Physical Demands During Contextualised Peak Intensity Periods: Analysis of Transitional Play, High-Pressure Activities and 30-second Worst-Case Scenarios in Elite Football

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Abstract

Transitional activities (TA's) and high-pressure actions are the key phases of play in modern football. They present a broad context within game play, as they depict actions in/out of possession as well as represent tactical offensive and defensive team collective movements and behaviours. A detailed definition of these tactical moments is presented in Table 2 and 3, which can be found in Chapter 3 (page 86-87). Previous studies have not explored the physical demands during transitions in football and most authors have reported whole and average match GPS-derived data neglecting fluctuations of intensity across 90-min. These shorts bouts of high-intensity periods could expose players to the highest physical outputs within a contemporary match play. The increased body of knowledge on TA's might provide new multivariate insights about physical demands of competition and offer more effective team/individual contextualised training design that integrates physical and technical-tactical aspects in practical settings. Therefore, the primary aim of this thesis was to analyse short and specific blocks of activities commonly observed in football matches and determine their impact on external load metrics to optimise physical preparation of players, enhance performance, and potentially reduce injury risk.

Chapter 3 analysed the mean and peak team physical demands during transitional activities and compared them to the 90-min averages. Chapter 4 explored physical demands across different playing positions during these phases. Players were categorised to the following positional groups: center backs (CB), full backs (FB), central defensive midfielders (CDM), central midfielders (CM), central attacking midfielders (CAM), wingers (W), and attackers (A). The aims of Chapter 5 and Chapter 6 were to analyse the effect of contextual variables (match half, match outcome, and 15min blocks) on locomotor and mechanical metrics and investigate repeated high-intensity specific efforts (clusters) during these key periods of play. Frequency, type, duration, and recovery periods between clusters of transitional activities (CTA) were also determined. Chapter 7 investigated 30-second peak intensity periods also referred to as the worst-case-scenarios (WCS) within training and game play. The aim was to compare commonly selected football specific drills to the competition WCS demands, establish the effect of position, playing status (starters vs. non-starters), and different recovery periods between games (long vs moderate vs congested) on match day physical performance during 30-second peak phases.

Findings demonstrated largely elevated physical metrics when contextualised into transitions, especially in relation to high-velocity activities, which were 7-9 times greater when compared to the whole match averages. It was revealed that during football matches players could be frequently exposed ($n = 50 \pm 11.1$) to short maximum physical outputs (transitions) lasting around 10 seconds. Moreover, 66% of all transitions were identified as clusters (CTA), which means more than 2 TA's occurred within 1 min. Additionally, all locomotor metrics (high velocity) were found to be insufficiently imposed in training across all playing positions. It was also shown that the congested

fixtures could have a detrimental effect on mechanical metrics and the gap between training and competition for maximum intensity periods could even be greater in substitute players.

Such information could help practitioners prescribe position specific high-velocity and high-intensity exposures within a weekly microcycle to better prepare players for short and specific peak intensity periods experienced in official matches. Practitioners should move away from training design guided only by 90-minute averages and focus more on condensed match demands in practical settings to counteract the detrimental effects of fatigue on the second half physical performance. Isolated running based drills in conjunction with transitional games during team and/or top-up conditioning sessions would be highly recommended based on these findings.

This thesis provides novel data about short specific and contextualised maximum intensity periods. The chapters presented in this work contribute to the body of existing knowledge and provide further valuable insights into the physical demands of professional football. Collectively therefore, they should serve as high importance to practitioners. Coaches are encouraged to apply these findings and adopt practical recommendations presented in Chapter 8 in team and individual training prescription.

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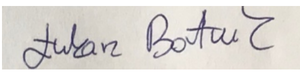
Signature of Candidate: 

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For my Dad, Waclaw

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My parents

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Outputs arising from this thesis

Publications

Peer reviewed publications as a first author from this series of research:

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Bortnik, L., Bruce-Low, S., Burger, J., Alexander, J., Harper, D., Carling, C., & Rhodes, D. (2023a). Transitional Activities in Elite Football: Frequency, Type, Effect on Match Outcome and the Novel Concept of Clusters. *Research & Investigations in Sports Medicine*, 9(5), 872–886. https://doi.org/10.31031/RISM.000721.2023

Bortnik, L., Burger, J., Morgans, R., Rhodes, D. (2023b). Utilisation of Transitional Clusters Exhibited within Game Play to Inform Training Design: Are we meeting the required demands? *Scientific Journal of Sport Performance*, 2(4): 439 - 453. https://doi.org/10.55860/ZURN6735

Bortnik, L., Nir, O., Forbes, N., Alexander, J., Harper, D., Bruce-Low, S., Carling, C., & Rhodes, D. (2023c). Worst Case Scenarios in Soccer Training and Competition: Analysis of Playing Position, Congested Periods, and Substitutes. *Research Quarterly for Exercise and Sport*, 1–13. Advanced online publication. https://doi.org/10.1080/02701367.2023.2290265

Bortnik, L., Bruce-Low, S., Burger, J., Alexander, J., Harper, D., Morgans, R., Carling, C., McDaid, K., & Rhodes, D. (2024). Physical match demands across different playing positions during transitional play and high-pressure activities in elite soccer. *Biology of Sport*, 41(2), 73-82. https://doi.org/10.5114/biolsport.2024.131815

Additional Publications

Rhodes, D., Valassakis, S., **Bortnik, L**., Eaves, R., Harper, D., & Alexander, J. (2021). The Effect of High-Intensity Accelerations and Decelerations on Match Outcome of an Elite English League Two Football Team. *International Journal of Environmental Research and Public Health*, *18*(18), 9913. https://doi.org/10.3390/ijerph18189913 (Appendix 3).

Peleg-Sagy, T., Zeller, L., Perelman, Y., **Bortnik, L**., Maman, T., & Sagy, I. (2023). The effect of pre-match sexual intercourse on football players' performance: a prospective cross over study. *The Journal of Sports Medicine and Physical Fitness*, *63*(2), 250–255. https://doi.org/10.23736/S0022-4707.22.14022-3 (Appendix 4).

Conference Presentations

Bortnik, L., & Rhodes D. (2023, July 4-7). *The Physical Demands During Transitions in Elite Soccer: Analysis of Positional Differences, The Novel Concept of Clusters, and Implications for Training Design.* 28th Annual Congress of the European College of Sports Science. Paris, France (Appendix 5).

Bortnik L. (2022, April 7). *Aerobic Training Principles in Football.* The Israel Football Association. Wingate Institute, Netania, Israel.

Bortnik L. (2022, February 24). *Injuries in Football and Physical Match Demands.* The Israel Football Association. Wingate Institute, Netania, Israel.

Bortnik L. (2020, November 15). *The Challenges in Returning to Football During the COVID-19 Pandemic: Facts vs Myths, Practical and Evidence-based Conclusions*. 3rd Annual Congress of Science4Football. Warsaw, Poland. Available at: https://science4football.com/en/ (Appendix 6).

Bortnik L. (2019, May 1-2). *Practical Applications of GPS Technology in Football*. 2nd Annual Congress of Science4Football. Warsaw, Poland.

Knowledge Exchange Activities

Bortnik L. (2022, December 22). *Worst Case Scenarios in Football: Practical Applications and Future Directions.* OH Leuven FC Academy Sport Science Department. Zoom Meeting and Presentation (Appendix 7).

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List of Common Abbreviations

A, Attacker

A+D, Number of High-Intensity Accelerations and Decelerations (number of efforts > 3 $m \cdot s^{-2}$)

Acc B3 Dist, Acceleration Distance (distance with variations in running speed > 3 $m \cdot s^{-2}$)

Acc, Number of High-Intensity Accelerations (number of efforts > 3 $m \cdot s^{-2}$)

ACWR, Acute:Chronic Workload Ratio

ANOVA, Univariate Analysis of Variance

ApP, Area per Player

ASR, Anaerobic Speed Reserve (difference between MSS and MAS)

Ave Acc, Average Acceleration

Ave Acc/Dec, Average Acceleration-Deceleration

Ave Dec, Average Deceleration

BiP, Ball-In-Play

CAM, Central Attacking Midfielder

CB, Center Back

CDM, Central Defensive Midfielder

CI, Confidence Interval

CL, Champions League

CM, Central Midfielder

CR10, Ten-Point Borg Scale

CTA, Clusters of Transitional Activities (minimum 2 transitions within 1 minute)

CV, Coefficient of Variation

Dec, Number of High-Intensity Decelerations (number of efforts > -3 $m \cdot s^{-2}$)

DOP, Dilution of Precision

DT, Defensive Transition (attack-to-defence transition)

EL, External Load

EPTS, Electronic Performance Tracking Systems

ES, Effect Size

EWMA, Exponentially Weighted Moving Averages

FA, Fast Attack

FB, Full Back

FIFA, Football Internationale de Football Association

GNSS, Global Navigation Satellite System

GPS, Global Positioning System

HI Acc, Number of High-Intensity Accelerations (number of efforts > 3 $m \cdot s^{-2}$)

HI Dec, Number of High-Intensity Decelerations (number of efforts > -3 $m \cdot s^{-2}$)

HP, High-Pressure Activities

HR, Heart Rate

HSRD, High-Speed Running Distance (distance accumulated > 19.8 km · h^{-1})

Hz, Hertz

ICC, Intra-Class Correlation Coefficient

IFAB, International Football Association Board

IL, Internal Load

LPS, Local Positioning System

LSG, Large-Sided Game

LSG10, Large-Sided Game (10-aside)

MAS, Maximal Aerobic Speed

Max Acc, Maximum Acceleration

Max Dec, Maximum Deceleration

MD-1, Match-Day Minus One

MD-2, Match-Day Minus Two

MD-3, Match-Day Minus Three

MD-4, Match-Day Minus Four

MD, Match-Day

MDS, Most Demanding Scenario

MED, Minimum Effort Duration

MEMS, Micro-Electrical Mechanical Systems

MSG, Medium-Sided Game

MSS, Maximum Sprint Speed

NT, Negative Transition (attack-to-defence transition)

OT, Offensive Transition (counter-attack)

P_{gps}, Estimated Energy Expenditure

P_{met}, Metabolic power

PT, Positive Transition (counter-attack)

Rel B5, Relative Sprint Distance (MAS plus 30% ASR)

REOFUT, REndimiento Ofensivo en FUTbol (in English: offensive performance in football)

RPE, Rating of Perceived Exertion

SD, Sprint Distance (distance accumulated > 25.2 km · h^{-1})

SD, Standard Deviation

SPR, Sprinting

SSG, Small-Sided Game

SSG5, Small-Sided Game (5-aside)

SSG6, Small-Sided Game (6-aside)

TA’s, Transitional Activities

TD, Total Distance

TEE, Technical Error of Estimate

UEFA, Union of European Football Associations

Vel B5, Relative Sprint Distance (MAS plus 30% ASR)

VelB4, Relative High-Speed Running Distance (MAS minus 30% ASR)

VO_2, Oxygen Consumption

VO_2max, Maximum Oxygen Uptake

W, Winger

W/kg, Watts per Kilogram

WCS, Worst Case Scenario

Chapter 1: General Introduction

1.1 Personal Approach as a Practitioner and Researcher

My pure desire to become a better coach and more knowledgeable professional who is using his own research to make evidence based and informed decisions in his daily work, had pushed me towards pursuing a Professional Doctorate study at University of Central Lancashire. At the beginning of my journey, while writing up a literature review about monitoring load in professional football, I was not sure what would my main research topic be, until I began an internal project at my former club Legia Warsaw FC regarding transitional behaviours of our team in matches (Table 1). It is noteworthy that tracking data technologies in football including global positioning systems (GPS), have focused on the physical performance of footballers in competition and training and allowed practitioners to bridge the gap between these two scenarios, better understand the physical load footballers are exposed to in matches, and hence more optimally tailor training to the physical match demands (Carling et al., 2008; Wass et al., 2020). Traditionally, this approach has analysed longer match play periods and/or drills in training and explored locomotor and mechanical metrics over their entire duration, neglecting fluctuations in physical, technical-tactical intensity across any given period. This could be useful for practitioners about the insights of volume of activity but might underrepresent and underestimate the true demands during short and important tactical moments in match play (Lacome et al., 2016; Rico-Gonzalez et al., 2022). In practical settings including my own previous approach, both above scenarios (matches and training session) have been analysed in a traditional way, which meant GPS reports did not identify short blocks of activity when players experienced higher physical demands (e.g. transitional activities) nor provided any additional information and/or metrics regarding technical-tactical performance. In other words, coaches would not know what was happening physically during these short and highly dynamic offensive and defensive tactical passages when a team was in- and/or out-of-possession.

