-speed running load between starting and non-starting players during congested fixture periods. High-speed running was mainly influenced by the total exposure to training: when non-starting players were not adequately trained during the days when starting players aimed to recover from the previous match, the existing gap between the two groups was not bridged. Comparing different sprint thresholds, it was evident that higher thresholds, in addition to the commonly used one (i.e., distance above $25 \text{ km} \cdot \text{h}^{-1}$), are needed to identify the stimulus non-starting players require in terms of sprint training.

The workload data collected for the original study presented in Chapter 4 was further analysed in Chapter 5. In Chapter 4, the 21-day mesocycle load was reported comprehensively, only separating training and match load. In Chapter 5, the workload for each individual day was analysed, comparing strategies adopted in microcycles with different numbers of days. In this case, the higher velocity threshold set at 80% of the individual maximum speed was useful in distinguishing different strategies, especially during the three-day microcycle, the shortest one analysed. Most importantly, longer microcycles resulted in lower mean daily load, allowing the load to be distributed over more days. The day after the match, the most important training session for non-starting players, were confirmed to have the highest load of every microcycle during congested fixture periods, but they did not reach the volume of the match demand.

To effectively prepare players, particularly those with limited match exposure, the total or mean value of the match may not be sufficient. The intermittent nature of football games can concentrate physical demands into very short periods. Therefore, in Chapter 6, the most demanding passages of the games were described to provide an additional benchmark to those analysed in Chapter 5. The most intense periods require dedicated analysis during

training sessions to ensure that non-starting players experience these high-intensity scenarios, regardless of their exposure to official matches.

7.2 Velocity thresholds for high-speed running

The comprehensive review of the literature presented in Chapter 2 underscores the absence of a consensus regarding specific thresholds that define high-speed running and sprinting in professional football, encompassing both male and female athletes. The most common absolute high-speed running entry velocities appear to be $12.5 \text{ km}\cdot\text{h}^{-1}$ for female players and $19.8 \text{ km}\cdot\text{h}^{-1}$ for male players. Similarly, common absolute entry velocities for sprint running can be identified, such as $22.5 \text{ km}\cdot\text{h}^{-1}$ for female players and $25.2 \text{ km}\cdot\text{h}^{-1}$ for male players. These “most common threshold among practitioners” align to some extent with the FIFA suggested absolute velocity thresholds, which are $19 \text{ km}\cdot\text{h}^{-1}$ and $20 \text{ km}\cdot\text{h}^{-1}$ for female and male high-speed running entry speeds, respectively, and $23 \text{ km}\cdot\text{h}^{-1}$ and $25 \text{ km}\cdot\text{h}^{-1}$ for female and male sprint running entry speeds, respectively.

It is suggested that both absolute and relative thresholds can be useful for coaches. Absolute thresholds, such as those reported in the previous lines, can be employed to analyse and compare performances across different players, when the absolute value makes a difference in terms of performance. In other words, a player capable of performing more sprint distance during a match may be preferable to a player who is not ready to cope with high match physical demands. On the other hand, relative thresholds can help monitor training at velocities approaching individual maximums, aiming to bring each player as close as possible to their maximum velocity to achieve the consequent physical response, regardless of individual maximal capacity. Indeed, training players to run at or just below their maximal velocity has been shown to have a protective effect, particularly in preventing hamstring injuries. This approach helps condition the muscles to handle high-intensity efforts, reducing the risk of injury during matches and training sessions. By incorporating such training strategies, coaches can enhance player performance while also prioritizing their long-term health and fitness. Additionally, relative thresholds proved to be more sensitive in both Chapter 4 and Chapter 5 to highlight differences between starting and non-starting players. This was mainly due to the higher speed absolute value described by the selected relative threshold. The selected percentage of the individual maximum velocity, set at 80%, was higher than the entry speed for the sprint threshold set at $25 \text{ km}\cdot\text{h}^{-1}$. Therefore, for adult professional players with peak velocities above $31.5 \text{ km}\cdot\text{h}^{-1}$, where 80% is 25.2

km·h⁻¹, it could be particularly important to add one or more relative speed thresholds to raise the bar of the velocity monitoring.

7.3 Starting and non-starting players workload during congested fixture periods

The playing time in the match day discriminate between starting and non-starting players. This differentiation is needed since the match is the highest single day load a football player experience during his week. During matches, the distances covered in high-speed running and sprinting are contingent upon the player's position and exhibit significant variability across different phases of the game, especially during the most intense passages of the match describe in Chapter 6. To ensure adequate exposure to high-speed running and sprinting during training sessions, especially for non-starting players, it is recommended to utilize a combination of contextualized game-based drills and running-based exercises. Although high-speed running and sprint distances have the potential to cause muscle injuries, when correctly integrated into training regimens, they may serve a protective function.

During periods of congested fixtures, when two matches per week must be played, the disparity in the volumes of internal and external load experienced by starting and non-starting players is exacerbated. In Chapter 4, it was found that this workload gap is primarily attributable to the differing total exposure times and the unique workload demands of matches, particularly in terms of high-speed running and sprinting distance. Importantly, to underline the significance of adopting both absolute and relative velocity thresholds, individualized thresholds for very high-speed running distances, as described in Chapter 2, can assist in identifying the workload deficits of non-starting players reported in Chapter 4. The monitoring of external and internal loads should be employed to manage training sessions and to plan compensatory drills for both starting and non-starting players. For starting players, the need for additional training during congested fixture periods is rare, as the days between consecutive games are typically just enough to recover from the match load before playing again. Conversely, to fill the exposure gap with starting players, non-starters must take advantage of any available window of opportunity. Nowadays, professional football is definitely characterized by congested fixture seasons, but international football governing bodies should consider the time necessary for players to physiologically recover from the physical demands of matches. Additionally, they should

recognize that less frequently used squad players may be exposed to lower loads, resulting in fewer opportunities to support the team and a higher risk of injury due to the inevitable load spike from playing a match after several weeks on the bench. In particular, as reported in Chapter 4, the distance above 80% of the individual peak speed for non-starting players was 63% and 53% of the distance run by starting players during a 21-day congested fixture mesocycle. To determine the timing for compensating this gap, Chapter 5 analysed the microcycle distribution of the main markers used to monitor training. This analysis provided insights into how training loads should be distributed throughout the microcycle to effectively address the disparities in high-speed running distances between starting and non-starting players. By understanding these patterns, coaches can better plan training sessions to ensure all players are adequately prepared and conditioned.

7.4 High-speed running distribution during congested fixture microcycles

The gap of distance above 80% of individual maximum velocity indicated in Chapter 4 is extremely large and would have been even larger if no compensation strategy had been adopted on the day after the match. In fact, as highlighted in Chapter 5, on the day after the match non-starting players produced from 15% to 60% of the distance at velocities above 80% of their individual peak speed run during a match. The day after the match, during three-, four-, or five-day microcycles, is the only window of opportunity to condition non-starting players with a compensatory session, especially when aiming to reach high-speed running intensities. In fact, to perform sprints safely, a player must be properly warmed up for an adequate duration, a condition that is difficult to achieve at the end of the game. Additionally, a player on the bench is constrained to remain seated for 90 minutes, which affects joint mobility and muscle temperature, especially during night matches, which are quite common for top-level teams. Another aggravating factor is the tension, both mental and physical, that a match can provoke, which increases muscle stiffness. For these reasons, a compensatory session at the end of the match for non-starting players can be safe if low-speed activities are proposed, such as continuous or intermittent running or any activity aimed at stimulating the aerobic system with minimal muscular involvement.

In Chapter 5 the daily workload for three-, four-, and five-day microcycles is reported. Regardless of the microcycle length, the training duration and session Rating of Perceived Exertion-Training Load of individual sessions are generally not affected. On the other hand,

when considering accelerations and decelerations, coaches seem to be influenced by shorter microcycles, favouring training sessions with generally reduced muscular impact when fewer days are available between matches. This training load adaptation is managed by decreasing the number of drills not directly focused on the tactical preparation for the subsequent match, without reducing the overall exposure of each session.

Analysing training load trends, the daily load decreased when MD approached and only the five-day microcycle allowed for the alternation of higher and lower training load days, which is essential for the health and performance enhancement of players. Proposing a high load for non-starting players on MD+1 can permit coaches to let non-starting players rest on MD+2. This is crucial, as a MD+2 session with a low load can be beneficial for both starting and non-starting players. The former have not yet fully recovered from the physical demands of the match, while the latter need to recover from a high-load compensation session conducted on MD+1. Additionally, training non-starting players on MD+1 allows coaches to decide on a day off on MD+2, which is indispensable for being ready to perform on MD+3, with minimal differences between starting and non-starting players in terms of accumulated load and recovery stage.

On the other hand, reducing the length of the microcycle establishes a detrimental cycle, with average lower loads that can lead to undertraining for non-starting players. Simultaneously, these loads may be higher than what starting players can manage effectively. This imbalance can negatively impact both sub-groups of a team, highlighting the importance of carefully planning microcycle lengths primarily by football governing bodies to ensure optimal training and recovery for all players, respecting their health, and in turn to provide a high-quality sport product.

Focusing on the day before the match, four-day microcycle presented the greater number of accelerations and deceleration at MD-1, compared to three-day microcycle, but no differences were found compared to five-day microcycle. This result appears to be weak and more analysis on larger dataset are needed to get a definitive conclusion on the training load strategies adopted in the last day before the match during congested fixture periods.

Focusing on match day, four-day microcycle presented the greater number of accelerations and deceleration compared to three- and five-day microcycles. Apart for the number of accelerations and decelerations, the game physical demand was not affected by the microcycle length, but it is important to highlight that only different types of congested periods were compared. In fact, comparing congested and non-congested periods, lower

accelerative and decelerative load was reported at match day when more matches were played and less training sessions were available.

7.5 The most intense periods during matches

The average match demand described in the previous paragraph is one of the most commonly used benchmarks among coaches. Reporting training session demand as a percentage of a 90-minute match is very common and represents the volume produced at different velocities or acceleration intensities. However, the average match demand per minute, often used as an average intensity index, can significantly underestimate the demands of the most intense passages of the game.

For this reason, the quantification of peak match demands reported in Chapter 6 is crucial for adequately preparing players for the most intense periods of the game through the use of football-specific drills. Specifying "through the use of football-specific drills" is pivotal, as such specific markers of intensity can only be compared to very specific football training exercises. Producing the same load using different forms of training, such as running drills, can appear easy. It is easy because players are asked to run the same distance they would during a football match, but without performing all the other high-intensity activities described in Chapter 1, such as kicking, dribbling the ball, and fighting with opponents. In other words, it means using the same benchmark for two different contexts. To illustrate, the most intense 1 minute of the match accounts for 206 meters per minute, a distance completed while playing football, including accelerations, decelerations, and all other high-intensity activities. Converting this average speed from meters per minute to kilometres per hour, it corresponds to 12.4 km·h⁻¹. This means that running at a constant speed around the pitch, with no opponents or teammates, at 12.4 km·h⁻¹ would theoretically prepare players for the most intense periods of the match. However, this is obviously not the case, as it does not replicate the complex and varied demands of actual match play.

In Chapter 6, the results and innovations presented are noteworthy. For the first time, periods of intense activity during official matches lasting less than one minute were identified and described, underscoring the remarkable intensity that professional football players must exhibit during top-level matches in the Italian championship. By identifying the five most intense seconds of a match, it was revealed that players may need to cover 38 meters in five seconds, with 36 of these 38 meters being covered at sprinting velocity exceeding 25 km·h⁻¹. This finding can guide coaches in structuring training drills, particularly the day after

a match, when non-starting players need to compensate for the match load of starting players through football-specific exercises to reduce the gap highlighted in Chapter 4, in particular for sprint running distances.

When examining a one-minute time window, it was observed that during the most intense minute of a match in terms of running demand slightly higher sprint distances occurred in home matches. This is likely due to the support of the home crowd. This factor should be considered when planning mesocycles, particularly when defining the first match for a player recovering from a hamstring injury, as this muscular group is significantly taxed by high velocities. By doing so, the match demand is appropriately considered as part of the training stimulus imposed on the player, which is a more coherent and appropriate approach compared to the traditional method of considering match demand as a performance indicator.

Although the most advisable approach to defining the most intense periods remains individualized, with specific benchmarks for each player, a more general diversification based on playing roles is acceptable, particularly when a limited amount of data points per player is available. Midfielders were found to cover the greatest total distances during the most intense minute, while centre-backs recorded the lowest high-speed running distances. No significant differences were observed between roles in terms of sprint distance. This suggests a team behaviour when speeds above $25 \text{ km}\cdot\text{h}^{-1}$ are required during the game, typically during offensive and defensive transition phases that necessitate all players to sprint quickly into the opposite midfield to attack or defend, respectively. As previously hypothesized, the rationale for this may be the nature of the most intense periods, which compel all players to act suddenly to either score a goal or prevent the opponent's progression towards a goal-scoring opportunity.

7.6 Areas for future research

A notable limitation of the results presented in Chapters 4, 5, and 6 is the relatively small sample size, limited to a single Italian team. Ideally, sample size should be determined based on an a priori estimation; however, this was not feasible due to the restricted availability of top-level football players, an inherent constraint in team sports such as football. Nonetheless, studies involving highly specific populations can still have a significant impact on real-world practice, particularly in comparable contexts. However, caution is required

when generalizing these findings to other leagues, where differences in match schedules and culturally driven training habits may lead to divergent planning strategies.

For instance, in the English Premier League, it is common to observe a designated day off during the week, typically on MD-3 or MD-2, depending on the length of the microcycle. Such cultural habits may influence the training strategies for both starting and non-starting players, potentially diverging significantly from those described in the previous chapters. Another example is the head coach's philosophy and experience: some coaches prefer granting a day off on MD+1 to allow for psychological recovery following match-related stress, which in turn alters the entire compensation strategy for non-starting players.

Another limitation is the use of GNSS and video tracking systems for monitoring training sessions and matches respectively, which may introduce variability in the data. Furthermore, the univariate approach used in our Chapter 5 to describe the most intense periods, focusing solely on velocity, does not account for other high-intensity actions such as jumping, dribbling, accelerating, decelerating, or physical contests, which require dedicated analysis to determine peak demands during games. However, running demand remains the key performance indicator of most interest to practitioners for training purposes, especially when using football-specific drills. Incorporating other contextual factors, such as tactical situations, in the analysis would provide a more holistic and reliable approach, leading to improved training proposals. Despite these limitations, the high ecological validity of Chapter 4, Chapter 5 and Chapter 6 is a strength, as data from a specific population can significantly impact real-world practice.

Apart from the definition of thresholds, the performance aspects investigated in Chapters 3, 4, and 5 could also be of significant interest in the context of elite female football. Currently, there is a paucity of data regarding top-level female players during congested fixture periods, encompassing both starting and non-starting players. Recently, preliminary reference data on the maximum intensity periods in female football have been published (Riboli *et al.*, 2024). These data appear to differ significantly from those reported in Chapter 6 and more generally in male football, suggesting that it would be valuable to examine these demands in other top-level female teams. Another aspect to be strengthened is the association between high-speed running and injuries, in particular hamstring injuries. Very few studies, reported in Chapter 2, have been published, all of them with a reduced number of amateur level athletes.

7.7 Practical applications

Given the lack of consensus on specific absolute thresholds for defining high-speed running and sprinting in adult female and male football players, practitioners may adopt the velocity thresholds endorsed by FIFA and UEFA, which are $19 \text{ km}\cdot\text{h}^{-1}$ and $23 \text{ km}\cdot\text{h}^{-1}$ for females, and $20 \text{ km}\cdot\text{h}^{-1}$ and $25 \text{ km}\cdot\text{h}^{-1}$ for males, respectively. Additionally, relative thresholds should be considered for specific training sessions aimed at achieving near-maximal velocity exposure, taking into account the individual physical velocity capacities of players.

In addition, individualized thresholds for very high-speed running distance as distance above 80% of the individual maximum velocity are instrumental in identifying the workload requirements of non-starting players during congested fixture periods. This external load metric is essential for sport scientists and coaches to optimally prepare players for the most demanding phases of matches and to prevent de-training in non-starting players. Consequently, the systematic monitoring of both external and internal workload metrics is imperative for effectively managing training sessions and planning compensatory drills for both starting and non-starting players.

Practitioners working in contexts similar to the one described (i.e. top 6 Italian Serie A teams) can utilize findings of Chapter 5 to refine training plans across three-, four-, and five-day microcycles. In particular, reducing the frequency of accelerations and decelerations within a session of the same duration facilitates recovery for starting players between matches. A five-day microcycle during congested fixture mesocycles can function as a recovery opportunity for starting players that play the majority of the season in a congested fixture scenario. For non-starting players, the day after the match represents an opportunity to achieve high velocities, compensating for reduced stimulus during the other days of the microcycle. It is recommended that football governing bodies consider extending the minimum interval between official games to enhance player recovery, protect player (worker) health and subsequently maintain or improve the quality of matches.

Focusing on the most intense phases of the match, no significant differences in sprint distance were observed between roles during matches, likely attributable to team dynamics during those intense phases of the game. For this reason, when training aims to reproduce the sprint distance demand during the most intense minute, positional differences can be disregarded. Importantly, practitioners should utilize the most intense periods benchmark exclusively to monitor the physical demand of football-specific drills, rather than running-based drills.

7.8 Concluding summary

To answer Chapter 1 research questions, it is possible to conclude that there is no consensus on a specific absolute threshold defining high-speed running and sprinting in adult female and male football players. For this reason, practitioners could adopt the thresholds proposed by FIFA such as $19 \text{ km}\cdot\text{h}^{-1}$ and $23 \text{ km}\cdot\text{h}^{-1}$ for females and $20 \text{ km}\cdot\text{h}^{-1}$ and $25 \text{ km}\cdot\text{h}^{-1}$ for males. Relative thresholds should be considered for specific training sessions to reach near to maximal velocity exposure accounting for players' maximum velocity capacity. Additionally, players' individualized thresholds for sprinting distance may help identify the needs of non-starters: in fact, they can reach velocity above $25 \text{ km}\cdot\text{h}^{-1}$ in a relatively easy way, but they can lack higher speeds above 80% of the individual maximum velocity if not specifically trained. This is more common during congested periods, i.e. when a few days are available between two consecutive games. In these scenarios, coaches seem to be influenced by shorter microcycles in their training proposal, preferring sessions with a reduced muscle impact when fewer days are available. For non-starting players only, the day after the match represented the only opportunity to train, with the highest training load independently by the microcycle length. Finally, the quantification of the peak match demands is important to appropriately prepare players for the most intense periods of the game using football-specific drills. In fact, midfielders run the highest values for total distance, centre-back produce the lowest high-speed running distance value and no significant differences between roles were found in terms of sprint distance, probably because of team behaviour during the most intense phases of the game such as offensive and defensive transition phases.

In summary, the novel results reported in Chapter 4, Chapter 5, and Chapter 6 can assist coaching staff working in similar contexts in training players who are less taxed due to reduced playing time and in preparing the entire team to endure the most demanding phases of a football match.

Appendices

Appendix 1 – Ethical approval



Waterfront Building,
Neptune Quay,
Ipswich IP4 1QJ

+44 (0)1473 338 000
info@uos.ac.uk
uos.ac.uk

15 November 2019

Project Lead: Marco Beato
Project Title: GPS and football data analysis a posteriori
Start Date: 15 November 2019
End Date: 1 October 2024
Paper Number: RETH19/020

Dear Marco

Following the submission of your proportionate review application for ethical approval to the Ethics Committee on 23 October 2019, the University of Suffolk Research Ethics Committee have reviewed your application to conduct the above mentioned study with yourself as the Principal Investigator.

The Committee considered the application and agreed there were no ethical concerns and therefore Approved this research project as proportionate review On Condition that you clarify to me that all your participants have consented to taking part and their data shared in the Informed Consent Form.

As principal investigators, your responsibilities include:

- ✓ ensuring that (where applicable) all the necessary legal and regulatory requirements in order to conduct the research are met, and the necessary licenses and approvals have been obtained;
- ✓ reporting any ethics-related issues that occur during the course of the research or arising from the research to the University of Suffolk REC to the Committee Secretary s.raychaudhuri@uos.ac.uk (e.g. unforeseen ethical issues, complaints about the conduct of the research, adverse reactions such as extreme distress);
- ✓ submitting details of proposed substantive amendments to the protocol/proposal to the University of Suffolk REC for further approval.

Yours sincerely

A handwritten signature in black ink, appearing to read 'Emma Bond'.

Professor Emma Bond
Director of Research and Chair of the University Research Ethics Committee
University of Suffolk

Appendix 2 – Presentation at World Conference on Science and Soccer, Coimbra (Portugal), June 15th-17th 2022

HIGH-SPEED RUNNING AND SPRINTING IN PROFESSIONAL ADULT SOCCER PLAYERS: METHODOLOGICAL DEFINITIONS, MATCH DEMANDS AND TRAINING RECOMMENDATIONS. A SYSTEMATIC REVIEW

Antonio Gualtieri ^{1,2}, Ermanno Rampinini ³, Antonio Dello Iacono ⁴, Duccio Ferrari Bravo ¹, Marco Beato ²

¹ Sport Science and R&D Department, Juventus Football Club, Torino, Italy; ² School of Health and Sports Sciences, University of Suffolk, Ipswich, United Kingdom; ³ Human Performance Laboratory, Sport Service Mapei Srl, Olgiate Olona, Italy; ⁴ Division of Sport and Exercise, School of Health and Life Sciences, University of the West of Scotland, Hamilton, United Kingdom.

High-speed and sprint running match demands have progressively increased in the last years, thus becoming one of the hallmarks of modern professional soccer.

The aims of this review were to: summarize the evidence on absolute and relative velocity thresholds used to classify high-speed running and sprinting in adult soccer players, describe high-speed and sprint running distance match demands, and provide practical applications for training high-speed and sprint running in professional adult soccer players.

To date, there is no consensus on the absolute thresholds defining high-speed and sprint running in adult soccer players. Until international standards are defined, it is reasonable to set absolute thresholds considering the range of values found in the literature collected in this review. On the other hand, relative velocity thresholds could be considered for specific training sessions whose goal is to reach near to maximal velocity exposure and verify individual players training loads.

During official matches, high-speed and sprint running distances ranged from 911 to 1063 m and 223 to 307 m, respectively, in professional female soccer players, while ranges from 618 to 1001 m and 153 to 295 m, respectively, in professional male soccer players (note that lower absolute thresholds were used for female players compared to male players). Moreover, maximal intensity periods recorded during matches should also be considered: indeed, the most intense phases can be 2 and 4 times more demanding than the mean values for high-speed running and sprinting, respectively. In addition, high between-player, between-game and between-role variability for these external load demands were reported during official matches.

During training, sided-games designed in formats using relative areas per player greater than 225 m² appear to be adequate for achieving high-speed running and sprinting exposure, although large between-subject variability may be expected. The combination of sided-games, running exercises and soccer circuit-based drills is advisable to ensure adequate high-speed and sprint running exposure both at a team and individual level. Monitoring high-speed running and sprint distances during every single session can allow practitioners to assess the efficacy of the training process and best prepare players for the most demanding phases of the match.

Appendix 3 – Presentation at 29th Annual ECSS Congress in Glasgow, July 2nd-5th 2024

THREE-, FOUR- AND FIVE-DAY MICROCYCLES: THE NORMALITY IN PROFESSIONAL FOOTBALL

Gualtieri, A. 1,2, Vicens-Bordas, J. 3,4, Rampinini, E. 5,6, Ferrari Bravo, D. 1, Beato, M. 2

¹ Sport Science and R&D Department, Juventus FC, Turin, Italy; ² School of Health and Sports Science, University of Suffolk, Ipswich, UK; ³ Sport Performance Analysis Research Group (SPARG), University of Vic-Central University of Catalonia, Vic, Barcelona, Spain; ⁴ UVic-UCC Sport and Physical Activity Studies Centre (CEEAF), University of Vic-Central University of Catalonia, Vic, Barcelona, Spain; ⁵ Human Performance Laboratory, MAPEI Sport Research Centre, Olgiate Olona, Varese, Italy; ⁶ Sport and Exercise Discipline Group, Human Performance Research Centre, Faculty of Health, University of Technology Sydney, Moore Park, New South Wales, Australia

INTRODUCTION

In modern football, elite level teams frequently face periods with congested fixtures. This scenario requires teams to play more than once a week in national and international competitions [1]. Previous research reported a gradual reduction in training volume as match day approached [2], but limited information is currently available about shorter microcycles' training load distribution. Therefore, this study aimed to quantify training and match day (MD) load during three- (3dMC), four- (4dMC) and five-day microcycles (5dMC) in elite adult football and analyse the effect of microcycle length on the training load sustained the day before (MD-1) and after a match (MD+1).

METHODS

This study involved 20 male elite football players whose external load was monitored for a whole competitive season, assessing periods with congested fixtures (i.e., three-, four- and five-day microcycles). Training exposure (EXP), total distance covered (TD), high-speed running distance (HSR), sprint distance (SD), individual sprint distance (D>80%), number of accelerations (ACC) and decelerations (DEC) were quantified. The load recorded on MD+1 (sustained by non-starting players), MD-1 and MD was compared between the three congested microcycles.