There is a need for researchers to understand where their research interest sits within philosophical paradigms, and consequently understand their implications on the ontology, epistemology and methodological approaches within their own work. The philosophical stance of my research reflects those debates and has been influenced by several factors, such as my professional background, the identification of knowledge and innovation gaps justified in the need for this body of work and available evidence and opinions that surround performance reflective of professional football. Consequently, a pragmatic approach was adopted in this body of work. Pragmatism is a knowledge construct that emphasises practical solutions to applied problems, which aligns to my professional coaching style and provides an opportunity to bridge the gap between academia and the practical applications of questions that arise from practitioners in industry. I began to question match and training analysis approaches that mainly focused on volume aspects neglecting frequent shifts of intensity across 90 minutes. And although evidence from literature was available regarding maximum intensity passages, there was clearly a justification for exploration further into short, specific and highly contextual periods (transitions). Pragmatism has been supported as an alternative way to examine human behaviours in sporting contexts, therefore this approach is reflected in the methodologies used in the studies and of which are presented in Chapters 3 to 7. This body of work adopted a quantitative approach throughout which best reflects the style of methods required to answer the overall research question of the thesis and provide pragmatic interpretation of the impact of findings in industry of a practical and applied nature.

The internal project mentioned above was a breakthrough in my early journey, which gave me a clear understanding and direction I should take in planning my research steps. Moreover, it challenged my own way of match and training analysis and questioned my training prescription which should replicate true competition demands, especially during critical phases such as transitions and high-pressure actions. In fact, the project opened my eyes and made me realise about the largely elevated physical metrics during transitional activities in comparison to match play averages (Figure 1), their high frequency throughout the 90 minutes of game play, and overall importance to the match outcome. Indeed, this deeper and novel way of analysis could help better understand the dynamics of competition and underlying factors of success in professional football (Forcher et al., 2023; Oliva-Lozano et al., 2023c).

Table 1. Physical metrics during offensive transitions and their frequency in match play (internal project – unpublished data).

	Mean duration (s)	HSRD (m·min^{-1})	SD (m·min^{-1})	Sprints (n·min^{-1})
Offensive transition	00:00:09	54.3	31.1	1.3
Offensive transition	00:00:12	106.2	57.8	3.3
Offensive transition	00:00:15	115.4	54.4	2.0
Offensive transition	00:00:19	61.1	12.3	0.4
Offensive transition	00:00:10	33.2	14.2	0.7
Offensive transition	00:00:07	9.4	0.0	0.0
Offensive transition	00:00:11	40.0	5.9	0.5
Offensive transition	00:00:13	37.6	5.6	0.5
MEAN	**00:00:12**	**57.2**	**22.7**	**1.1**

Football match play has been constantly evolving physically and tactically (Allen et al., 2023; Barnes et al., 2014). Practitioners and conditioning coaches should consider all changes that have occurred in the past decade in their training design and better prepare players for the modern match play demands to enhance performance and decrease number of injuries, which have been on the rise in professional football. As a practitioner working in this industry for over a decade across many different countries, I have been searching new and effective training methods, which could allow me to reflect and mimic game-like scenarios in training, especially regarding crucial phases of the game. Anecdotally, these moments are characterised by a high tempo and speed of play usually described as very dynamic phases transitioning from offensive to defensive actions and vice-versa. Given that elite football teams frequently perform high tempo actions below 20 seconds (González-Rodenas et al., 2020), more focus should be paid to shorter duration epochs (e.g., < 30 seconds) that give technical-tactical context and inform about offensive and defensive team and individual activities and behaviours (Ju et al., 2022a; Weaving et al., 2022). These short periods could offer more football-specific ways to expose players to maximum physical outputs they achieve in competition and hence, improve training prescription in contemporary football. Furthermore, a very popular tactical concept commonly used by elite teams also referred to as counter-pressing that attempts to regain ball possession within 5 seconds, should be explored more deeply, since it could increase the physical demands of certain positional groups and impose greater mechanical load on footballers (Bauer et al., 2021).

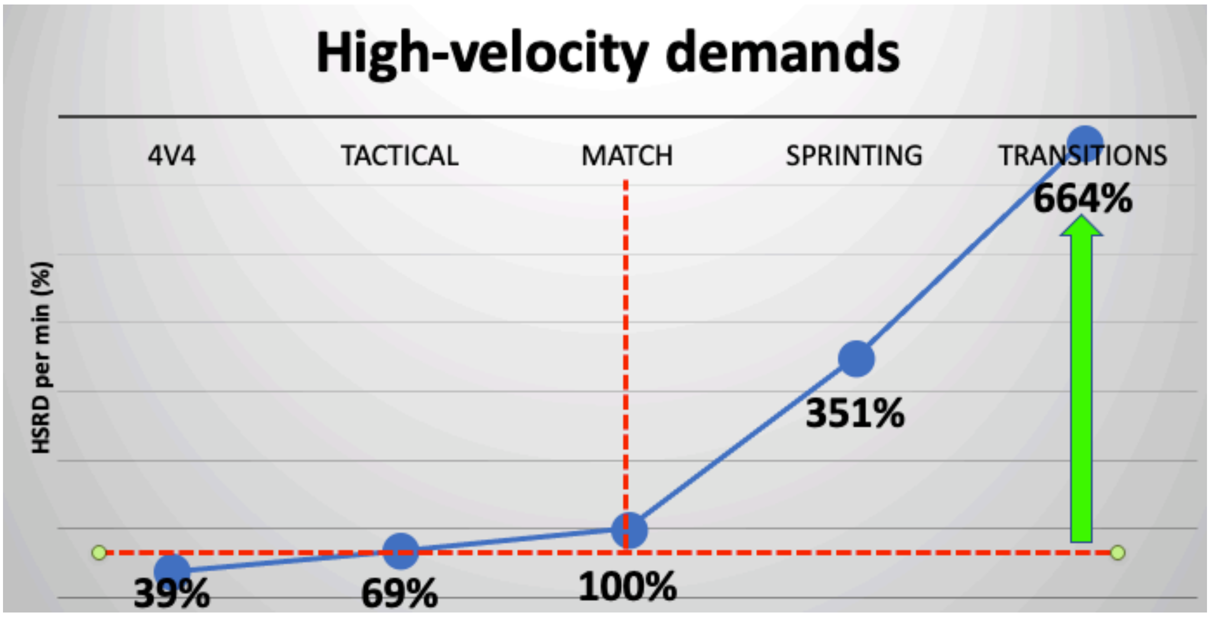

Figure 1. High-velocity demands relative to the 90-min averages in different modes of exercise commonly used in modern training design (unpublished data – internal investigation).

My aim was to create recommendations for football practitioners regarding training intensity relative to match peak demands (high-velocity running and accelerations/decelerations), guide football-specific and running-based drills selection, inform about the positional differences that should be considered in practical settings for both starters and non-starters, and deliver tips for congested fixture periods which have been increasing in elite football. Finally, yet importantly, outlining work-to-rest-ratios regarding peak match demands training could offer a novel and evidence based approach to the WCS concept potentially enriching practitioners' knowledge and improving a quality of training sessions in football.

1.2 Background and Introduction

Football match play could be described as short bouts of high intensity linear and multidirectional activities interspersed with longer recovery breaks at lower intensity (Barnes et al., 2014). Top class players perform 150 – 250 intense actions per match (Anderson et al., 2016a; Mohr et al., 2003) and cover between 10-12 kilometers (Bangsbo et al., 2006; Di Salvo et al., 2007; Dellal et al., 2011), while 8% comes from very-high intensity running distance (speed <19.8 km/h) performed on average every 72 seconds (Bradley et al., 2009; Rampinini et al., 2007). Modern football requires players to possess optimal technical, tactical, and physical skills (Stølen et al., 2005; Weston 2018), and training design should appropriately reflect the increased physical and technical demands of contemporary match play (Barnes et al., 2014; Bradley et al., 2016; Harper et al., 2019).

It is commonplace in all levels of elite football to compete three games a week, due to domestic and European competitions, which poses a very high neuromuscular demands in the form of accelerations, decelerations, changes of direction, jumps and tackles (Bush et al., 2015a; Harper et al., 2019; Stølen et al., 2005;). Despite an intermittent nature and a high physical demand, football is also a complex and unpredictable sport (Gregson et al., 2010). Interestingly, high-intensity accelerations precede any football specific actions such as dribbles or penetrative passes and alongside decelerations provide a further insight into a true player's workload during football specific exercises (Kelly et al., 2020; Russell et al., 2016). Research has shown that possibly due to fatigue there was a reduction in the number and distance of high-intensity accelerations and decelerations in the second half and during congested periods, which could increase the risk of injury (Harper et al., 2019; Russell et al., 2016). These metrics have been previously linked to match outcome in professional football (Rhodes et al., 2021). Hence, future research should further explore this topic and link mechanical load indicators to the maximum-intensity periods during various contextual and situational scenarios in elite football.