RESULTS

Microcycles length affected most of the variables of interest: HSR ($F = 9.04$, $p < 0.01$), SD ($F = 13.90$, $p < 0.01$), D>80% ($F = 20.25$, $p < 0.01$), accelerations ($F = 10.12$, $p < 0.01$) and decelerations ($F = 6.01$, $p < 0.01$). Comparisons highlighted that 3dMC and 4dMC had greater daily average HSR and D>80% demands than the 5dMC, while 4dMC and 5dMC produced more ACC than 3dMC ($p < 0.05$).

There was an interaction effect between training day and microcycle type for SD ($F = 5.46$, $p < 0.01$), D>80% ($F = 4.51$, $p < 0.01$), ACC ($F = 2.24$, $p = 0.06$) and DEC ($F = 3.91$, $p < 0.01$). In particular, the microcycle type affected D>80% on MD+1 (higher in 3dMC), and ACC and DEC on MD-1 and MD. 4dMC presented a greater number of ACC on MD-1, compared to 3dMC (-8.5 , $p < 0.01$, $d = -0.29$) and on MD compared to 3dMC (-11.6 , $p < 0.01$, $d = -0.36$) and 5dMC (-9.3 , $p < 0.01$, $d = 0.25$). 4dMC presented the greater number of DEC on MD-1, compared to 3dMC (-7.9 , $p < 0.01$, $d = -0.23$) and on MD compared to 3dMC (-16.4 , $p < 0.01$, $d = -0.43$) and 5dMC (14.2 , $p < 0.01$, $d = 0.33$).

CONCLUSIONS

During congested fixtures players external training load is influenced by microcycles length, where coaches seem to prefer technical and tactical drills with a reduced muscular impact during shorter microcycles allowing starting players to recover from the previous match. On the other side, non-starting players can be exposed to high-speed running on MD+1 since they may not have this stimulus on the other training days of the week. Independently of the length of the congested fixture microcycle, daily load does appear to decrease when MD approaches.

Appendix 4 – Article published including aspects from Chapter 2

Direct link: <https://www.frontiersin.org/journals/sports-and-active-living/articles/10.3389/fspor.2023.1116293/full>



OPEN ACCESS

EDITED BY

Gavin L. Moir,
East Stroudsburg University, United States

REVIEWED BY

Matthew Miltenberger,
East Stroudsburg University, United States
Brandon Snyder,
East Stroudsburg University, United States

*CORRESPONDENCE

Antonio Gualtieri
✉ antonio.gualtieri@juventus.com

SPECIALTY SECTION

This article was submitted to Elite Sports and Performance Enhancement, a section of the journal Frontiers in Sports and Active Living

RECEIVED 05 December 2022

ACCEPTED 02 January 2023

PUBLISHED 13 February 2023

CITATION

Gualtieri A, Rampinini E, Dello Iacono A and Beato M (2023) High-speed running and sprinting in professional adult soccer: Current thresholds definition, match demands and training strategies. A systematic review. *Front. Sports Act. Living* 5:1116293. doi: 10.3389/fspor.2023.1116293

COPYRIGHT

© 2023 Gualtieri, Rampinini, Dello Iacono and Beato. This is an open-access article distributed under the terms of the [Creative Commons Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

High-speed running and sprinting in professional adult soccer: Current thresholds definition, match demands and training strategies. A systematic review

Antonio Gualtieri^{1,2*}, Ermanno Rampinini^{3,4}, Antonio Dello Iacono⁵ and Marco Beato²

¹Sport Science and R&D Department, Juventus Football Club, Torino, Italy, ²School of Health and Sports Sciences, University of Suffolk, Ipswich, United Kingdom, ³Human Performance Laboratory, MAPEI Sport Research Centre, Olgiate Olona, Italy, ⁴Sport and Exercise Discipline Group, Human Performance Research Centre, Faculty of Health, University of Technology Sydney, Moore Park, NSW, Australia, ⁵Division of Sport and Exercise, School of Health and Life Sciences, University of the West of Scotland, Hamilton, United Kingdom

The aims of this systematic review were (1) to summarize the evidence on absolute velocity thresholds used to classify high-speed running and sprinting, (2) to examine the existing evidence about the individualized thresholds approach, (3) to describe high-speed and sprint running distance match demands, and (4) to provide training strategies for eliciting HSR and sprinting during training sessions in professional adult soccer. This systematic review was conducted following the PRISMA 2020 guidelines. After the authors' screening, 30 studies were included in this review. This review found that, to date, there is no consensus on the absolute thresholds defining high-speed and sprint running in adult soccer players. Until international standards are defined, it is reasonable to set absolute thresholds considering the range of values found in the literature collected in this review. Relative velocity thresholds could be considered for specific training sessions whose goal is to reach near maximal velocity exposure. During official matches, high-speed and sprint running distances ranged from 911 to 1,063 m and 223–307 m, respectively, in professional female soccer players, while ranges from 618 to 1,001 m and 153–295 m, respectively, in professional male soccer players. During training, game-based drills designed in formats using relative areas per player greater than 225 m² and 300 m² appear to be adequate for achieving high-speed running and sprinting exposure, respectively, for male players. The combination of game-based, running exercises and soccer circuit-based drills is advisable to ensure adequate high-speed and sprint running exposure both at a team and individual level.

KEYWORDS

football, GNSS, GPS, velocity thresholds, team sports, elite sports

Introduction

Soccer is a physically demanding team-sport characterized by an intermittent activity profile with high-intensity activities such as accelerations, decelerations, changes of direction, sprinting, jumping, and tackling interspersed by low-intensity phases of passive (i.e., standing) and active recovery (e.g., walking, jogging) (1, 2). The match play intensity in male soccer has considerably increased over the last 15 years, especially due to the greater high-speed running (HSR) (distance covered at speeds between 19.8 km·h⁻¹ and 25.1 km·h⁻¹ increased ~29%) and sprint (distance >25.1 km·h⁻¹ increased ~50%) locomotive demands, which now account for ~7%–11% and ~1%–3% relatively to the total distance covered during a match, respectively (2–4). Similarly,

Appendix 5 – Article published from Chapter 4

Direct link: <https://www.thieme-connect.de/products/ejournals/abstract/10.1055/a-1171-1865>

Workload Monitoring In Top-level Soccer Players During Congested Fixture Periods

Authors

Antonio Gualtieri¹, Ermanno Rampinini², Roberto Sassi¹, Marco Beato³

Affiliations

- 1 Juventus FC, Sports Science, Torino, Italy
- 2 MAPEI Sport Research Centre, Human Performance Laboratory, Varese, Italy
- 3 School of Health and Sports Sciences, University of Suffolk, Ipswich, United Kingdom of Great Britain and Northern Ireland

Key words

training, football, GPS, high speed running

accepted 21.04.2020

Bibliography

DOI <https://doi.org/10.1055/a-1171-1865>

Published online: 2020

Int J Sports Med

© Georg Thieme Verlag KG Stuttgart · New York

ISSN 0172-4622

Correspondence

Dr. Marco Beato
School of Health and Sports Science, University of Suffolk
Waterfront Building, Neptune Quay
Suffolk
IP4 1QJ Ipswich
United Kingdom of Great Britain and Northern Ireland
Tel.: +447541545205
m.beato@uos.ac.uk

ABSTRACT

This study assessed the internal and external workload of starters and non-starters in a professional top-level soccer team during a congested fixture period. Twenty Serie A soccer players were monitored in this study during two mesocycles of 21 days each. Starters and non-starters were divided based on the match time played in each mesocycle. The following metrics were recorded: exposure time, total distance, relative total distance, high-speed running distance over $20 \text{ km} \cdot \text{h}^{-1}$, very high-speed running distance over $25 \text{ km} \cdot \text{h}^{-1}$, individual very high-speed distance over 80 % of maximum peak speed, and rating of perceived exertion. Differences between starters and non-starters were found for: exposure time (effect size = large to very large), rating of perceived exertion (large to very large), total distance (large to very large), and individual very high-speed distance over 80 % of maximum peak speed (moderate to large). Furthermore, differences for relative total distance, high-speed running distance over $20 \text{ km} \cdot \text{h}^{-1}$ and very high-speed running distance over $25 \text{ km} \cdot \text{h}^{-1}$ were small to moderate, but not significant. This study reports that during congested fixture periods, starters had higher exposure time, rating of perceived exertion, total distance, and individual very high-speed distance over 80 % of maximum peak speed than non-starters.

Introduction

During a soccer game, players who start games (starters) typically cover distances between 10–13 km, performing a variety of intense activities such as sprints, accelerations, decelerations, and changes of direction [1]. Players who do not start games (non-starters) need to compensate for this lack of workload (WL) with additional training that can be planned at the end of a game or during the next training sessions to maintain an adequate fitness level throughout the season. The individual quantification of total WL, which is the combination of training and match load, has critical importance for professional soccer coaches and sports scientists aiming to obtain physical adaptations and reduce the risk of injury [2]. The most common technology utilized to quantify external WL parameters are global navigation satellite systems (GNSS) [3]. GNSS are used to monitor sport-specific metrics, such as total distance

covered (TD) and high-speed running, during training sessions and matches [3, 4]. Additionally, external WL can be integrated with internal load (e.g. rating of perceived exertion [RPE]) that might guarantee a better comprehension of the players' WL in soccer [2–4].

Recent research, conducted over an entire season on English Premier League players, reported that non-starters have a similar total exposure time and TD (considering both match and training time), but lower high-speed running and very high-speed running compared to starters [1]. Therefore, in order to compensate for different WL between starters and non-starters, practitioners should implement additional WL during training—with a focus on high-speed activities. However, proposing higher WL, in particular high-speed running and very high-speed running, could be complicated during congested fixture periods due to uncertainty regarding player selection and availability. Sports scientists have to manage the

Appendix 6 – Article published from Chapter 5

Direct link: <https://journals.humankinetics.com/view/journals/ijspp/19/10/article-p987.xml>

International Journal of Sports Physiology and Performance, (Ahead of Print)

<https://doi.org/10.1123/ijspp.2024-0144>

© 2024 Human Kinetics, Inc.

First Published Online: July 27, 2024

Human Kinetics
ORIGINAL INVESTIGATION

Three-, Four-, and Five-Day Microcycles: The Normality in Professional Football

Antonio Gualtieri,^{1,2} Jordi Vicens-Bordas,^{3,4} Ermanno Rampinini,^{5,6} Duccio Ferrari Bravo,¹ and Marco Beato²

¹Sport Science and R&D Department, Juventus Football Club, Turin, Italy; ²School of Health and Sports Science, University of Suffolk, Ipswich, United Kingdom;

³Sport Performance Analysis Research Group (SPARG), University of Vic–Central University of Catalonia, Barcelona, Spain; ⁴UVic-UCC Sport and Physical Activity Studies Center (CEEAF), University of Vic–Central University of Catalonia, Barcelona, Spain; ⁵Human Performance Laboratory, MAPEI Sport Research Center, Olgiate Olona, Italy; ⁶Sport and Exercise Discipline Group, Human Performance Research Centre, Faculty of Health, University of Technology Sydney, Moore Park, NSW, Australia

Purpose: This study aimed to quantify training and match-day (MD) load during 3-, 4-, and 5-day microcycles in professional adult football, as well as to analyze the effect of the microcycle length on training load produced the day after the match (MD + 1) and the day before the match (MD – 1). **Methods:** The study involved 20 male professional football players whose external and internal loads were monitored for a whole season. The training exposure, total distance covered, high-speed-running distance, sprint distance (SD), individual SD above 80% of the individual maximum velocity ($D > 80\%$), and the number of accelerations and decelerations were quantified, as well as rating of perceived exertion and session rating of perceived exertion training load. **Results:** Microcycle length affected most of the variables of interest: high-speed-running distance ($F = 9.04$, $P < .01$), SD ($F = 13.90$, $P < .01$), $D > 80\%$ ($F = 20.25$, $P < .01$), accelerations ($F = 10.12$, $P < .01$), and decelerations ($F = 6.01$, $P < .01$). There was an interaction effect between the training day and microcycle type for SD ($F = 5.46$, $P < .01$), $D > 80\%$ ($F = 4.51$, $P < .01$), accelerations ($F = 2.24$, $P = .06$), and decelerations ($F = 3.91$, $P < .01$). **Conclusions:** Coaches seem to be influenced by shorter microcycles in their training proposal, preferring sessions with a reduced muscle impact during shorter microcycles. Independent of the length of the congested fixture microcycle, the daily load seems to decrease when MD approaches.