The main objective of the training process in football should be to improve performance on an individual and team level to meet the elevated physical demands, and better prepare players for the match demands and their peak intensity periods (Akenhead et al., 2016b; Anderson et al., 2016a; Gabbett et al., 2012; Pollard et al., 2018). The ultimate purpose to monitoring is to determine if training load was sufficient and relative to the true game demands to achieve high levels of fitness, improve performance, and decrease injury risk (Anderson et al., 2016a; Jaspers et al., 2017; Weston 2018). Increased demands of the game, congested periods, inadequate training load, and a mismatch between training and game physical demands, could be linked to the higher injury rate in professional football (Ekstrand et al., 2023; Gabbett et al., 2012; Jaspers et al., 2017; Windt et al., 2017). Every detail in training must be carefully planned by sport scientists, practitioners, and coaches including the reflection of the most demanding passages to achieve best possible physical and tactical performance for competition (Ju et al., 2023b; Martin-Garcia et al., 2018; Pind et al., 2017). There is a need to more deeply analyse crucial tactical phases such as transitions, which inevitably expose footballers to maximum intensity in competition. A better understanding of the physical demands during these blocks, their frequency, magnitude, duration and recovery period would have a positive impact on modern training design aiming for most accurate reflection of the true match demands in practical settings. That said, coaches should acquire more knowledge regarding positional differences during the most demanding passages in modern game to be able to mimic mechanical and physiological stress in training, integrating technical and tactical components to holistically prepare footballers for these highly important blocks of activity. For this reason, frequent and regular monitoring becomes extremely important to not only retrospectively analyse relationship between load and performance, but also to better understand the actual load in games and training sessions. This could improve the entire athletes' management process and better prescribe, structure, and plan training in practical settings (Halson 2014; Jaspers et al., 2017; Stevens et al., 2017; Weston 2018).

1.3 Rationale

Tracking technical-tactical, and physical performance of modern match play informs the training process by making a comparison between competition and training prescription in all aspects (Harper et al., 2019; Stevens et al., 2017; Wass et al., 2020). Thus, coaches can better understand the required intensity of certain football specific drills and comprehend each player's activity profile to a higher extent (Carling et al., 2008; Delaney et al., 2018a). However, it is crucial how match physical metrics are presented. They should not only describe volume of activity over the full, half-match and/or quarter, but truly reflect intensity over shorter duration windows. This would avoid underestimation of peak periods and reflect physical and tactical fluctuations across 90-min. Additionally, as shown in Figure 2, adding context and trying to understand not only "what" happens physically, 'why" and "how" it takes place tactically, but also "when", "how many", "how often" and "how long" these moments occur could better prepare footballers for these maximum-intensity passages (Ju et al., 2023b; Sarmento et al., 2014).

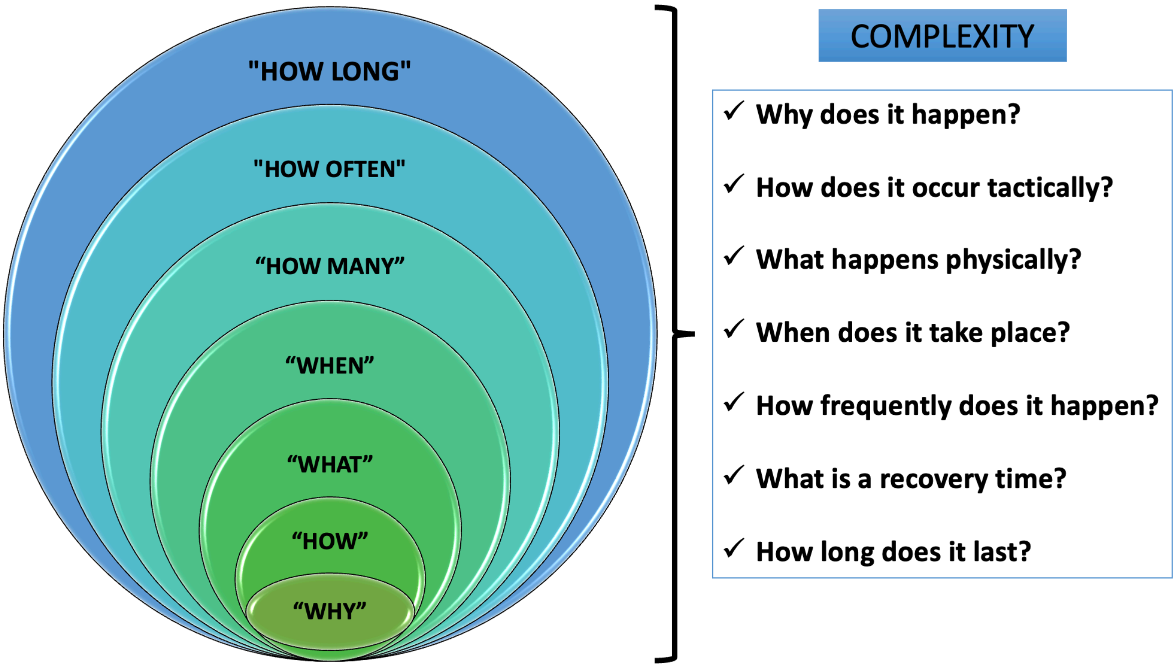

Figure 2. Adapted and further developed from "the golden circle", Sinek 2011.

The concept of peak intensity passages in football also called the worst case scenarios (WCS), most demanding scenarios (MDS), and most demanding passages has been recently introduced (Garcia et al., 2022; Novak et al., 2021; Riboli et al., 2021a; Riboli et al., 2021b). For simplicity, I will mostly refer to it as WCS throughout this research thesis. Different methods have been applied to measure physical performance during these periods, various time epochs studied, and positional differences determined (Fereday et al., 2020; Martin-Garcia et al., 2018; Oliva-Lozano et al., 2021a; Pollard et al., 2018). As depicted in Figure 3, understanding the maximal physical demands during specific and short-lasting periods of match play, might allow coaches to prepare players more precisely for these high intensities (Martin-Garcia et al., 2018; Oliva-Lozano et al., 2021a, Oliva-Lozano et al., 2021b; Wass et al., 2020). In all available methods to measure WCS, the idea is the same – to identify the most intense periods of match play to recreate the same physical stimulus in training and reach positive physiological outcome (McCall et al., 2020).

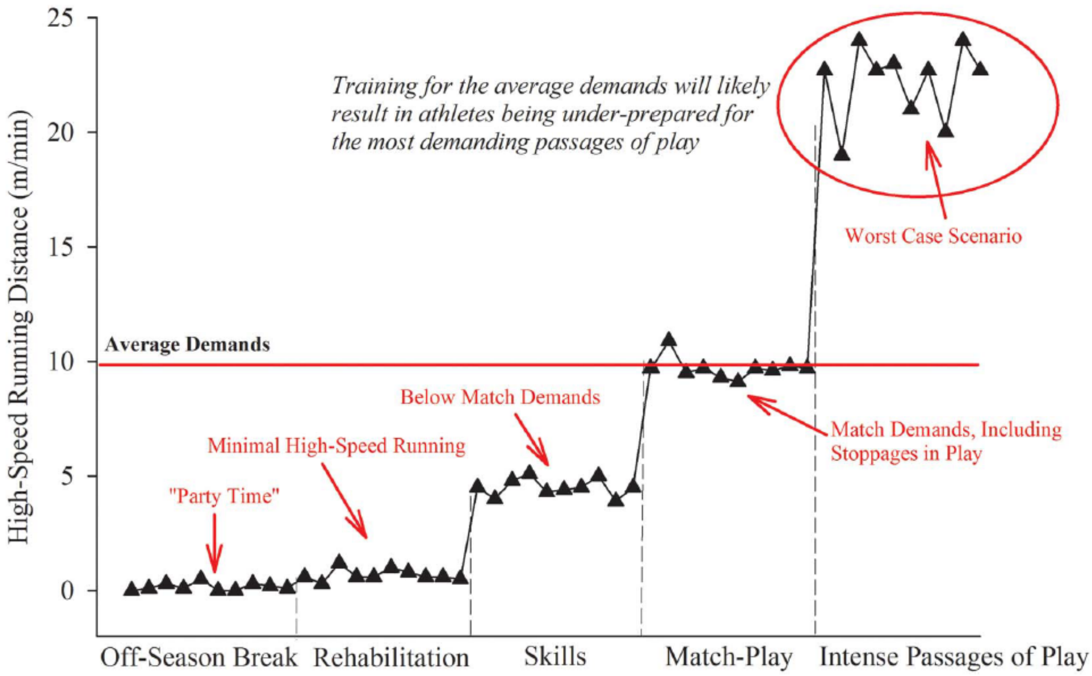

Figure 3. High-speed running distance compared between different scenarios including the match peak demands. Adopted from Gabbett et al. (2016b).

There is however a lack of knowledge how the WCS information could be used for team physical conditioning purposes (Carling et al., 2019). Moreover, the concept of WCS to inform training prescription has been recently questioned due to its high variability, instability as well as dependence on different physical, technical-tactical, and contextual factors (Novak et al., 2021). WCS represents an unstable benchmark that is very difficult to use in practical settings. Players don't achieve peak physical demands for different metrics simultaneously including total distance, high-speed running, and sprint distance. They occur in different phases of the game and not all players achieve high intensity during these timeframes (Novak et al., 2021). It is a challenge for practitioners to repropose and fully replicate these intense periods of match play in training.

Therefore, my novel approach is to analyse the key phases of play defined as transitional activities and high-pressure actions in football match play (Table 2 and 3), which represent and include a high technical-tactical context within. Offensive and defensive transitions are short-duration specific actions that have been identified among the key five moments of play in football (Figure 4), since most goals and risks take place during these moments (Lago-Peñas et al., 2018; Wass et al., 2020). Offensive transitions (counter-attacks) are defined as high-speed actions with the goal to outnumber opponents, exploit an open space, and surprise opposition's imbalanced and disorganised defence (Gonzalez-Rodenas et al., 2020; Riboli et al., 2020). On the other hand, defensive transitions are characterised by a very quick reorganisation of defensive shape to prevent a team from conceding a goal (Hewitt et al., 2016; Tenga et al., 2010). High pressing in the offensive third was found to generate seven times more goals and create more goalscoring opportunities (Tenga et al., 2010), but it has been believed to be linked to high levels of fitness (Wright et al., 2011) and hence, should be closely monitored within match play. By having identified these game phases we could measure and quantify different KPI's and gain a deeper understanding of different interactions and game styles that certain teams might acquire in elite football. Given that no previous studies exist on physical demands during these periods of football match play, this thesis might offer a new and practical way to further explore the WCS concept. It is hypothesised that regular exposure to maximum intensity activities in practical settings by using transitional games, tactical and conditioning drills that incorporate high-pressure activities and offensive/defensive transitions might better prepare players for the most demanding passages and reduce the risk of injuries in elite football.

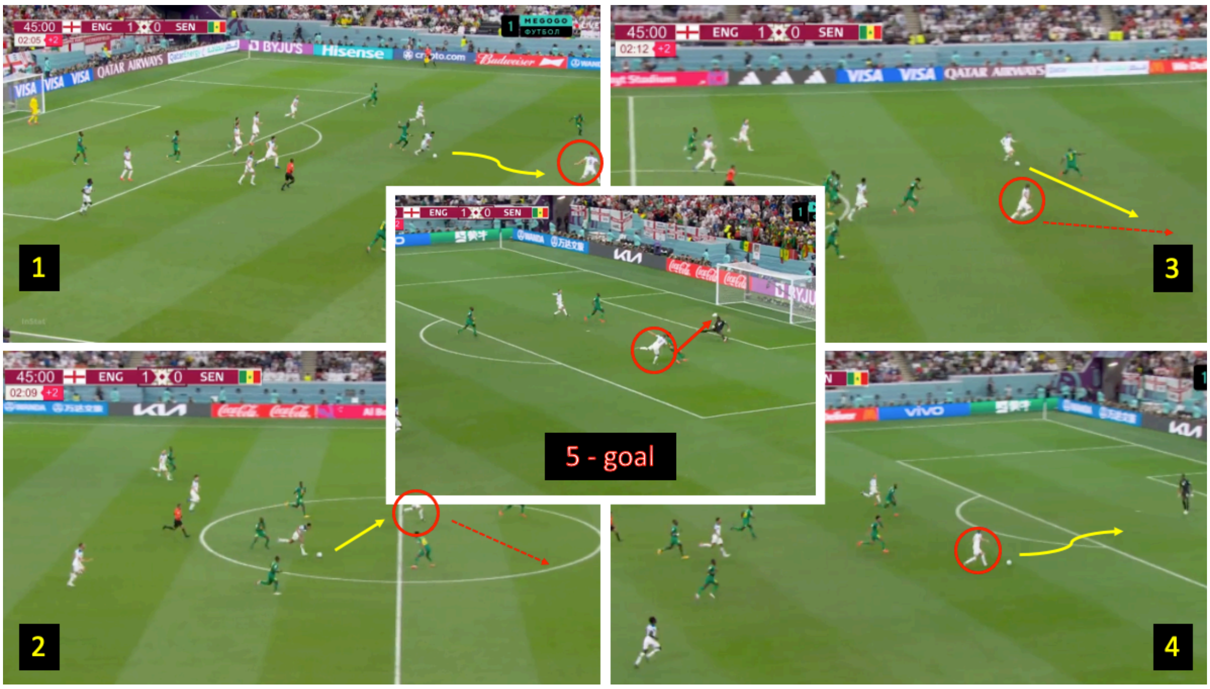

Figure 4. Offensive transition lasting 10.9 sec and consisting of interception (tile 1) and three forward passes (tile 2, 3 and 4) leading to a goal (tile 5) scored by Harry Kane (red circle) during the World Cup in Qatar (England vs Senegal).

1.4 Aims and Objectives

The main aim of the professional doctorate was to examine short and specific maximum intensity periods by measuring the key physical metrics, integrating technical-tactical performance and distinguishing offensive (in-possession) and defensive (out-of-possession) phases in matches. This might have a positive impact on training prescription and potentially lead to enhanced readiness to play, improved match performance, and lower risk of injury. Hence, the main objective of the current project is to determine the magnitude of importance of offensive/defensive transitions and high-pressure activities within an elite football team, explore a connection between training and competition and investigate the impact of different contextual factors on the physical metrics during these crucial phases (Figure 5).

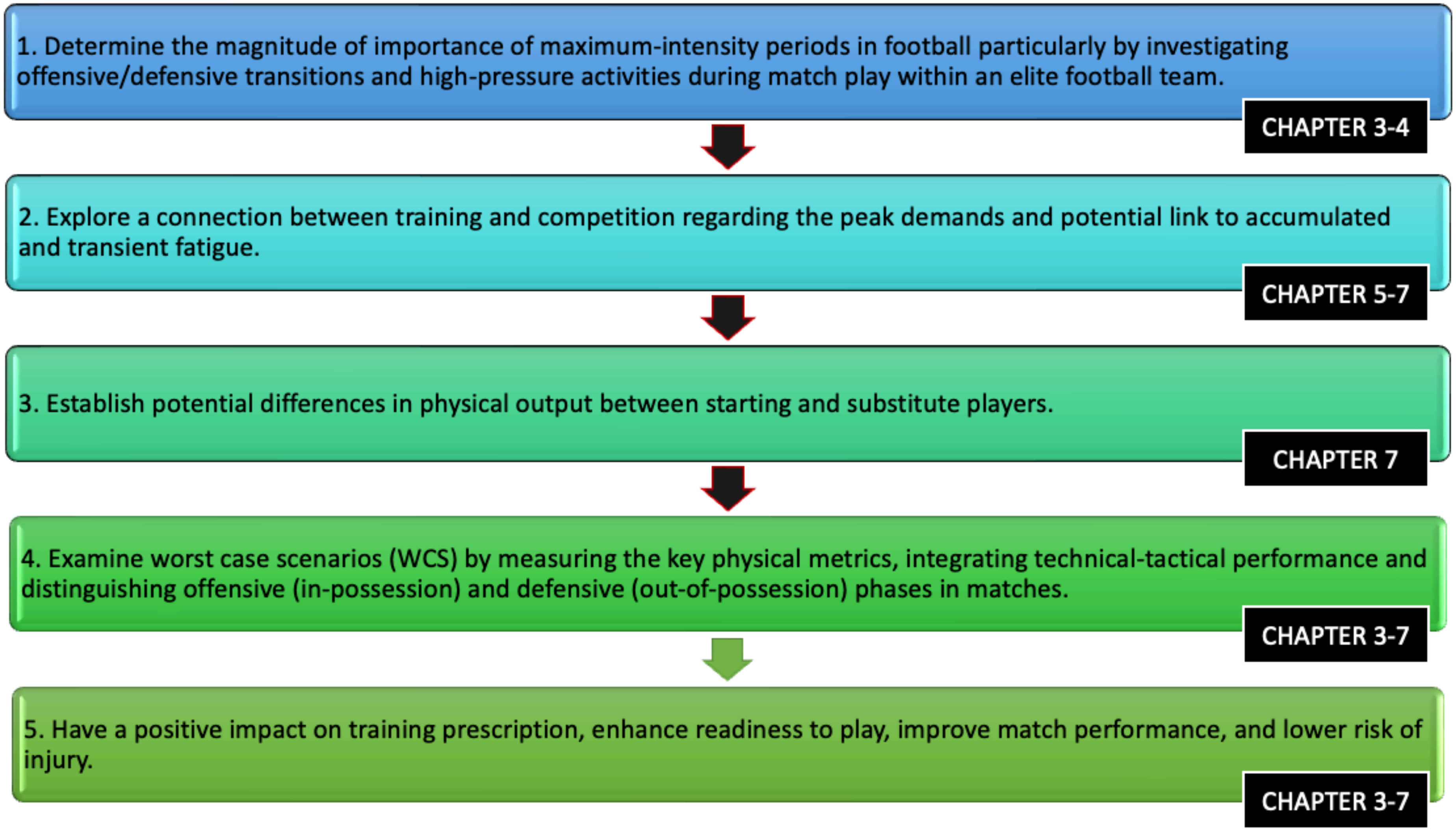

Figure 5. A list of general aims as part of this research thesis project.

The main aims have been achieved throughout different parts of this thesis from Chapter 2 to Chapter 8 and across all published work as part of the professional doctorate by addressing specific objectives presented in Figure 6.

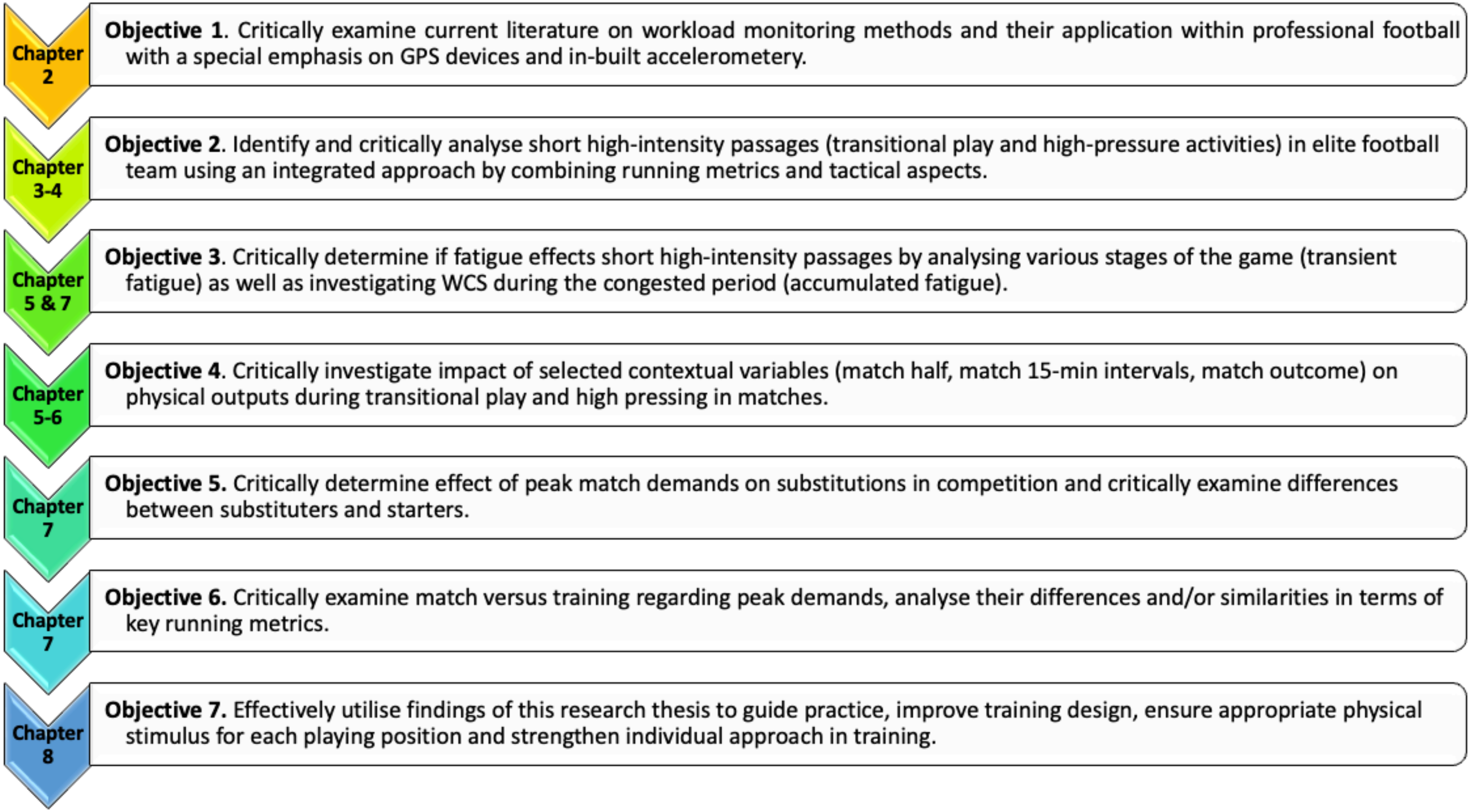

Figure 6. A list of specific objectives as part of this research thesis project.

Chapter 2: Review of the Literature: Monitoring Workload & Application of Microtechnology in Football

2.1 Introduction

Monitoring training load is a strongly debated area both within academic and practical settings, which have their own unique principles. Transfer of academic knowledge into practice is still evident in the form of successful application of monitoring training load and delivery of more optimal ways to use physical data to inform and design effective training in professional football. Practitioners should clearly follow and apply an evidence based approach in their training methodology, yet practice based evidence could also have high importance in practical world of elite football. Aside from recent literature, personal experience, and exchange of information between professionals still provides a significant amount of knowledge available in this specific area (Bourdon et al., 2017; Kelly et. al, 2020). Definition and utilisation of the "workload" and "load" has not been very consistent in team sports, and it could be explained as "the total stressors and demands applied to the players" (Quarrie et al., 2017). Therefore, a combination of volume, intensity and frequency make up what is called training load, which describes and relates to the process of physical training (Bartlett et al., 2017; Impellizzeri et al., 2004).