Keywords: team sports, soccer, GPS, monitoring, congested fixture

In football today, the best teams from each championship (eg, Serie A, Premier League) play frequently during the season to take part in international competitions or national cups. For instance, they play not only during the weekend (1 match a week) but also during the week (eg, 2–3 times in 7–8 d).¹ In these circumstances, the weekly number of training sessions is reduced to facilitate physical recovery (eg, in the days immediately after the game) and so to promote performance.² The training load is affected by this strategy to the point that the weekly load, especially the distance run at a higher speed, is mainly completed during the match itself.³ This type of “congested fixture season” does not allow practitioners to plan training as during a standard microcycle (6 training sessions a week with 1 match). Individual players may experience around 10 consecutive weeks of a congested calendar, including domestic and international matches.⁴ In this context, teams’ weekly schedules change during the season, so a standard nomenclature independent of the day of the week is adopted. More precisely, the training days (and their aims, such as recovery, development, or tapering) are defined on the basis of the distance from the previous or next match day (MD). In a traditional microcycle, it is common practice to define the days after the latest game as follows: MD plus 1 (MD + 1) and MD + 2, wherein the main aim is usually to promote physical and mental recovery, and MD – 4,

MD – 3, MD – 2, and MD – 1 for the remaining days before the MD.⁵ However, in congested fixture periods (as described earlier), the number of days between matches is reduced, and therefore, the training week is shorter (eg, for a 4-day microcycle: MD + 1, MD – 2, MD – 1, and MD).

The periodization of loading across the weekly microcycle is commonly observed in adult players. Previous research reported that training volume gradually decreased during the week as MD approached.^{6–9} Specifically, in an 8-day microcycle, the greatest distances and intensities were performed at MD – 5 and MD – 3, followed by a significant tapering phase at MD – 2 and MD – 1 in an attempt to reduce the residual fatigue accumulated during the previous days and to optimize MD performance.⁹ A similar trend has been reported by Lopategui et al¹⁰ in a 7-day microcycle wherein a short tapering on MD – 2 and MD – 1 was planned before the game to recover from the previous loading days, essential for maintaining or optimizing players’ physical performance during the season.¹⁰ Furthermore, Fleming et al¹¹ reported a similar organization of the training stimulus in 6-day microcycles wherein MD – 4 was the most demanding training session of the week, MD – 3 was a day off, and during MD – 2 and MD – 1, coaches decreased players’ load to favor players’ readiness.¹¹

However, this weekly plan cannot be used during congested fixture periods: for example, in a 4-day microcycle, the first session after the match (MD + 1) is the only available training day wherein players who did not play the previous MD (nonstarters, who are players that did not play or played only a fraction of the match) can actually perform physical development (72 h before the next MD). On MD + 2 (which is <48 h from the previous MD and 48 h from the next MD), starters are still recovering from the workload of

Vicens-Bordas <https://orcid.org/0000-0002-8388-8863>

Rampinini <https://orcid.org/0000-0002-9729-0862>

Ferrari Bravo <https://orcid.org/0009-0006-3941-4747>

Beato <https://orcid.org/0000-0001-5373-2211>

Gualtieri (antonio.gualtieri@juventus.com) is corresponding author, <https://orcid.org/0000-0001-5629-1490>

Appendix 7 – Article published including aspects from Chapter 6

Direct link: <https://journals.humankinetics.com/view/journals/ijspp/20/7/article-p986.xml>

International Journal of Sports Physiology and Performance, (Ahead of Print)

<https://doi.org/10.1123/ijspp.2024-0441>

© 2025 Human Kinetics, Inc.

First Published Online: May 22, 2025

Human Kinetics
ORIGINAL INVESTIGATION

Analysis of the Most Intense Periods During Elite Soccer Matches: Effect of Game Location and Playing Position

Antonio Gualtieri,^{1,2} Maria Angonese,³ Massimo Maddiotto,³ Ermanno Rampinini,^{4,5}
Duccio Ferrari Bravo,¹ and Marco Beato²

¹Sport Science and R&D Department, Juventus FC, Turin, Italy; ²School of Health and Sports Science, University of Suffolk, Ipswich, United Kingdom;

³SportAnalytics, Milan, Italy; ⁴Human Performance Laboratory, MAPEI Sport Research Center, Olgiate Olona, Italy; ⁵School of Sport, Exercise and Rehabilitation, Human Performance Research Centre, Faculty of Health, University of Technology Sydney, Moore Park, NSW, Australia

Purpose: This study aimed to quantify the game-speed demand of elite soccer players using time windows from 5 seconds to 10 minutes and to examine the effect of match location and playing position on game-speed outputs. **Methods:** Twenty-four Serie A (Italy) male professional soccer players (27.5 [4.1] y old) participated in this study across an entire season. The players' activity profiles during matches were analyzed using a semiautomatic video tracking system (Stats Perform), which provided 2-dimensional coordinates of the players, and from these data, total distance (TD) covered, high-speed running distance (HSRD), and sprint distance (SD) were calculated. The most intense periods of match play were calculated using a moving-average method within 15 time windows (ie, 5–10–15–30–60–90 s and from 2 to 10 min) and analyzed using a linear mixed model. **Results:** A slightly higher SD (estimate values = 3.98, $P = .0192$) was performed when playing a home match. Midfielders run the highest values for TD ($P = .0001$), center backs produced the lowest HSRD ($P = .0011$), and no significant differences between roles were found in terms of SD. **Conclusions:** A univariate approach based on velocity can aid in designing training for the most intense periods of a match, considering positional differences for TD and HSRD. On the other hand, the consistency in SD across different roles suggests a team behavior during the most intense periods of the game such as attacking and defensive transition phases.

Keywords: team sports, football, monitoring, worst-case scenario, peak locomotor demand

Soccer is a physically demanding sport with games lasting at least 90 minutes. Several studies have described the total physical demand of a match or its relative demand (ie, the average demand per minute) to define training targets and design training sessions.^{1,2} However, it was suggested that the average match activities do not fully explain the demands of the game, and they cannot be the only reference point for players' preparation.³ Specifically, using average match values to set training goals may not expose players to the most intense periods (MIPs), which occur intermittently throughout matches and increase as the length of the moving average used to calculate them decreases.⁴

Previous research showed that mathematical models adopting moving averages to assess the relationship between running intensity and duration have shown to be a valid way to quantify soccer match intensity and account for true periods of maximal player output,⁵ while using fixed durations lacks sensitivity and might underestimate true running demands by up to ~25%.^{3,6} The peak locomotor periods that occur during a game have been reported using different terms such as MIPs,⁷ peak match or physical demand,⁸ duration-specific running demands,⁹ worst-case scenarios,¹⁰ or other similar lexical alternatives. In this paper, we refer to this analysis as MIPs following the paper published by Novak et al.¹⁰ From a recent Delphi survey, the MIPs in professional soccer are used by practitioners as benchmarks for exercise

replication, especially when single repetitions have a short duration to keep as high as possible the training physical demand.¹¹

This approach can be useful for preparing players for various technical and tactical scenarios, requiring them to achieve high intensities and cover long distances quickly, such as during defensive and attacking transitions.¹² These situations are quite distinct from the typical demands of a game.^{13,14} In fact, a 5-minute peak match demand was reported to be more than 2-fold for high-speed running (HSR) distance and 3- to 6-fold for sprint distance (SD), depending on the playing position, compared with the match average both in elite female¹⁵ and male¹⁶ players. Raising the bar, previous research has reported that relative distance can be over 200 m·min⁻¹ when analyzed using short time windows (ie, 1 min) in US Major League Soccer,¹⁷ and this game-speed intensity is much higher than the average relative distance (ie, around 110 m·min⁻¹) reported considering the whole game in English professional football.^{2,18} Similarly, in other studies, the average locomotor demand was significantly lower than the 1-minute peak demand. Specifically, it accounted for approximately 53% to 59% of the total distance (TD), around 16% to 19% of the HSR distance, and roughly 6% to 9% of the sprinting distance.^{14,19} This very high game demand was not achieved with small, medium, or large-sided games; for this reason, other specific training options must be explored.^{13,20,21}

Differences across various playing positions during the 1- to 10-minute periods of highest physical demand in professional male soccer have also been documented.^{7,13,22,23} Therefore, playing positions should always be considered when applying the MIP concept. Specifically, central midfielders (CM) reported higher relative distance compared with wide midfielders (WM),²³ and

Rampinini <https://orcid.org/0000-0002-9729-0862>

Ferrari Bravo <https://orcid.org/0009-0006-3941-4747>

Beato <https://orcid.org/0000-0001-5373-2211>

Gualtieri (antonio.gualtieri@juventus.com) is corresponding author. <https://orcid.org/0000-0001-5629-1490>

Appendix 8 – Co-authored publications during the PhD Course

Gregson W, Carling C, **Gualtieri A**, O'Brien J, Reilly P, Tavares F, Bonanno D, Lopez E, Marques J, Lolli L, Salvo VD. A survey of organizational structure and operational practices of elite youth football academies and national federations from around the world: A performance and medical perspective. *Front Sports Act Living*. 2022 Nov 23;4:1031721. doi: 10.3389/fspor.2022.1031721. PMID: 36506723; PMCID: PMC9727309.

Connolly DR, Stolp S, **Gualtieri A**, Ferrari Bravo D, Sassi R, Rampinini E, Coutts AJ. How Do Young Soccer Players Train? A 5-Year Analysis of Weekly Training Load and its Variability Between Age Groups in an Elite Youth Academy. *J Strength Cond Res*. 2024 Aug 1;38(8):e423-e429. doi: 10.1519/JSC.0000000000004813. PMID: 39072663.

Connolly, D. R., Stolp, S., **Gualtieri, A.**, Franceschi, A., Ferrari Bravo, D., Rampinini, E., & Coutts, A. J. (2024). How do young soccer players train? A 5-year analysis of weekly microcycle training load characteristics in an elite youth academy. *International Journal of Sports Science & Coaching*, 20(1), 130-138. <https://doi.org/10.1177/17479541241292765>
(Original work published 2025)

References

1. Abbott, W., Brickley, G. and Smeeton, N.J. (2018) 'Positional differences in GPS outputs and perceived exertion during soccer training games and competition', *Journal of Strength and Conditioning Research*, 32(11), pp. 3222–3231. Available at: <https://doi.org/10.1519/JSC.0000000000002387>.
2. Abt, G. and Lovell, R. (2009) 'The use of individualized speed and intensity thresholds for determining the distance run at high-intensity in professional soccer', *Journal of Sports Sciences*, 27(9), pp. 893–898. Available at: <https://doi.org/10.1080/02640410902998239>.
3. Ade, J.D., Harley, J.A. and Bradley, P.S. (2014) 'Physiological response, time-motion characteristics, and reproducibility of various speed-endurance drills in elite youth soccer players: Small-sided games versus generic running', *International Journal of Sports Physiology and Performance*, 9(3), pp. 471–479. Available at: <https://doi.org/10.1123/IJSPP.2013-0390>.
4. Akenhead, R., Harley, J.A. and Twedde, S.P. (2016) 'Examining the external training load of an english premier league football team with special reference to acceleration', *Journal of Strength and Conditioning Research*, 30(9), pp. 2424–2432. Available at: <https://doi.org/10.1519/JSC.0000000000001343>.
5. Altmann, S. *et al.* (2021) 'Match-related physical performance in professional soccer: Position or player specific?', *PLOS ONE*, 16(9), p. e0256695. Available at: <https://doi.org/10.1371/JOURNAL.PONE.0256695>.
6. Anderson, L., Orme, P., Di Michele, R., Close, G.L., Milsom, J., *et al.* (2016) 'Quantification of seasonal-long physical load in soccer players with different starting status from the English premier league: Implications for maintaining squad physical fitness', *International Journal of Sports Physiology and Performance*, 11(8), pp. 1038–1046. Available at: <https://doi.org/10.1123/ijsp.2015-0672>.
7. Anderson, L., Orme, P., Di Michele, R., Close, G.L., Morgans, R., *et al.* (2016) 'Quantification of training load during one-, two- and three-game week schedules in professional soccer players from the English Premier League: implications for carbohydrate periodisation', *Journal of Sports Sciences*, 34(13). Available at: <https://doi.org/10.1080/02640414.2015.1106574>.
8. Asian-Clemente, J. *et al.* (2020) 'Can Small-side Games Provide Adequate High-

speed Training in Professional Soccer?', *International Journal of Sports Medicine* [Preprint]. Available at: <https://doi.org/10.1055/a-1293-8471>.