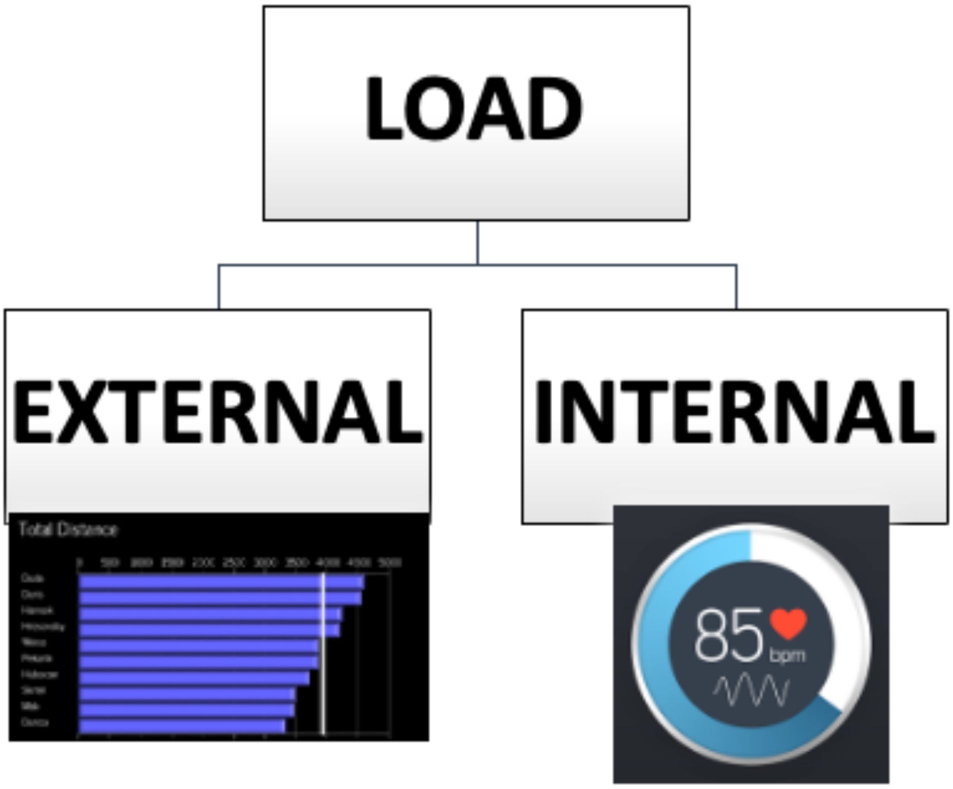

Figure 7. Training load division. Adopted and amended from Jaspers et al. (2017) and Weston (2018).

As presented in Figure 7, training load is consistently defined within practice as either internal or external load (Akubat et al., 2014; Akenhead et al., 2016a; Halson 2014; Jaspers et al., 2017; Weston, 2018). The concepts and terms of internal and external load were first proposed during a symposium organised by Tom Reilly in 2003, which they were presented in the context of team sports and today are used in both research and practice (Impellizzeri et al., 2019). Internal load (IL) is both a physiological and psychological response to an external stressor imposed during training and competition and therefore, it can be both objective and subjective (Bourdon et al., 2017; Halson, 2014; Quarrie et al., 2017). External load (EL) is an objective measure that is independent from internal load (Bourdon et al., 2017) and it has been traditionally viewed as the basic measure of work performed by the athlete in training and competition representing athletes' capacity and capability (Halson, 2014; Impellizzeri et al., 2004). EL could simply be defined as all activities imposed by the coach (Gabbett 2016a). Common variables quantified within elite football are total distance covered, number of high-intensity runs, sprint count, to name a few (Akenhead et al., 2016b; Gabbett 2016a; Jaspers et al., 2017), which will be described in the later part of this review in detail.

It is worth noting that due to biological differences of each athlete, the same external-intensity indicators will exhibit different internal responses (Gabbett 2016a; Impellizzeri et al., 2005) and thus, depend on many different intrinsic factors such as training and injury history, current fitness, strength asymmetries, body composition, weather conditions and psychological status (Bouchard et al., 2001; Impellizzeri et al., 2004; Impellizzeri et al., 2005; Jaspers et al., 2017). In practical terms, high external-intensity indicators do not always mean sufficient and/or excessive. In contrast, low indicators do not have to represent inadequate physical stress, because each individual would respond differently to a given training workload. Therefore, to evaluate training efficacy and determine if each player received an optimal physical/physiological stimulus, practitioners should rather rely on a larger array of variables including both external- and internal-intensity metrics (Pillitteri et al., 2023). Indeed, coaches usually prescribe training by the external load (work performed on the pitch), which might be provided by wearable technology such as global positioning system (GPS) and accelerometers, which are traditionally housed within the GPS unit (Akenhead et al., 2016b; Bartlett et. al, 2017). However, it is internal load that determines adaptation and desired fitness outcomes (Akubat et al., 2014; Akenhead et al., 2016b; Bartlett et. al, 2017). Therefore, both external- and internal-intensity indicators are necessary to fully comprehend the training workload and determine the athletes' relative response and their subsequent adaptation to the training programme (Halson, 2014). It is also believed that the relationship between external and internal load could help in detecting fatigue and/or readiness of an athlete to train or compete (Pyne et al., 2011). For this reason, sport scientists, coaches and medical professionals should use an integrated approach to monitoring training load and consider both measures to optimise the entire training process better and more accurately (Halson, 2014; Pyne et al., 2011).

Measuring heart rate (HR) and oxygen consumption, collecting blood lactate and checking levels of creatine kinase (Figure 8) are common ways to assess internal load in athletes in team sports, yet these methods have not been considered practical (Akenhead et al., 2016b; Bangsbo et al., 2006; Little et al., 2007). Rating perceived exertion (RPE) is another way to quantify internal load (Figure 9) that has become very popular in football due to its low-cost and non-invasive nature (Arcos et al., 2016; Bartlett et. al, 2017). It has been questioned however, which might explain why elite football teams prefer other more objective tools and measures (Akenhead et al., 2016b). It is important to highlight that the poorly educated and sceptical athlete might misuse the session RPE and easily manipulate its values, which has been considered a major limitation of this measure (Bourdon et al., 2017). Along the methods explained above, practitioners may use other ways to assess players' response to the training programme. This may include certain physiological, physical, and psychological assessments such as blood and saliva analysis, measurements of the autonomic nervous system (heart rate variability) and subjective self-submitted questionnaires (Akenhead et al., 2016a; Djaoui et al., 2017). However, internal-intensity indicators have not been included and analysed in this research thesis. Hence, future studies could explore the relationship between internal- and external-intensity metrics, which might allow more precise comparison between training and match demands. This could ensure an adequate internal load stimulus, optimal physiological response in training and a subsequent adaptation to the programme (Impellizzeri et al., 2019). Future research should somehow overcome the practical difficulties and challenges and include internal-intensity indicators in their analysis to fully understand the physical and physiological demands during the maximum-intensity periods in elite football.

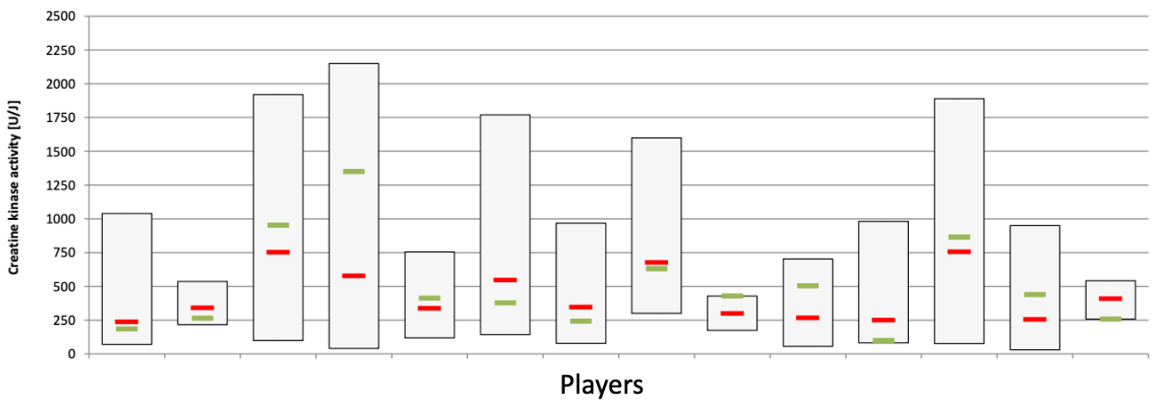

Figure 8. Creatine kinase (CK) concentration measured 24 hours post-match in 9 starting players. Data displays minimum and maximum (bottom and top, respectively), mean (red) and current results (green). Unpublished data (internal purposes).

Most frequently used ways to measure external load embrace power output, speed, acceleration, time-motion analysis, global positioning systems (GPS), and accelerometery (Akubat et al., 2018; Delaney et al., 2018a; Harper et al., 2019; Jobson et al., 2009; Linke et al., 2020). Modern technologies along with new analytical methods have been introduced to elite football giving practitioners new possibilities and offering practical solutions to monitoring training load. Global positioning systems (GPS) and other micro-technologies provide a plethora of variables such as distances at various speed zones, acceleration (different thresholds), estimated metabolic power, heart rate exertion and time spent in high heart rate (HR) zones (Abbott et al., 2018c; Akenhead et al., 2016a; Buchheit et al., 2014a; Malone et al., 2015; Malone et al., 2018). While external and internal load metrics analysed in isolation still seem to be useful in professional sport, a combination of both should best indicate and describe the physical and physiological demands of team sports including football (Buchheit et al., 2015; Stevens et al., 2017).

In summary, monitoring load in football should be viewed as an essential tool to understand match demands and peak intensity phases, optimise performance and adaptation, and reduce the risk of injury and illness (Halson, 2014). The main goal of load monitoring should be to better comprehend a true demands of game play and training to support and facilitate coach decision-making regarding players availability, training content, work-to-rest-ratios, fatigue, and readiness to compete (Bourdon et al., 2017).

#	Level of Perceived Exertion Scale		
	Original RPE Scale		**Revised RPE Scale**
6	No exertion	0	Nothing at all
7	Very, very light	0.5	Very, very weak
8		1	
9	Very light	2	Very weak
10		3	
11	Light	4	Somewhat strong
12		5	Strong
13	Somewhat hard	6	
14		7	Very strong
15	Hard (heavy)	8	
16		9	
17	Very hard	10	Very, very strong
18			
19	Extremely hard		
20	Maximal		

Figure 9. Two Borg RPE scales used today by practitioners in football: Borg 6-20 and CR10 (Arney et al., 2019; Rago et al., 2020).