9. Askling, C.M., Tengvar, M. and Thorstensson, A. (2013) 'Acute hamstring injuries in Swedish elite football: a prospective randomised controlled clinical trial comparing two rehabilitation protocols', *British journal of sports medicine*, 47(15), pp. 953–959. Available at: <https://doi.org/10.1136/BJSPORTS-2013-092165>.
10. Banister, E.W., Carter, J.B. and Zarkadas, P.C. (1999) 'Training theory and taper: validation in triathlon athletes', *European journal of applied physiology and occupational physiology*, 79(2), pp. 182–191. Available at: <https://doi.org/10.1007/S004210050493>.
11. Baptista, I. et al. (2018) 'Position specific player load during matchplay in a professional football club', *PLoS ONE*, 13(5). Available at: <https://doi.org/10.1371/journal.pone.0198115>.
12. Baptista, I. et al. (2019) 'Positional Differences in Peak- and Accumulated- Training Load Relative to Match Load in Elite Football', *Sports*, 8(1), p. 1. Available at: <https://doi.org/10.3390/sports8010001>.
13. Barnes, C. et al. (2014) 'The evolution of physical and technical performance parameters in the English Premier League', *Int J Sports Med*, 35(13), pp. 1095–1100. Available at: <https://doi.org/10.1055/s-0034-1375695>.
14. Barrett, S. et al. (2020) 'Understanding the Influence of the Head Coach on Soccer Training Drills—An 8 Season Analysis', *Applied Sciences*, 10(22), p. 8149. Available at: <https://doi.org/10.3390/app10228149>.
15. Baumgart, C., Freiwald, J. and Hoppe, M. (2018) 'Sprint Mechanical Properties of Female and Different Aged Male Top-Level German Soccer Players', *Sports*, 6(4), p. 161. Available at: <https://doi.org/10.3390/sports6040161>.
16. Beato, M. et al. (2018) 'The validity and between-unit variability of GNSS units (STATSports apex 10 and 18 Hz) for measuring distance and peak speed in team sports', *Frontiers in Physiology*, 9(SEP). Available at: <https://doi.org/10.3389/fphys.2018.01288>.
17. Beato, M. (2022) 'Recommendations for the design of randomized controlled trials in strength and conditioning. Common design and data interpretation', *Frontiers in Sports and Active Living*, 4. Available at: <https://doi.org/10.3389/fspor.2022.981836>.
18. Beato, M. et al. (2023) 'Training load comparison between small, medium, and

large-sided games in professional football', *Frontiers in Sports and Active Living*, 5, p. 1165242. Available at: <https://doi.org/10.3389/FSPOR.2023.1165242/BIBTEX>.

19. Beato, M., Devereux, G. and Stiff, A. (2018) 'Validity and reliability of global positioning system units (STATSports Viper) for measuring distance and peak speed in sports', *Journal of Strength and Conditioning Research*, 32(10), pp. 2831–2837. Available at: <https://doi.org/10.1519/JSC.0000000000002778>.
20. Beato, M., Drust, B. and Iacono, A. Dello (2021) 'Implementing High-speed Running and Sprinting Training in Professional Soccer', *International Journal of Sports Medicine*, 42(4), pp. 295–299. Available at: <https://doi.org/10.1055/a-1302-7968>.
21. Beato, M. and Jamil, M. (2018) 'Intra-system reliability of SicS: Video-tracking system (digital.Stadium®) for performance analysis in soccer', *Journal of Sports Medicine and Physical Fitness*, 58(6), pp. 831–836. Available at: <https://doi.org/10.23736/S0022-4707.17.07267-X>.
22. Beato, M. and de Keijzer, K.L. (2019) 'The inter-unit and inter-model reliability of GNSS STATSports Apex and Viper units in measuring peak speed over 5, 10, 15, 20 and 30 meters', *Biology of Sport*, 36(4), pp. 317–321. Available at: <https://doi.org/10.5114/biolSport.2019.88754>.
23. Beato, M., de Keijzer, K.L. and Costin, A.J. (2023) 'External and internal training load comparison between sided-game drills in professional soccer', *Frontiers in Sports and Active Living*, 5, p. 1150461. Available at: <https://doi.org/10.3389/FSPOR.2023.1150461/BIBTEX>.
24. Beato, M., Wren, C. and de Keijzer, K.L. (2023) 'The Interunit Reliability of Global Navigation Satellite Systems Apex (STATSports) Metrics During a Standardized Intermittent Running Activity', *Journal of strength and conditioning research* [Preprint]. Available at: <https://doi.org/10.1519/JSC.0000000000004613>.
25. Beato, M., Youngs, A. and Costin, A.J. (2024) 'The Analysis of Physical Performance During Official Competitions in Professional English Football: Do Positions, Game Locations, and Results Influence Players' Game Demands?', *Journal of Strength and Conditioning Research* [Preprint]. Available at: <https://doi.org/10.1519/JSC.0000000000004717>.
26. Borg, G. (1982) 'Ratings of perceived exertion and heart rates during short-term cycle exercise and their use in a new cycling strength test', *International journal*

- of sports medicine*, 3(3), pp. 153–158. Available at: <https://doi.org/10.1055/S-2008-1026080>.
27. Borg, G. and Borg, E. (2001) 'A new generation of scaling methods: Level-anchored ratio scaling', *Psychologica*, 28, pp. 15–45.
 28. Borg, G. and Dahlstrom, H. (1962) 'A pilot study of perceived exertion and physical working capacity.', *Acta Societatis Medicorum Upsaliensis*, 67, pp. 21–7.
 29. Bortnik, L., Burger, J. and Rhodes, D. (2022) 'The mean and peak physical demands during transitional play and high pressure activities in elite football', *Biology of Sport* [Preprint]. Available at: <https://doi.org/10.5114/biolsport.2023.112968>.
 30. Bowen, L. *et al.* (2019) 'Spikes in acute:chronic workload ratio (ACWR) associated with a 5-7 times greater injury rate in English Premier League football players: a comprehensive 3-year study', *Br J Sports Med* [Preprint]. Available at: <https://doi.org/10.1136/bjsports-2018-099422>.
 31. Bradley, P.S. and Vescovi, J.D. (2015) 'Velocity thresholds for women's soccer matches: Sex specificity dictates high-speed-running and sprinting thresholds-female athletes in motion (FAiM)', *International Journal of Sports Physiology and Performance*. Human Kinetics Publishers Inc., pp. 112–116. Available at: <https://doi.org/10.1123/ijsp.2014-0212>.
 32. Branquinho, L. *et al.* (2023) 'Perspectives on Player Performance during FIFA World Cup Qatar 2022: A Brief Report', *Sports (Basel, Switzerland)*, 11(9). Available at: <https://doi.org/10.3390/SPORTS11090174>.
 33. Buchheit, M. *et al.* (2014) 'Integrating different tracking systems in football: multiple camera semi-automatic system, local position measurement and GPS technologies', *J Sports Sci*, 32(20), pp. 1844–1857. Available at: <https://doi.org/10.1080/02640414.2014.942687>.
 34. Buchheit, M. *et al.* (2020) 'Occurrences of near-to-maximal speed-running bouts in elite soccer: insights for training prescription and injury mitigation', <https://doi.org/10.1080/24733938.2020.1802058>, 5(2), pp. 105–110. Available at: <https://doi.org/10.1080/24733938.2020.1802058>.
 35. Buchheit, M. and Laursen, P.B. (2013) 'High-intensity interval training, solutions to the programming puzzle: Part I: cardiopulmonary emphasis', *Sports medicine (Auckland, N.Z.)*, 43(5), pp. 313–338. Available at:

<https://doi.org/10.1007/S40279-013-0029-X>.

36. Buckthorpe, M. *et al.* (2019) 'Recommendations for hamstring injury prevention in elite football: Translating research into practice', *British Journal of Sports Medicine*. BMJ Publishing Group, pp. 449–456. Available at: <https://doi.org/10.1136/bjsports-2018-099616>.
37. Bush, M. *et al.* (2015) 'Evolution of match performance parameters for various playing positions in the English Premier League', *Hum Mov Sci*, 39, pp. 1–11. Available at: <https://doi.org/10.1016/j.humov.2014.10.003>.
38. Calder, A. and Gabbett, T. (2022) 'Influence of Tactical Formation on Average and Peak Demands of Elite Soccer Match-Play', *International Journal of Strength and Conditioning* [Preprint]. Available at: <https://doi.org/10.47206/ijsc.v2i1.75>.
39. Carling, C. *et al.* (2008) 'The role of motion analysis in elite soccer: Contemporary performance measurement techniques and work rate data', *Sports Medicine*. Sports Med, pp. 839–862. Available at: <https://doi.org/10.2165/00007256-200838100-00004>.
40. Carling, C. *et al.* (2016) 'Match-to-match variability in high-speed running activity in a professional soccer team', *Journal of Sports Sciences*, 34(24), pp. 2215–2223. Available at: <https://doi.org/10.1080/02640414.2016.1176228>.
41. Carling, C., Le Gall, F. and Dupont, G. (2012) 'Analysis of repeated high-intensity running performance in professional soccer', *J Sports Sci*, 30(4), pp. 325–336. Available at: <https://doi.org/10.1080/02640414.2011.652655>.
42. Casamichana, D. *et al.* (2019) 'The most demanding passages of play in football competition: A comparison between halves', *Biology of Sport*, 36(3), pp. 233–240. Available at: <https://doi.org/10.5114/biolsport.2019.86005>.
43. Casamichana, D., Bradley, P.S. and Castellano, J. (2018) 'Influence of the Varied Pitch Shape on Soccer Players Physiological Responses and Tim-otion Characteristics during Small-Sided Games', *Journal of Human Kinetics*, 64(1), pp. 171–180. Available at: <https://doi.org/10.1515/hukin-2017-0192>.
44. Castagna, C. *et al.* (2006) 'Aerobic fitness and yo-yo continuous and intermittent tests performances in soccer players: A correlation study', *Journal of Strength and Conditioning Research*, 20(2), pp. 320–325. Available at: <https://doi.org/10.1519/R-18065.1>.
45. Castagna, C. *et al.* (2013) 'Preseason variations in aerobic fitness and performance in elite-standard soccer players: a team study', *J Strength Cond*

- Res, 27(11), pp. 2959–2965. Available at: <https://doi.org/10.1519/JSC.0b013e31828d61a8>.
46. Chaize, C., Allen, M. and Beato, M. (2024) 'Physical Performance Is Affected by Players' Position, Game Location, and Substitutions During Official Competitions in Professional Championship English Football', *Journal of strength and conditioning research* [Preprint]. Available at: <https://doi.org/10.1519/JSC.0000000000004926>.
 47. Chmura, P. *et al.* (2017) 'Analysis of Motor Activities of Professional Soccer Players during the 2014 World Cup in Brazil', *Journal of Human Kinetics*, 56(1), pp. 187–195. Available at: <https://doi.org/10.1515/hukin-2017-0036>.
 48. Chmura, P. *et al.* (2018) 'Match outcome and running performance in different intensity ranges among elite soccer players', *Biology of Sport*, 35(2), pp. 197–203. Available at: <https://doi.org/10.5114/biol sport.2018.74196>.
 49. Clemente, F.M., Owen, A., *et al.* (2019) 'Characterization of the Weekly External Load Profile of Professional Soccer Teams from Portugal and the Netherlands', *Journal of Human Kinetics*, 66(1), pp. 155–164. Available at: <https://doi.org/10.2478/hukin-2018-0054>.
 50. Clemente, F.M., Rabbani, A., *et al.* (2019) 'Training/match external load ratios in professional soccer players: A full-season study', *International Journal of Environmental Research and Public Health*, 16(17). Available at: <https://doi.org/10.3390/ijerph16173057>.
 51. Clemente, F.M., Sarmento, H., *et al.* (2019) 'Variations of external load variables between medium- and large-sided soccer games in professional players', *Research in Sports Medicine*, 27(1), pp. 50–59. Available at: <https://doi.org/10.1080/15438627.2018.1511560>.
 52. Colby, M.J. *et al.* (2018) 'Improvement of prediction of noncontact injury in elite australian footballers with repeated exposure to established high-risk workload scenarios', *International Journal of Sports Physiology and Performance*, 13(9), pp. 1130–1135. Available at: <https://doi.org/10.1123/ijsp.2017-0696>.
 53. Connor, M., Mernagh, D. and Beato, M. (2022) 'Quantifying and modelling the game speed outputs of English Championship soccer players', *Research in Sports Medicine* [Preprint]. Available at: <https://doi.org/10.1080/15438627.2021.1888108>.
 54. Costa, J.A. *et al.* (2022) 'Using the Rating of Perceived Exertion and Heart Rate

to Quantify Training Intensity in Female Soccer Players: Validity and Utility.’, *Journal of strength and conditioning research*, 36(1), pp. 201–206. Available at: <https://doi.org/10.1519/JSC.00000000000003407>.

55. Coutts, A.J. *et al.* (2009) ‘Heart rate and blood lactate correlates of perceived exertion during small-sided soccer games’, *Journal of science and medicine in sport*, 12(1), pp. 79–84. Available at: <https://doi.org/10.1016/J.JSAMS.2007.08.005>.
56. Cummins, C., Orr, R. and Connor, H.O. (2013) ‘Global Positioning Systems (GPS) and microtechnology sensors in team sports: a systematic review’, *Sports medicine*, 43, pp. 1025–1042. Available at: <https://doi.org/10.1007/s40279-013-0069-2>.
57. Dalen, T. *et al.* (2019) ‘Differences in Acceleration and High-Intensity Activities Between Small-Sided Games and Peak Periods of Official Matches in Elite Soccer Players’, *Journal of Strength and Conditioning Research*, p. 1. Available at: <https://doi.org/10.1519/jsc.00000000000003081>.
58. Delaney, J.A. *et al.* (2015) ‘Establishing Duration-Specific Running Intensities From Match-Play Analysis in Rugby League’, *International Journal of Sports Physiology and Performance*, 10(6), pp. 725–731. Available at: <https://doi.org/10.1123/IJSP.2015-0092>.
59. Delaney, J.A. *et al.* (2018) ‘Modelling the decrement in running intensity within professional soccer players’, *Science and Medicine in Football*, 2(2), pp. 86–92. Available at: <https://doi.org/10.1080/24733938.2017.1383623>.
60. Dellagrana, R.A., Nunes, R.F.H. and Silva, R.L.P. (2023) ‘The Importance of Crowd Support and Team Quality to Home Advantage in Brazilian Soccer League First Division’, *Perceptual and motor skills*, 130(3), pp. 1255–1268. Available at: <https://doi.org/10.1177/00315125231169876>.
61. de Dios-Álvarez, V. *et al.* (2021) ‘Accumulative Weekly External and Internal Load Relative to Match Load in Elite Male Youth Soccer Players’, *Pediatric exercise science*, 34(3), pp. 119–124. Available at: <https://doi.org/10.1123/PES.2021-0048>.
62. Djaoui, L. *et al.* (2022) ‘Effects of congested match periods on acceleration and deceleration profiles in professional soccer’, *Biology of sport*, 39(2), pp. 307–317. Available at: <https://doi.org/10.5114/BIOLSPORT.2022.103725>.
63. Douchet, T., Paizis, C. and Babault, N. (2022) ‘Physical Impact of a Typical

Training Session with Different Volumes on the Day Preceding a Match in Academy Soccer Players', *International journal of environmental research and public health*, 19(21). Available at: <https://doi.org/10.3390/IJERPH192113828>.

64. Duhig, S. *et al.* (2016) 'Effect of high-speed running on hamstring strain injury risk', *British Journal of Sports Medicine*, 50(24), pp. 1536–1540. Available at: <https://doi.org/10.1136/bjsports-2015-095679>.
65. Duthie, G.M. *et al.* (2018) 'Running intensities in elite youth soccer by age and position', *Journal of Strength and Conditioning Research*, 32(10), pp. 2918–2924. Available at: <https://doi.org/10.1519/JSC.0000000000002728>.
66. Dwyer, D.B. and Gabbett, T.J. (2012) 'Global positioning system data analysis: velocity ranges and a new definition of sprinting for field sport athletes', *Journal of strength and conditioning research*, 26(3), pp. 818–824. Available at: <https://doi.org/10.1519/JSC.0B013E3182276555>.
67. Esposito, F. *et al.* (2004) 'Validity of heart rate as an indicator of aerobic demand during soccer activities in amateur soccer players', *Eur J Appl Physiol*, 93(1–2), pp. 167–172. Available at: <https://doi.org/10.1007/s00421-004-1192-4>.
68. Faude, O., Koch, T. and Meyer, T. (2012) 'Straight sprinting is the most frequent action in goal situations in professional football', *Journal of Sports Sciences*, 30(7), pp. 625–631. Available at: <https://doi.org/10.1080/02640414.2012.665940>.
69. Fereday, K. *et al.* (2020) 'A comparison of rolling averages versus discrete time epochs for assessing the worst-case scenario locomotor demands of professional soccer match-play', *Journal of Science and Medicine in Sport*, 23(8), pp. 764–769. Available at: <https://doi.org/10.1016/j.jsams.2020.01.002>.
70. FIFA (2019) *Physical analysis of the FIFA Women's World Cup France 2019*. Available at: <https://www.fifa.com/tournaments/womens/womensworldcup/france2019/news/physical-analysis-of-france-2019-shows-increase-in-speed-and-intensity> (Accessed: 9 April 2022).
71. FIFPRO (2022) *Player and High-Performance Coach Surveys*. Available at: <https://fifpro.org/en/reports/fifpro-pwm-flash-report-2022-a-calendar-that-respects-players-health-small>.
72. Fleming, A. *et al.* (2023) 'A Comparison of Training and Match Play External Load During a Congested In-Season Period in English League 2 Football', *Journal of*

- strength and conditioning research*, 37(9), pp. E527–E534. Available at: <https://doi.org/10.1519/JSC.0000000000004458>.
73. Foster, C. *et al.* (1995) 'Effects of specific versus cross-training on running performance', *European journal of applied physiology and occupational physiology*, 70(4), pp. 367–372. Available at: <https://doi.org/10.1007/BF00865035>.
 74. Foster, C. *et al.* (2001) 'A new approach to monitoring exercise training', *J Strength Cond Res*, 15(1), pp. 109–115. Available at: <https://www.ncbi.nlm.nih.gov/pubmed/11708692>.
 75. Freeman, B.W. *et al.* (2021) 'Sprinting and hamstring strain injury: Beliefs and practices of professional physical performance coaches in Australian football', *Physical Therapy in Sport*, 48, pp. 12–19. Available at: <https://doi.org/10.1016/J.PTSP.2020.12.007>.
 76. Gaudino, P. *et al.* (2013) 'Monitoring training in elite soccer players: Systematic bias between running speed and metabolic power data', *International Journal of Sports Medicine*, 34(11), pp. 963–968. Available at: <https://doi.org/10.1055/s-0033-1337943>.
 77. González-García, J. *et al.* (2023) 'Assessment of Peak Physical Demands in Elite Women Soccer Players: Can Contextual Variables Play a Role?', *Research quarterly for exercise and sport*, 94(2), pp. 435–443. Available at: <https://doi.org/10.1080/02701367.2021.2004297>.
 78. Gregson, W. *et al.* (2010) 'Match-to-Match Variability of High-Speed Activities in Premier League Soccer', *International Journal of Sports Medicine*, 31(04), pp. 237–242. Available at: <https://doi.org/10.1055/S-0030-1247546>.
 79. Gregson, W. *et al.* (2020) 'Harmful association of sprinting with muscle injury occurrence in professional soccer match-play: A two-season, league wide exploratory investigation from the Qatar Stars League', *Journal of Science and Medicine in Sport*, 23(2), pp. 134–138. Available at: <https://doi.org/10.1016/j.jsams.2019.08.289>.
 80. Gualtieri, A. *et al.* (2020) 'Workload Monitoring in Top-level Soccer Players during Congested Fixture Periods', *International Journal of Sports Medicine*, 41(10), pp. 677–681. Available at: <https://doi.org/10.1055/a-1171-1865>.
 81. Gualtieri, A. *et al.* (2024) 'Three-, Four-, and Five-Day Microcycles: The Normality in Professional Football', *International journal of sports physiology and*

- performance, pp. 1–9. Available at: <https://doi.org/10.1123/IJSP.2024-0144>.
82. Guerrero-Calderón, B. *et al.* (2023) 'Analysis of the Competitive Weekly Microcycle in Elite Soccer: Comparison of Workload Behavior in Absolute and Relative Terms', *Journal of Strength and Conditioning Research*, 37(2), pp. 343–350. Available at: <https://doi.org/10.1519/JSC.0000000000004219>.
 83. Harriss, D.J., MacSween, A. and Atkinson, G. (2019) 'Ethical standards in sport and exercise science research: 2020 update', *International Journal of Sports Medicine*, 40(13), pp. 813–817. Available at: <https://doi.org/10.1055/a-1015-3123>.
 84. Hecksteden, A., Kellner, R. and Donath, L. (2022) 'Dealing with small samples in football research', *Science and Medicine in Football*, 6(3), pp. 389–397. Available at: <https://doi.org/10.1080/24733938.2021.1978106>.
 85. Hegyi, A. *et al.* (2019) 'Individual Region- and Muscle-specific Hamstring Activity at Different Running Speeds', *Medicine and science in sports and exercise*, 51(11), pp. 2274–2285. Available at: <https://doi.org/10.1249/MSS.0000000000002060>.
 86. Helgerud, J. *et al.* (2001) 'Aerobic endurance training improves soccer performance', *Medicine and science in sports and exercise*, 33(11), pp. 1925–1931. Available at: <https://doi.org/10.1097/00005768-200111000-00019>.
 87. Higashihara, A. *et al.* (2010) 'Functional differences in the activity of the hamstring muscles with increasing running speed', *Journal of Sports Sciences*, 28(10), pp. 1085–1092. Available at: <https://doi.org/10.1080/02640414.2010.494308>.
 88. Hills, S.P. *et al.* (2019) 'A match-day analysis of the movement profiles of substitutes from a professional soccer club before and after pitch-entry', *PLoS ONE*, 14(1). Available at: <https://doi.org/10.1371/journal.pone.0211563>.
 89. Hopkins, W.G. *et al.* (2009) 'Progressive statistics for studies in sports medicine and exercise science.', *Medicine and science in sports and exercise*, 41(1), pp. 3–13. Available at: <https://doi.org/10.1249/MSS.0b013e31818cb278>.
 90. Dello Iacono, A. *et al.* (2021) 'Training load responses to football game profile-based training (GPBT) formats: effects of locomotive demands manipulation', *Biology of Sport*, 39(1), pp. 145–155. Available at: <https://doi.org/10.5114/BIOLSPORT.2021.102919>.
 91. Dello Iacono, A. *et al.* (2022) 'Quantifying Exposure and Intra-Individual Reliability of High-Speed and Sprint Running During Sided-Games Training in Soccer

- Players: A Systematic Review and Meta-analysis', *Sports medicine (Auckland, N.Z.)* [Preprint]. Available at: <https://doi.org/10.1007/S40279-022-01773-1>.
92. Dello Iacono, A., Beato, M. and Unnithan, V. (2021) 'Comparative Effects of Game Profile-Based Training and Small-Sided Games on Physical Performance of Elite Young Soccer Players', *Journal of strength and conditioning research*, 35(10), pp. 2810–2817. Available at: <https://doi.org/10.1519/JSC.0000000000003225>.
 93. Impellizzeri, F.M. *et al.* (2004) 'Use of RPE-based training load in soccer.', *Medicine and science in sports and exercise*, 36(6), pp. 1042–7. Available at: <https://doi.org/10.1249/01.MSS.0000128199.23901.2F>.
 94. Impellizzeri, F.M., Marcora, S.M. and Coutts, A.J. (2019) 'Internal and External Training Load: 15 Years On', *International Journal of Sports Physiology and Performance*, 14(2), pp. 270–273. Available at: <https://doi.org/10.1123/IJSPP.2018-0935>.
 95. Jaspers, A. *et al.* (2018) 'Examination of the external and internal load indicators' association with overuse injuries in professional soccer players', *Journal of Science and Medicine in Sport*, 21(6), pp. 579–585. Available at: <https://doi.org/10.1016/j.jsams.2017.10.005>.
 96. Jastrzębski, Z. and Radzimiński, Ł. (2015) 'Individual vs general time-motion analysis and physiological response in 4 vs 4 and 5 vs 5 small-sided soccer games', *International Journal of Performance Analysis in Sport*, 15(1), pp. 397–410. Available at: <https://doi.org/10.1080/24748668.2015.11868801>.
 97. Jiménez, S.L. *et al.* (2023) 'Analysis of the most demanding passages of play in elite youth soccer: a comparison between congested and non-congested fixture schedules', *Science and Medicine in Football*, 7(4), pp. 358–365. Available at: <https://doi.org/10.1080/24733938.2022.2117404>.
 98. Johnston, R.J. *et al.* (2012) 'The validity and reliability of 5-Hz global positioning system units to measure team sport movement demands', *Journal of strength and conditioning research*, 26(3), pp. 758–765. Available at: <https://doi.org/10.1519/JSC.0B013E318225F161>.
 99. Johnston, R.J. *et al.* (2014) 'Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands', *Journal of Strength and Conditioning Research*, 28(6), pp. 1649–1655. Available at: <https://doi.org/10.1519/JSC.0000000000000323>.