2.2 Methods to Quantify External Load (EL)

2.1.1 Time-motion Analysis Systems

The need to measure external training load in football and "fill" the gap between internal-external load monitoring continuum was inevitable (Malone et al., 2015). Contemporary football teams would most likely use a combination of a few Electronic Performance Tracking Systems (EPTS) to determine players' activity demands in training and competition (Buchheit et al., 2014b; Carling et al., 2008; Linke et al., 2020; Malone et al., 2015). These sophisticated technologies which should meet certain quality criteria as shown in Figure 10 and Figure 12, have developed over time and advanced from video and notational analysis to traditional multiple semi-automatic cameras (e.g. ProZone, Amisco, TRACAB) and further to a local positioning system (LPS) and global positioning system (GPS) (Buchheit et al., 2014b; Sarmento et al., 2014). Optical video-based systems have been used to collect positional data during official matches in the most competitive football leagues (Bundesliga, La Liga, Premier League, and Ligue 1) and provide additional technical and tactical variables to coaches (Buchheit et al., 2014b; Linke et al., 2020). It is commonplace in elite football that semi-automatic camera systems are used during competition, whereas GPS and/or LPS systems in training (Buchheit et al., 2017a). It is noteworthy to state that different systems could be properly calibrated and interchanged, however caution should still be taken when comparing these results (Buchheit et al., 2014b; Buchheit et al., 2017a).

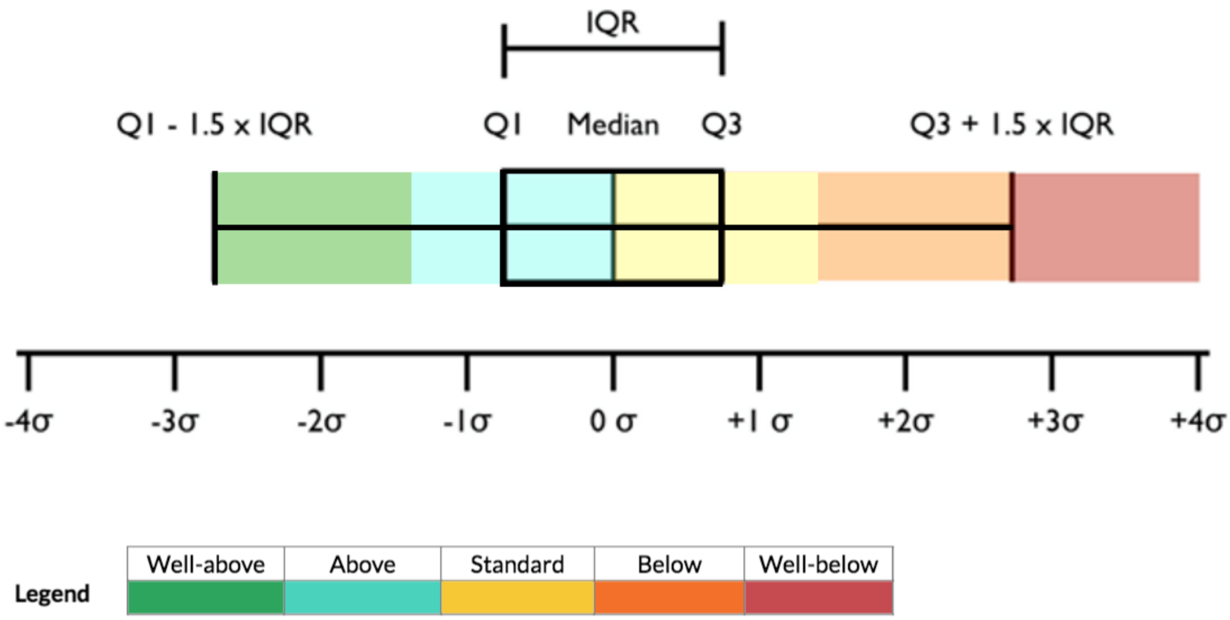

Figure 10. The rating system (5-level scale) used to determine the Electronic Performance and Tracking Systems (EPTS) quality. Adopted from Ju (2022c): redrawn from FIFA Handbook of Test Methods for EPTS devices (2019).

2.1.2 Global Positioning System (GPS) and Other Wearables

Global Positioning System (GPS) is a navigational technology based on satellites, which was originally designed for the military use by the American Department of Defence (Cummins et al., 2013; Scott et al., 2016). Since it has been released to the public, it became widely available to describe spatial context of activities and measure athletes' movements in different team sports such as Australian football, cricket, hockey, rugby union and league, and football (Cummins et al., 2013; Scott et al., 2016). At least 4 out of 27 satellites in orbit around the Earth are needed to triangulate the position of GPS receiver to calculate movement speeds and distances (Carling et al., 2008; Malone et al., 2017a; Scott et al., 2016). The number of connected satellites below 6 could indicate poor signal, whereas the dilution of precision (DOP) equal to 1 might state the ideal satellites distribution in the sky (Malone et al., 2019; Scott et al., 2016). Distance and velocity can be quantified via positional differentiation or Doppler-shift method (Malone et al., 2017a; Scott et al., 2016). Based on a complex algorithm, the Doppler-shift method shows higher precision and more accurate measurement for velocity than the positional differentiation and hence, it is the most often used method (Malone et al., 2017a). This technology has advanced very rapidly and a new Global Navigation Satellite System (GNSS), which integrated both US-based and Russian-based satellite systems, recently became available to further increase the number of available satellites and improve signal strength (Jackson et al., 2018). Interestingly, GNSS-enabled devices could be more sensitive to measure physical demands of team-sport movements, but more studies are warranted before any further conclusions are drawn (Jackson et al., 2018).

Additional technological developments have led to the micro-electrical mechanical systems (MEMS), which integrate different inertial sensors within GPS devices (Akenhead et al., 2016b; Harper et al., 2019). MEMS are equipped with tri-axial accelerometers, gyroscopes, and magnetometers to provide and measure additional external load variables in training and competition (Akenhead et al., 2013; Hulin et al., 2017; Malone et al., 2017a). These sensors called the inertial measurement units (IMUs) surpass a sampling frequency of GPS units (100 Hz versus 5-20 Hz, respectively) and can be used indoors, since no satellite connection is needed (Malone et al., 2017a). GPS-embedded accelerometers allow to quantify impacts (e.g. G-forces) and measure manufacturer specific parameters such as Body load (GPSports) or PlayerLoad (Catapult), which has been shown to have an acceptable level of inter and intra-unit reliability (Barrett, 2017; Cummins et al., 2013; Malone et al., 2017a). Hulin et al. (2017) showed that MEMS have enough sensitivity (97.6% collisions detected) and specificity (91.7%) in contact sports to detect another accelerometer-based variable called a collision. However, most of the available research in team sports has quantified external load as a measure of locomotive variables (distance in various speed thresholds) using GPS technology rather than the MEMS devices (Barrett, 2017; Malone et al., 2017a). Yet, GPS technology allowed scientist to conduct numerous validation and reliability studies and through a wide application to various field sports, it has significantly increased the current body of knowledge about activity profile of field sport athletes including football (Aughey et al., 2011; Cummins et al., 2013).

A local positioning system (LPS) is a navigation system, which uses anchor nodes (stations) located at known spots around a pitch to calculate athletes' position via radio signal transmission (Luteberget et al., 2018). This radio-frequency based technology is the most often used LPS system in team sports today and its main advantage is that it could be used both outdoors, indoors, and in large stadia (Buchheit et al., 2014b; Luteberget et al., 2018; Stevens et al., 2014). Despite being more expensive and not as flexible as GPS and video-based tracking systems, LPS systems could also be effectively used to accurately quantify football-specific acceleration-based efforts, especially during live tracking in training and match play (Stevens et al., 2014; Stevens et al., 2017). Real-time feedback might truly have some benefits in football including taking immediate actions in contrast to post-session decisions (Malone et al., 2017a) (Figure 11).

Figure 11. Real-time feedback allows making instantaneous decisions during training.

2.1.3 Validity, Reliability and Limitations of Wearables

It is imperative that practitioners assess the amount of error ("noise") within any system and variables they are using (Malone et al., 2019). Both video-based as well as GPS systems show acceptable levels of accuracy and reliability when measuring football-specific performance (Gray et al., 2010; Linke et al., 2020; Rago et al., 2019a; Stevens et al., 2014). Factors such as sampling frequency, distance and duration of activity, velocity of movement and changes in speed (number of changes of direction) all affect validity and reliability of GPS (Coutts et al., 2008; Stevens et al., 2014). It has been extensively shown that accuracy of GPS technology increased with a sampling frequency (Aughey et al., 2011; Jennings et al., 2010; Rago et al., 2019a). Scott et al. (2016) in his review states that 10Hz devices are capable of accurate measurements of short distances at varied speeds with good intra-unit reliability. Nevertheless, the inter-unit reliability for high-speed and very high-speed running is still limited (Scott et al., 2017). For these reasons, it has been recommended that players wear the same units consistently, since comparisons between players and sessions (inter-unit) and consistency in providing accurate information about an athlete (intra-unit) might be described as essential in practical settings (Coutts et al., 2008; Malone et al., 2019; Scott et al., 2016). Regardless of limitations, current literature shows that GPS units have an acceptable level of validity and reliability for quantifying athletes' movement patterns if the caution is taken while interpreting individual high-velocity and high-intensity activities in team sports (Aughey et al., 2011; Cummins et al., 2013; Scott et al., 2017). Also, the high frequency (1000 Hz) radio-based technology (LPS) has been determined as highly accurate to track football players movements outdoors and indoors despite small underestimations in distance and speed measurements (Frencken et al., 2010). Hoppe et al. (2018) conducted a comparison study of GPS versus LPS system and found that 20 Hz LPS system had higher overall validity and reliability in distance covered and sprint mechanical measures (TEE: 1.0-6.0%; CV: 0.7-5.0% and TEE: 2.1-9.2%; CV: 1.6-7.3%, respectively). The study further reported however that higher-frequency LPS system measured plenty of noise during standing and concluded that its application in practical settings was still limited (Hoppe et al., 2018).

Recently the International Football Association Board (IFAB) allowed the use of GPS devices during official matches, which has drawn many practitioners to use it regularly in training and competition to track players' physical performance (Harper et al., 2019; IFAB, 2015; Rago et al., 2019a). GPS technology out of all available tracking systems offers the most practical, time-efficient, and popular solution to practitioners today (Burgess, 2017; Scott et al., 2016). GPS units are very small and cause very little discomfort during training and games, which makes it easy to transport them anywhere outside of teams' training grounds (Burgess, 2017). Nevertheless, GPS receivers can only be used outdoors, and their signal might be obstructed in large stadia with high walls and roofs, which obviously is a limitation of this technology in elite football (Aughey 2011; Buchheit et al., 2014b; Cummins et al., 2013; Scott et al., 2016). It is worth noting that GPS-embedded inertial sensors overcome this limitation and can be used indoors (Malone et al., 2017a). It was previously mentioned that during high-speed and high-intensity non-linear movements, distance reliability of GPS decreases and therefore, athletes' critical movements might not be recorded, which is another limitation of GPS technology that should be taken into consideration (Jackson et al., 2018).