100. Jones, R.N. *et al.* (2019) 'The influence of short-term fixture congestion on position specific match running performance and external loading patterns in English professional soccer', *Journal of Sports Sciences*, 37(12), pp. 1338–1346. Available at: <https://doi.org/10.1080/02640414.2018.1558563>.
101. Julian, R., Page, R.M. and Harper, L.D. (2021) 'The Effect of Fixture Congestion on Performance During Professional Male Soccer Match-Play: A Systematic Critical Review with Meta-Analysis', *Sports Medicine*, 51(2), pp. 255–273. Available at: <https://doi.org/10.1007/S40279-020-01359-9/TABLES/4>.
102. Kalkhoven, J.T. *et al.* (2021) 'Training Load and Injury: Causal Pathways and Future Directions', *Sports Medicine* 2020 51:6, 51(6), pp. 1137–1150. Available at: <https://doi.org/10.1007/S40279-020-01413-6>.
103. Kelly, D.M. *et al.* (2020) 'Quantification of training and match-load distribution across a season in elite English Premier League soccer players', *Science and Medicine in Football*, 4(1), pp. 59–67. Available at: <https://doi.org/10.1080/24733938.2019.1651934>.
104. Kenneally-Dabrowski, C.J.B. *et al.* (2019) 'Late swing or early stance? A narrative review of hamstring injury mechanisms during high-speed running', *Scandinavian Journal of Medicine and Science in Sports*. Blackwell Munksgaard, pp. 1083–1091. Available at: <https://doi.org/10.1111/sms.13437>.
105. Kobal, R. *et al.* (2016) 'Comparison of physical performance among Brazilian elite soccer players of different age-categories', *J Sports Med Phys Fitness*, 56(4), pp. 376–82. Available at: https://www.researchgate.net/publication/269712042_Comparison_of_physical_performance_among_Brazilian_elite_soccer_players_of_different_age-categories (Accessed: 2 April 2020).
106. Köklü, Y. *et al.* (2020) 'Acute effects of small-sided games combined with running drills on internal and external loads in young soccer players', *Biology of sport*, 37(4), pp. 375–381. Available at: <https://doi.org/10.5114/BIOLOSPORT.2020.96943>.
107. Krstrup, P. *et al.* (2003) 'The Yo-Yo intermittent recovery test: Physiological response, reliability, and validity', *Medicine and Science in Sports and Exercise*, 35(4), pp. 697–705. Available at: <https://doi.org/10.1249/01.MSS.0000058441.94520.32>.
108. Kyprianou, E. *et al.* (2019) 'To Measure Peak Velocity in Soccer, Let the Players

- Sprint', *Journal of Strength and Conditioning Research*, p. 1. Available at: <https://doi.org/10.1519/jsc.0000000000003406>.
109. Lacome, M. *et al.* (2018) 'Small-sided games in elite soccer: Does one size fit all?', *International Journal of Sports Physiology and Performance* [Preprint]. Available at: <https://doi.org/10.1123/ijsp.2017-0214>.
 110. Lago-Peñas, C. *et al.* (2022) 'Evolution of physical and technical parameters in the Spanish LaLiga 2012-2019', *Science & medicine in football* [Preprint]. Available at: <https://doi.org/10.1080/24733938.2022.2049980>.
 111. Lang, S. and Kleijnen, J. (2010) 'Quality assessment tools for observational studies: lack of consensus', *International journal of evidence-based healthcare*, 8(4), p. 247. Available at: <https://doi.org/10.1111/J.1744-1609.2010.00195.X>.
 112. Lino-Mesquita, J. *et al.* (2024) 'The Complexity of Defining and Assessing the Most Demanding Periods of Play in Team Sports: A Current Opinion', *Strength and Conditioning Journal* [Preprint]. Available at: <https://doi.org/10.1519/SSC.0000000000000859>.
 113. Lopategui, I.G., Paulis, J.C. and Escudero, I.E. (2021) 'Physical Demands and Internal Response in Football Sessions According to Tactical Periodization', *International Journal of Sports Physiology and Performance*, 16(6), pp. 858–864. Available at: <https://doi.org/10.1123/IJSPP.2019-0829>.
 114. Malone, J.J. *et al.* (2015) 'Seasonal training-load quantification in elite English Premier League soccer players', *International Journal of Sports Physiology and Performance*, 10(4), pp. 489–497. Available at: <https://doi.org/10.1123/ijsp.2014-0352>.
 115. Malone, S. *et al.* (2016) 'High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football', *J Sci Med Sport* [Preprint]. Available at: <https://doi.org/10.1016/j.jsams.2016.08.005>.
 116. Malone, S. *et al.* (2018) 'High-speed running and sprinting as an injury risk factor in soccer: Can well-developed physical qualities reduce the risk?', *Journal of Science and Medicine in Sport*, 21(3), pp. 257–262. Available at: <https://doi.org/10.1016/j.jsams.2017.05.016>.
 117. Mara, J.K. *et al.* (2017) 'Quantifying the high-speed running and sprinting profiles of elite female soccer players during competitive matches using an optical player tracking system', *Journal of Strength and Conditioning Research*, 31(6), pp. 1500–1508. Available at: <https://doi.org/10.1519/JSC.0000000000001629>.

118. Martín-García, A., Casamichana, D., *et al.* (2018) 'Positional differences in the most demanding passages of play in football competition', *Journal of Sports Science and Medicine*, 17(4), pp. 563–570. Available at: <https://pubmed.ncbi.nlm.nih.gov/30479524/> (Accessed: 2 February 2021).
119. Martín-García, A., Gómez Díaz, A., *et al.* (2018) 'Quantification of a professional football team's external load using a microcycle structure', *Journal of Strength and Conditioning Research*, 32(12), pp. 3511–3518. Available at: <https://doi.org/10.1519/jsc.0000000000002816>.
120. Martínez-Hernández, D., Quinn, M. and Jones, P. (2022) 'Linear advancing actions followed by deceleration and turn are the most common movements preceding goals in male professional soccer', *Science & medicine in football* [Preprint]. Available at: <https://doi.org/10.1080/24733938.2022.2030064>.
121. Massard, T., Eggers, T. and Lovell, R. (2018) 'Peak speed determination in football: is sprint testing necessary?', *Science and Medicine in Football*, 2(2), pp. 123–126. Available at: <https://doi.org/10.1080/24733938.2017.1398409>.
122. Maullin-Sapey, T. and Nichols, T.E. (2021) 'Fisher scoring for crossed factor linear mixed models', *Statistics and Computing*, 31(5), pp. 1–25. Available at: <https://doi.org/10.1007/s11222-021-10026-6>.
123. McCall, A. *et al.* (2020) 'Exercise-Based Strategies to Prevent Muscle Injury in Male Elite Footballers: An Expert-Led Delphi Survey of 21 Practitioners Belonging to 18 Teams from the Big-5 European Leagues', *Sports Medicine* [Preprint]. Available at: <https://doi.org/10.1007/s40279-020-01315-7>.
124. McGrath, T.M. *et al.* (2020) 'Determinants of hamstring fascicle length in professional rugby league athletes', *Journal of Science and Medicine in Sport* [Preprint]. Available at: <https://doi.org/10.1016/j.jsams.2019.12.006>.
125. Mendez-Villanueva, A. *et al.* (2011) 'Does on-field sprinting performance in young soccer players depend on how fast they can run or how fast they do run?', *Journal of strength and conditioning research*, 25(9), pp. 2634–2638. Available at: <https://doi.org/10.1519/JSC.0B013E318201C281>.
126. Miñano-Espin, J. *et al.* (2017) 'High Speed Running and Sprinting Profiles of Elite Soccer Players', *Journal of Human Kinetics*, 58(1), pp. 169–176. Available at: <https://doi.org/10.1515/hukin-2017-0086>.
127. Modric, T. *et al.* (2019) 'Analysis of the association between running performance and game performance indicators in professional soccer players', *International*

Journal of Environmental Research and Public Health, 16(20). Available at: <https://doi.org/10.3390/ijerph16204032>.

128. Morgans, R., Di Michele, R. and Drust, B. (2018) 'Soccer match play as an important component of the power-training stimulus in Premier League players.', *International journal of sports physiology and performance*, 13(5), pp. 665–667. Available at: <https://doi.org/10.1123/ijsp.2016-0412>.
129. Mueller-Wohlfahrt, H.W. *et al.* (2013) 'Terminology and classification of muscle injuries in sport: the Munich consensus statement', *Br J Sports Med*, 47(6), pp. 342–350. Available at: <https://doi.org/10.1136/bjsports-2012-091448>.
130. Muggleston, C. *et al.* (2013) 'Half-time and high-speed running in the second half of soccer', *International Journal of Sports Medicine*, 34(6), pp. 514–519. Available at: <https://doi.org/10.1055/s-0032-1327647>.
131. Novak, A.R. *et al.* (2021) 'Analysis of the worst-case scenarios in an elite football team: Towards a better understanding and application', <https://doi.org/10.1080/02640414.2021.1902138> [Preprint]. Available at: <https://doi.org/10.1080/02640414.2021.1902138>.
132. O'Connor, F. *et al.* (2020) 'Greater association of relative thresholds than absolute thresholds with noncontact lower-body injury in professional australian rules footballers: Implications for sprint monitoring', *International Journal of Sports Physiology and Performance*, 15(2), pp. 204–212. Available at: <https://doi.org/10.1123/ijsp.2019-0015>.
133. Oliva-Lozano, J.M. *et al.* (2020) 'Worst case scenario match analysis and contextual variables in professional soccer players: a longitudinal study', *Biology of sport*, 37(4), pp. 429–436. Available at: <https://doi.org/10.5114/BIOLSPORT.2020.97067>.
134. Oliva-Lozano, J.M., Gómez-Carmona, C.D., *et al.* (2022) 'Effect of training day, match, and length of the microcycle on workload periodization in professional soccer players: a full-season study', *Biology of Sport*, 39(2), p. 397. Available at: <https://doi.org/10.5114/BIOLSPORT.2022.106148>.
135. Oliva-Lozano, J.M., Fortes, V., *et al.* (2022) 'When and how do professional soccer players experience maximal intensity sprints in LaLiga?', <https://doi.org/10.1080/24733938.2022.2100462> [Preprint]. Available at: <https://doi.org/10.1080/24733938.2022.2100462>.
136. Oliva-Lozano, J.M. *et al.* (2023) 'Monitoring physical match performance relative

to peak locomotor demands: implications for training professional soccer players', *Biology of Sport* [Preprint]. Available at: <https://doi.org/10.5114/BIOLSPORT.2023.116450>.

137. Oliva Lozano, J.M. *et al.* (2023) 'Effect of the Length of the Microcycle on the Daily External Load, Fatigue, Sleep Quality, Stress, and Muscle Soreness of Professional Soccer Players: A Full-Season Study', *Sports Health*, 15(5), p. 695. Available at: <https://doi.org/10.1177/19417381221131531>.
138. Oliveira, R. *et al.* (2019) 'In-season internal and external training load quantification of an elite European soccer team', *PLoS ONE*, 14(4). Available at: <https://doi.org/10.1371/journal.pone.0209393>.
139. Oliveira, R. *et al.* (2023) 'Are non-starters accumulating enough load compared with starters? Examining load, wellness, and training/match ratios of a European professional soccer team', *BMC Sports Science, Medicine and Rehabilitation*, 15(1), pp. 1–11. Available at: <https://doi.org/10.1186/S13102-023-00743-Y/FIGURES/1>.
140. Ouzzani, M. *et al.* (2016) 'Rayyan-a web and mobile app for systematic reviews', *Systematic Reviews*, 5(1), p. 210. Available at: <https://doi.org/10.1186/s13643-016-0384-4>.
141. Page, M.J. *et al.* (2021) 'The PRISMA 2020 statement: an updated guideline for reporting systematic reviews', *BMJ*, 372. Available at: <https://doi.org/10.1136/BMJ.N71>.
142. Panduro, J. *et al.* (2022) 'Physical performance and loading for six playing positions in elite female football: full-game, end-game, and peak periods', *Scandinavian Journal of Medicine & Science in Sports*, 32(S1), pp. 115–126. Available at: <https://doi.org/10.1111/SMS.13877>.
143. Park, L.A.F., Scott, D. and Lovell, R. (2019) 'Velocity zone classification in elite women's football: where do we draw the lines?', *Science and Medicine in Football*, 3(1), pp. 21–28. Available at: <https://doi.org/10.1080/24733938.2018.1517947>.
144. Querido, S.M. *et al.* (2022) 'Analysis of Recovery Methods' Efficacy Applied up to 72 Hours Postmatch in Professional Football: A Systematic Review With Graded Recommendations', *International Journal of Sports Physiology and Performance*, 17(9), pp. 1326–1342. Available at: <https://doi.org/10.1123/IJSP.2022-0038>.