Coaches and practitioners analysing EL using GPS technology must also be aware that different filtering techniques as well as the minimum effort duration (MED) will likely have implications on their data, especially for accelerations and decelerations (Malone et al., 2017a; Rago et al., 2019a; Thornton et al., 2019). GPS manufacturers use different filtering algorithms to detect poor quality data and then automatically interpolate it or smooth a raw velocity/acceleration data appropriately (Thornton et al., 2019). A 'dwell time' or minimum effort duration (MED) could be described as a movement effort when GPS velocity/acceleration reaches a specific threshold (e.g. speed) and lasts for a minimum duration (Varley et al., 2017). Different filtering techniques and MED could largely impact the number of high-intensity efforts such as high-speed running, sprints and accelerations using GPS during football matches. Therefore, being consistent with data processing method has been recommended for coaches and practitioners (Thornton et al., 2019; Varley et al., 2017).

(A)

Rating by FIFA Velocity Band: Well-above | Above | Standard | Below | Well-below

Manufacturer	Product	EPTS	TEST			0-7 km/h	7-15 km/h	15-20 km/h	20-25 km/h	25+ km/h
CATAPULT	S5	GPS (13-16)	Circuit 2 v 2 Game 3 v 3 Game 5 v 5 Game Full Pitch Coverage	✓ ✓ ✓ ✓ ✓	Velocity Position	Above	Standard	Standard	Standard	
CATAPULT	Vector GPS	GPS (13-16)	Circuit 2 v 2 Game 3 v 3 Game 5 v 5 Game Full Pitch Coverage	✓ ✓ ✓ ✓ ✓	Velocity Position	Well-above	Above	Above	Standard	Above
Fitogether	OhCoach Cell B	GPS (13-16)	Circuit 2 v 2 Game 3 v 3 Game 5 v 5 Game Full Pitch Coverage	✓ ✓ ✓ ✓ ✓	Velocity Position	Well-above	Well-above	Above	Above	Well-above
RealTrackGPS	Realtrack GPS	GPS (13-16)	Circuit 2 v 2 Game 3 v 3 Game 5 v 5 Game Full Pitch Coverage	✓ ✓ ✓ ✓ ✓	Velocity Position	Well-above	Standard	Standard	Well-above	
STATSports®	Apex	GPS (12-14)	Circuit 2 v 2 Game 3 v 3 Game 5 v 5 Game Full Pitch Coverage	✓ ✓ ✓ ✓ ✓	Velocity Position	Well-above	Standard	Standard		

Figure 12. Different Electronic Performance and Tracking Systems (EPTS) tested by the FIFA Quality Programme; (A) Global Positioning Systems (GPS), (B) Optical Tracking Systems (OTS), and (C) Local Positioning Systems (LPS). Values in parentheses display the number of satellites, cameras, and antennas, respectively. Adopted from Ju (2022c): redrawn from FIFA Quality Performance Reports for EPTS (2020).

(B)

Manufacturer	Product	EPTS	TEST: Circuit	2 v 2 Game	3 v 3 Game	5 v 5 Game	Full Pitch Coverage
CHYRONHEGO	TRACAB Gen5	OTS (16)	✓	✓	✓	✓	
HAWK-EYE	Ball & Player Tracking	OTS (12)	✓	✓	✓	✓	✓
InStat	InStat Fitness	OTS (3)	✓	✓	✓	✓	✓
STATSports	SportVU 2.0	OTS (4)	✓	✓	✓	✓	✓
TRACK160	Coach160	OTS (3)	✓	✓	✓	✓	✓

Rating by FIFA Velocity Band

Well-above | Above | Standard | Below | Well-below

Manufacturer		0-7 km/h	7-15 km/h	15-20 km/h	20-25 km/h	25+ km/h
CHYRONHEGO	Velocity	Well-above	Well-above	Well-above	Well-above	
	Position	Well-above	Well-above	Well-above	Well-above	
HAWK-EYE	Velocity	Well-above	Well-above	Well-above	Well-above	Well-above
	Position	Well-above	Well-above	Well-above	Well-above	Above
InStat	Velocity	Above	Standard	Standard	Standard	Well-above
	Position	Well-above	Above	Standard	Standard	Above
STATSports	Velocity	Well-above	Above	Above	Well-above	Well-above
	Position	Well-above	Well-above	Well-above	Well-above	Well-above
TRACK160	Velocity	Well-above	Well-above	Well-above	Well-above	Well-above
	Position	Well-above	Well-above	Above	Standard	Standard

Figure 12 ***Cont*****. Different Electronic Performance and Tracking Systems (EPTS) tested by the FIFA Quality Programme; (A) Global Positioning Systems (GPS), (B) Optical Tracking Systems (OTS), and (C) Local Positioning Systems (LPS). Values in parentheses display the number of satellites, cameras, and antennas, respectively. Adopted from Ju (2022c): redrawn from FIFA Quality Performance Reports for EPTS (2020).**

(C)

Manufacturer	Product	EPTS	TEST
CATAPULT	Vector	LPS (24)	Circuit ✓ 2 v 2 Game ✓ 3 v 3 Game ✓ 5 v 5 Game ✓ Full Pitch Coverage ✓
RealTrackGPS	Wimu Pro LPS	LPS (8)	Circuit ✓ 2 v 2 Game ✓ 3 v 3 Game ✓ 5 v 5 Game ✓ Full Pitch Coverage ✓

Rating by FIFA Velocity Band

Well-above | Above | Standard | Below | Well-below

Manufacturer		0-7 km/h	7-15 km/h	15-20 km/h	20-25 km/h	25+ km/h
CATAPULT	Velocity	Well-above	Well-above	Above	Above	Well-above
	Position	Well-above	Well-above	Well-above	Well-above	Well-above
RealTrackGPS	Velocity	Well-above	Above	Well-above	Well-above	
	Position	Well-above	Above	Standard	Below	

Figure 12 ***Cont*****. Different Electronic Performance and Tracking Systems (EPTS) tested by the FIFA Quality Programme; (A) Global Positioning Systems (GPS), (B) Optical Tracking Systems (OTS), and (C) Local Positioning Systems (LPS). Values in parentheses display the number of satellites, cameras, and antennas, respectively. Adopted from Ju (2022c): redrawn from FIFA Quality Performance Reports for EPTS (2020).**

2.2 Physical Metrics

2.2.1 General Introduction

Despite GPS technology being commonplace in professional settings, there is still lack of clarity which metrics should be used to track locomotive and mechanical loading (Malone et al., 2019). As mentioned before in this review, most of research in team sports has quantified external load as a measure of locomotive variables using GPS technology rather than the MEMS devices (Barrett, 2017; Malone et al., 2017a). The key variables extensively used today to quantify workload in football training and games are total distance, distance at various speed zones as depicted in Figure 15 (high-speed, very high-speed and sprint distance), mean and maximum speed, accelerations, decelerations and accelerometer-based variables such as impacts, collisions, Body load and PlayerLoad (Abbott et al., 2018a; Akenhead et al., 2016b; Buchheit et al., 2015; Clemente et al., 2019a Delaney et al., 2018a; Lu et al., 2017; Malone et al., 2015; Malone et al., 2018;). The present body of work will further build on such current knowledge and use widely researched variables such as total distance as a measure of volume, high velocity running (high-speed and sprint distance) as an indication of intensity (Riboli et al., 2021b). Mechanical load will be presented as a number of high-intensity accelerations and decelerations (A+D, > 3 $m{\cdot}s^{-2}$; $n{\cdot}min^{-1}$). In addition, relative high-speed running and sprinting actions will be analysed, which might allow a better comparison between footballers including various playing positions by taking into consideration their unique physical capabilities (Rago et al., 2019b). Nevertheless, relatively novel metrics in elite football such as acceleration distance (Acc B3 Dist, distance with variations in running speed > 3 $m{\cdot}s^{-2}$) as well as maximum values of acceleration: Max Acc ($m{\cdot}s^{-2}$) and deceleration: Max Dec ($m{\cdot}s^{-2}$) will be added to the knowledge base by this research thesis. Findings from the current body of work might provide additional tools for coaches and practitioners to their training prescription and develop new drills that could effectively achieve desired goals in practical settings.

2.2.2 Accelerations and Decelerations

Locomotor high-speed activities reported by 2-dimensional (2D) video-based systems don't inform about the effort needed to change to another speed, which consequently might lead to underestimated total workload (Dalen et al., 2016; Rago et al., 2019b). Rapid changes of speed are crucial in elite football and efficient and quick ability to accelerate, decelerate, change of direction have been linked to success in field-sport teams (Delaney et al., 2018a; Harper et al., 2019; Rhodes et al., 2021). Despite accelerations being a distinct quality and requiring greater neural activation of the muscle than running at constant speed, they are pre-cursor to high-velocity movements (Akenhead et al., 2013; Delaney et al., 2018a). They occur 3 to 8 times more frequently than sprints in competition and it is well accepted that accelerations and decelerations are more energetically demanding than speed-based activities (Akenhead et al., 2013; Akenhead et al., 2016b). High decelerations take place more often than high accelerations in match play, which causes greater levels of neuromuscular stress, cumulative tissue microtrauma and associated fatigue (Abbott et al., 2018b; Akenhead et al., 2013; Dalen et al., 2016; Polglaze et al., 2019). Deceleration capacities have a significant impact on football players' physical performance in match play (Figure 13) and therefore, there should be more attention given to these actions (Harper et al., 2018). It has been suggested that constantly increasing volume and intensity of deceleration activities in training might alleviate the risk of tissue damage and soft tissue injury (Harper et al., 2018).

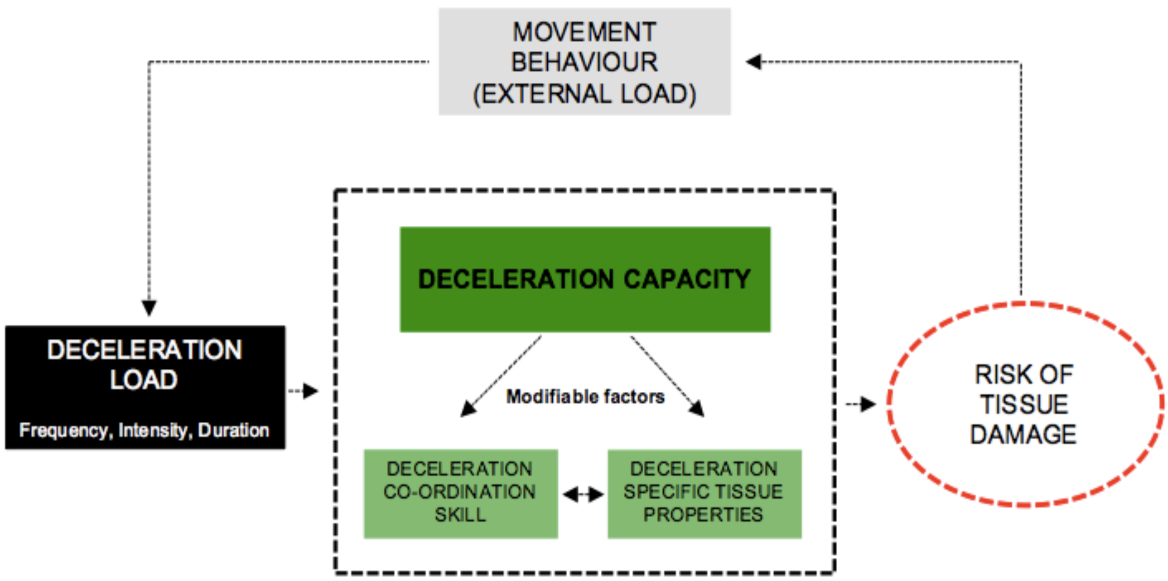

Figure 13. Deceleration capacity represented as a 'critical mediator' moderating the performers risk of tissue damage. Adopted from Harper et al. (2018).