145. Rago, V. *et al.* (2019) 'Relationship between External Load and Perceptual Responses to Training in Professional Football: Effects of Quantification Method', *Sports*, 7(3), p. 68. Available at: <https://doi.org/10.3390/sports7030068>.
146. Ramos, G.P. *et al.* (2017) 'Movement Patterns of a U-20 National Women's Soccer Team during Competitive Matches: Influence of Playing Position and Performance in the First Half', *International Journal of Sports Medicine* [Preprint]. Available at: <https://doi.org/10.1055/s-0043-110767>.
147. Ramos, G.P. *et al.* (2019) 'Activity Profiles in U17, U20, and Senior Women's Brazilian National Soccer Teams During International Competitions: Are There Meaningful Differences?', *Journal of strength and conditioning research*, 33(12), pp. 3414–3422. Available at: <https://doi.org/10.1519/JSC.0000000000002170>.
148. Rampinini, E. *et al.* (2007) 'Variation in top level soccer match performance', *International Journal of Sports Medicine*, 28(12), pp. 1018–1024. Available at: <https://doi.org/10.1055/s-2007-965158>.
149. Reynolds, J. *et al.* (2021) 'Quantifying and Comparing the Match Demands of U18, U23, and 1ST Team English Professional Soccer Players', *Frontiers in Physiology*, 12. Available at: <https://doi.org/10.3389/FPHYS.2021.706451/FULL>.
150. Riboli, A. *et al.* (2020) 'Area per player in small-sided games to replicate the external load and estimated physiological match demands in elite soccer players', *PLoS ONE*, 15(9). Available at: <https://doi.org/10.1371/JOURNAL.PONE.0229194>.
151. Riboli, A. *et al.* (2021) 'Effect of formation, ball in play and ball possession on peak demands in elite soccer', *Biology of Sport* [Preprint]. Available at: <https://doi.org/10.5114/BIOLSPORT.2020.98450>.
152. Riboli, A. *et al.* (2024) 'Top-class women's soccer performance: peak demands and distribution of the match activities relative to maximal intensities during official matches', *Biology of sport*, 41(1), pp. 207–215. Available at: <https://doi.org/10.5114/BIOLSPORT.2024.129477>.
153. Riboli, A., Esposito, F. and Coratella, G. (2022) 'The distribution of match activities relative to the maximal intensities in elite soccer players: implications for practice', *Research in sports medicine (Print)*, 30(5), pp. 463–474. Available at: <https://doi.org/10.1080/15438627.2021.1895788>.
154. Riboli, A., Esposito, F. and Coratella, G. (2023) 'Small-Sided Games in Elite Football: Practical Solutions to Replicate the 4-min Match-Derived Maximal

- Intensities', *Journal of Strength and Conditioning Research* [Preprint]. Available at: <https://doi.org/10.1519/JSC.00000000000004249>.
155. Rico-González, M. *et al.* (2022) 'Players' performance during worst-case scenarios in professional soccer matches: A systematic review', *Biology of Sport* [Preprint]. Available at: <https://doi.org/10.5114/BIOLOSPORT.2022.107022>.
 156. Roecker, K. *et al.* (2017) 'The relationship between movement speed and duration during soccer matches', *PLOS ONE*, 12(7), p. e0181781. Available at: <https://doi.org/10.1371/JOURNAL.PONE.0181781>.
 157. Sandford, G.N., Laursen, P.B. and Buchheit, M. (2021) 'Anaerobic Speed/Power Reserve and Sport Performance: Scientific Basis, Current Applications and Future Directions', *Sports medicine (Auckland, N.Z.)*, 51(10), pp. 2017–2028. Available at: <https://doi.org/10.1007/S40279-021-01523-9>.
 158. Schimpchen, J., Gopaladesikan, S. and Meyer, T. (2021) 'The intermittent nature of player physical output in professional football matches: An analysis of sequences of peak intensity and associated fatigue responses', *European journal of sport science*, 21(6), pp. 793–802. Available at: <https://doi.org/10.1080/17461391.2020.1776400>.
 159. Schober, P. and Schwarte, L.A. (2018) 'Correlation coefficients: Appropriate use and interpretation', *Anesthesia and Analgesia*, 126(5), pp. 1763–1768. Available at: <https://doi.org/10.1213/ANE.00000000000002864>.
 160. Scott, B.R. *et al.* (2013) 'A comparison of methods to quantify the in-season training load of professional soccer players', *Int J Sports Physiol Perform*, 8(2), pp. 195–202. Available at: <https://www.ncbi.nlm.nih.gov/pubmed/23428492>.
 161. Scott, D. and Lovell, R. (2018) 'Individualisation of speed thresholds does not enhance the dose-response determination in football training', *Journal of Sports Sciences*, 36(13), pp. 1523–1532. Available at: <https://doi.org/10.1080/02640414.2017.1398894>.
 162. Scott, D., Norris, D. and Lovell, R. (2020) 'Dose–Response Relationship Between External Load and Wellness in Elite Women's Soccer Matches: Do Customized Velocity Thresholds Add Value?', *International Journal of Sports Physiology and Performance*, 15(9), pp. 1245–1251. Available at: <https://doi.org/10.1123/ijsp.2019-0660>.
 163. Scott, M.T., Scott, T.J. and Kelly, V.G. (2016) 'The validity and reliability of global positioning systems in team sport: A brief review', *Journal of Strength and*

- Conditioning Research*, 30(5), pp. 1470–1490. Available at: <https://doi.org/10.1519/JSC.0000000000001221>.
164. Silva, H. *et al.* (2022) 'Acceleration and deceleration demands during training sessions in football: a systematic review', *Science and Medicine in Football*, pp. 1–16. Available at: <https://doi.org/10.1080/24733938.2022.2090600>.
 165. Silva, J.R. *et al.* (2013) 'Training status and match activity of professional soccer players throughout a season', *Journal of Strength and Conditioning Research*, 27(1), pp. 20–30. Available at: <https://doi.org/10.1519/JSC.0b013e31824e1946>.
 166. Silva, J.R. *et al.* (2023) 'Building Bridges Instead of Putting Up Walls: Connecting the “Teams” to Improve Soccer Players’ Support', *Sports Medicine*, 53(12), pp. 2309–2320. Available at: <https://doi.org/10.1007/S40279-023-01887-0/FIGURES/1>.
 167. Small, K. *et al.* (2009) 'Soccer fatigue, sprinting and hamstring injury risk', *International Journal of Sports Medicine*, 30(8), pp. 573–578. Available at: <https://doi.org/10.1055/s-0029-1202822>.
 168. Soroka, A. (2018) 'The locomotor activity of soccer players based on playing positions during the 2010 World cup', *Journal of Sports Medicine and Physical Fitness*, 58(6), pp. 837–842. Available at: <https://doi.org/10.23736/S0022-4707.17.04323-7>.
 169. Stevens, T.G.A. *et al.* (2017) 'Quantification of in-season training load relative to match load in professional Dutch Eredivisie football players', *Science and Medicine in Football*, 1(2), pp. 117–125. Available at: <https://doi.org/10.1080/24733938.2017.1282163>.
 170. Stolen, T. *et al.* (2005) 'Physiology of soccer: an update', *Sports Medicine*, 35(6), pp. 501–536. Available at: <https://doi.org/10.2165/00007256-200535060-00004>.
 171. Suarez-Arrones, L. *et al.* (2020) 'Player Monitoring in Professional Soccer: Spikes in Acute:Chronic Workload Are Dissociated From Injury Occurrence', *Frontiers in Sports and Active Living*, 2. Available at: <https://doi.org/10.3389/fspor.2020.00075>.
 172. Sweeting, A.J. *et al.* (2017) 'When is a sprint a sprint? A review of the analysis of team-sport athlete activity profile', *Frontiers in Physiology*. Frontiers Media S.A. Available at: <https://doi.org/10.3389/fphys.2017.00432>.
 173. Sziget, G. *et al.* (2021) 'Quantification of Training Load Relative to Match Load of Youth National Team Soccer Players',

- <https://doi.org/10.1177/19417381211004902>, 14(1), pp. 84–91. Available at: <https://doi.org/10.1177/19417381211004902>.
174. Taberner, M. *et al.* (2019) 'Interchangeability of position tracking technologies; can we merge the data?', *Science and Medicine in Football*, 3938, pp. 1–6. Available at: <https://doi.org/10.1080/24733938.2019.1634279>.
 175. Thornton, H.R. *et al.* (2019) 'Interunit reliability and effect of data-processing methods of global positioning systems', *International Journal of Sports Physiology and Performance*, 14(4), pp. 432–438. Available at: <https://doi.org/10.1123/ijsp.2018-0273>.
 176. Thorpe, R.T. *et al.* (2015) 'Monitoring Fatigue During the In-Season Competitive Phase in Elite Soccer Players', *Int J Sports Physiol Perform*, 10(8), pp. 958–964. Available at: <https://doi.org/10.1123/ijsp.2015-0004>.
 177. Thorpe, R.T. *et al.* (2017) 'Monitoring fatigue status in elite team-sport athletes: Implications for practice', *International Journal of Sports Physiology and Performance*, 12, pp. 27–34. Available at: <https://doi.org/10.1123/ijsp.2016-0434>.
 178. Thoseby, B. *et al.* (2023) 'Positional and temporal differences in peak match running demands of elite football', *Biology of Sport* [Preprint]. Available at: <https://doi.org/10.5114/biolsport.2023.116006>.
 179. van den Tillaar, R., Solheim, J.A.B. and Bencke, J. (2017) 'COMPARISON OF HAMSTRING MUSCLE ACTIVATION DURING HIGH-SPEED RUNNING AND VARIOUS HAMSTRING STRENGTHENING EXERCISES', *International Journal of Sports Physical Therapy*, 12(5), pp. 718–727. Available at: <https://doi.org/10.26603/ijsp.20170718>.
 180. Tokutake, G. *et al.* (2018) 'The risk factors of hamstring strain injury induced by high-speed running', *Journal of Sports Science and Medicine*, 17(4), pp. 650–655.
 181. Trewin, J. *et al.* (2018) 'The match-to-match variation of match-running in elite female soccer', *Journal of Science and Medicine in Sport*, 21(2), pp. 196–201. Available at: <https://doi.org/10.1016/J.JSAMS.2017.05.009>.
 182. Vardakis, L. *et al.* (2023) 'Application of a Structured Training Plan on Different-Length Microcycles in Soccer—Internal and External Load Analysis between Training Weeks and Games', *Applied Sciences* 2023, Vol. 13, Page 6935, 13(12), p. 6935. Available at: <https://doi.org/10.3390/AP13126935>.

183. Varley, M.C., Elias, G.P. and Aughey, R.J. (2012) 'Current match-analysis techniques' underestimation of intense periods of high-velocity running', *International Journal of Sports Physiology and Performance* [Preprint]. Available at: <https://doi.org/10.1123/ijspp.7.2.183>.
184. Vieira, L.H.P. *et al.* (2018) 'Running performance in Brazilian professional football players during a congested match schedule', *Journal of Strength and Conditioning Research*, 32(2), pp. 313–325. Available at: <https://doi.org/10.1519/JSC.0000000000002342>.
185. Weaving, D. *et al.* (2022) 'The Maximal Intensity Period: Rationalising its Use in Team Sports Practice', *Sports Medicine - Open* [Preprint]. Available at: <https://doi.org/10.1186/s40798-022-00519-7>.
186. Wehbe, G.M., Hartwig, T.B. and Duncan, C.S. (2014) 'Movement analysis of australian national league soccer players using global positioning system technology', *Journal of Strength and Conditioning Research*, 28(3), pp. 834–842. Available at: <https://doi.org/10.1519/JSC.0b013e3182a35dd1>.
187. Whitehead, S. *et al.* (2018) 'The Use of Microtechnology to Quantify the Peak Match Demands of the Football Codes: A Systematic Review', *Sports Medicine*, 48(11), pp. 2549–2575. Available at: <https://doi.org/10.1007/S40279-018-0965-6/TABLES/9>.
188. Whiteley, R. *et al.* (2020) 'Match High-Speed Running Distances Are Often Suppressed After Return From Hamstring Strain Injury in Professional Footballers.', *Sports health*, p. 1941738120964456. Available at: <https://doi.org/10.1177/1941738120964456>.
189. Wolski, L. *et al.* (2021) 'Is there an association between high-speed running biomechanics and hamstring strain injury? A systematic review', <https://doi.org/10.1080/14763141.2021.1960418> [Preprint]. Available at: <https://doi.org/10.1080/14763141.2021.1960418>.
190. Woods, C. *et al.* (2004) 'The Football Association Medical Research Programme: an audit of injuries in professional football--analysis of hamstring injuries', *British journal of sports medicine*, 38(1), pp. 36–41. Available at: <https://doi.org/10.1136/BJSM.2002.002352>.