Bowen et al. (2020) found that the greatest soft-tissue injury risk occurred when there was a sudden spike in decelerations, which supports the concept of building a solid chronic load of this mechanical variable. Interestingly, higher-playing standard teams might produce more high-intensity accelerations and short-lasting actions, which further highlights the importance of monitoring these activities in elite football (Akenhead et al., 2013; Castillo et al., 2021; Harper et al., 2019). Measuring accelerations and decelerations might allow coaches and practitioners to better prescribe the external load to reach optimum match performance and reduce the risk of injury (Figure 14) (Abbott et al., 2018b; Castillo et al., 2021; Delaney et al., 2018a).

Yet, it is noteworthy that coaches and practitioners should be cautious when analysing, interpreting, and prescribing training load based on acceleration-derived data, since they show the highest variability in GPS monitoring (Buchheit et al., 2014c). Furthermore, it might be crucial for professionals to know that units with a minimum sampling rate of 10 Hz are recommended for more accurate measurements (Akenhead et al., 2013; Harper et al., 2019) and averaging the acceleration/deceleration profile (Ave Acc, Ave Dec, Ave Acc/Dec) of an activity might be more appropriate method to track accelerations due to greater inter-unit reliability (Delaney et al., 2018a).

Fixture Details	Total Accelerations (m/s^2)	Average Accelerations (m/s^2)	Total Decelerations (m/s^2)	Average Decelerations (m/s^2)	Number of Games
Midweek Game	2772	185 ± 53	5473	365 ± 91	15
Saturday Game Following Midweek Game	2272	151 ± 36	4576	305 ± 65	15
Saturday Game Only	2475	155 ± 26	5211	326 ± 51	15
Total (all games)	7355	165 ± 43	14,866	330 ± 75	45

Figure 14. Frequency of team high-intensity (>3 $m \cdot s^{-2}$) accelerations and decelerations (mean ± SD) for different game scenarios (midweek game, Saturday game following a midweek game, Saturday game only, and total games). Adopted from Rhodes et al. (2021).

2.2.3 Metabolic Power

Given that traditional time-motion analysis systems do not inform about the highly energetic changes in speed (accelerations and decelerations), a new metabolic power (P_{met}) concept has been proposed to better estimate overall energetic demands of football and represent a more thorough measure of volume and intensity (Buchheit et al., 2015; Polglaze et al., 2019). The P_{met} model is based on a theoretical concept proposed by Di Prampero et al. (2005), which postulates that acceleration on a flat surface is energetically equivalent to a constant-speed uphill running. Osgnach et al. (2010) and Gaudino et al. (2013) showed that high-intensity work defined only via locomotive variables (high-speed distance) might be underestimated in football match play, which highlights the importance of monitoring activities reported as distance at high metabolic load or high-power output (< 20 W/kg). Analysing high-power output efforts becomes useful particularly during position-oriented drills where high-speed activities do not occur frequently (Gaudino et al., 2013). Buchheit et al. (2015) reported P_{met} as invalid to estimate energy demands during football-specific drills due to weak correlations between estimated energy expenditure (P_{gps}) and measured oxygen consumption (VO_2). However, according to Polglaze et al. (2019) these two parameters should not be compared in intermittent (non-steady) activities, since VO_2 is a measure on energy supply, whereas P_{met} quantifies instantaneous energy demand (the amount of energy needed per second per kilogram). In addition, using 4 Hz GPS devices could be seen as a limitation of this study, since it has been generally accepted that higher-frequency receivers could be more accurate to track football-specific activities (Akenhead et al., 2013; Buchheit et al., 2015; Harper et al., 2019). Overall, metabolic power could be useful in football and despite many limitations, current developments of GPS technology along with P_{met} updates, open interesting venues in the future for this concept (Malone et al., 2015; Polglaze et al., 2019; Rago et al., 2019a). More studies are warranted to recognize P_{met} as a valid and reliable tool in elite football (Buchheit et al., 2015; Malone et al., 2015; Polglaze et al., 2019; Rago et al., 2019a).

2.2.4 Absolute vs Individual Zones

Global zones widely adopted in football enable workload comparisons to be made between athletes, however fail to reflect players' individual physical characteristics nor inform about their relative intensity and maturation status (Abbott et al., 2018a; Akenhead et al., 2016b; Harper et al., 2019; Hunter et al., 2015; Rago et al., 2019a; Rago et al., 2019b). Studies suggest the following absolute speed zones for elite football players: 14.4-19.8 $km \cdot h^{-1}$ as moderate-speed running (MSR), 19.9-25.1 $km \cdot h^{-1}$ as high-speed running (HSR) and above or equal to 25.2 $km \cdot h^{-1}$ as sprinting (SPR) (Anderson et al., 2016b; Bradley et al., 2009). For accelerations and decelerations most studies used 3/-3 $m \cdot s^{-2}$ as a threshold of intense accelerations/decelerations, but some authors suggest adopting 2/-2 $m \cdot s^{-2}$ due to poor reliability of these variables as intensity increases (Delaney et al., 2018a; Rago et al., 2019a).

Studies	Subjects	HSR		Sprint	
Mara et al. 2017	Women – Elite Australian	*12.2–19 km·h⁻¹*	2,452 m	*>19 km·h⁻¹*	615 m
Scott et al. 2020	Women – Elite United States	*≥12.5 km·h⁻¹*	2,401 m	*≥22.5 km·h⁻¹*	122 m
Ramos et al. 2019	Women – Adult	*15.6–20 km·h⁻¹*	**756 m**	*>20 km·h⁻¹*	**307 m**
Ramos et al. 2019	Women – U20	*15.6–20 km·h⁻¹*	**688 m**	*>20 km·h⁻¹*	**223 m**
Anderson et al. 2016	Men – Premier League	*19.8–25.1 km·h⁻¹*	**706 m**	*>25.1 km·h⁻¹*	**295 m**
Modric et al. 2019	Men – Elite Croatian	*19.8–25.1 km·h⁻¹*	**462 m**	*>25.1 km·h⁻¹*	**156 m**
Carling et al. 2016	Men – League 1	*19.8–25.2 km·h⁻¹*	**587 m**	*>25.2 km·h⁻¹*	**184 m**
Kelly et al. 2020	Men – Premier League	*19.8–25.2 km·h⁻¹*	620 m	–	–
Miñano-Espin et al. 2017	Men – La Liga	*21.1–24.0 km·h⁻¹*	277 m	*>24 km·h⁻¹*	247 m
Wehbe et al. 2014	Men – Elite Australian	*>19.7 km·h⁻¹*	**645 m**	–	–
Baptista et al. 2018	Men – Elite Norwegian	*≥19.8 km·h⁻¹*	**744 m**		
Rampinini et al. 2007	Men – League 1	*>19.8 km·h⁻¹*	**821 m**	–	–
Stevens et al. 2017	Men – Eredivisie	*>19.8 km·h⁻¹*	**738** m		
Dalen et al. 2019	Men – Elite Norwegian	*>19.8 km·h⁻¹*	**747 m**	*>25.2 km·h⁻¹*	**153 m**
Clemente et al. 2019	Men – Dutch and Spanish 2nd Division	*>20 km·h⁻¹*	**730 m**		
Asian-Clemente et al. 2020	Men – U19 elite Spanish	*>21 km·h⁻¹*	414 m	–	–
Altmann et al. 2021	Men – Bundesliga	*17.0–23.99 km·h⁻¹*	1,340 m	*≥24 km·h⁻¹*	495 m

Figure 15. High-speed running and sprint match thresholds and demands for elite female and male football players. Adopted from Gualtieri et al. (2023).

Research has tried to individualise speed zones based on combined fitness components such as ventilatory thresholds, maximal aerobic speed (MAS), and maximum sprint speed (MSS) to include limits of both endurance and sprint capabilities (Abbott et al., 2018a; Abbott et al., 2018b; Hunter et al., 2015). According to Rago et al. (2019b) integrating both MAS and MSS into the external training load quantification would enable the anaerobic speed reserve (ASR) calculation, which allows more accurate definition of speed zones. Furthermore, it has been shown that significant discrepancies between global and individual methods exist to measure high-speed activities and/or high-intensity accelerations in football players (Abbott et al., 2018a; Abbott et al., 2018b). Carling et al. (2016) used individual speed zones to quantify players' running performance and concluded that match-to-match variability in high-speed running activities was lower compared to global zones, which could implicate that relative speed zones might be more appropriate to assess running performance and fatigue in elite football players during competition. Therefore, relativising intensity zones to individual characteristics in elite football could better advise practitioners about players' true workload, their adaptation, and perceptual responses to the training programme (Abbott et al., 2018a; Abbott et al., 2018b; Harper et al., 2019; Rago et al., 2019a; Rago et al., 2019b).

2.3 Application of Time-motion Systems

The main aim of using GPS technology and other tracking systems in elite football is to optimise performance, manage workload, and reduce injury occurrence (Abbott et al., 2018a; Jackson et al., 2018; Rago et al., 2019a; Stevens et al., 2017). Recently the International Football Association Board allowed the use of GPS devices during official matches, which has attracted many practitioners to monitor match and training load regularly (Harper et al., 2019; IFAB, 2015). Since match play represents the highest and most strenuous activity during a week as well as provides reference for load prescription, it should be monitored and added to the weekly load (Anderson et al., 2016a; Castillo et al., 2021; Rago et al., 2019a). Match-analyses are necessary to develop football-specific training programme, which should mimic and/or overload physical/physiological demands of competition (Abbott et al., 2018c; Di Salvo et al., 2007; Lago-Peñas et al., 2009). Many studies used computerised multi-camera analysis systems to analyse elite football players match activity patterns, assess high-speed profiles, determine differences in positional demands and playing standards in running performance, compare physical outputs between starters and substitute players, identify peak running demands, investigate accumulated and transient fatigue, and determine match-to-match and in-match variability in high-intensity actions (Ade et al., 2016; Anderson et al., 2016a; Bradley et al., 2009; Bradley et al., 2010; Carling et al., 2012; Carling et al., 2016; Di Mascio et al., 2013; Fransson et al., 2017; Lago- Mohr et al., 2003; Peñas et al., 2009).

Central defenders have been found to run the lowest total distance, cover less high-intensity running, and have the longest recovery duration between consecutive high-intensity efforts compared to other positions (Allen et al., 2023; Fransson et al., 2017). This positional group however has recently showed significant increases in high intensity running metrics compared to previous seasons (Allen et al., 2023). Additional positional analysis revealed that central midfielders cover the highest total distance and perform higher number of high-intensity runs separated by a short recovery (< 20 seconds), whereas full backs and wingers achieve the most repeated high-intensity efforts and accumulate the highest sprint distance (Allen et al., 2023; Carling et al., 2012; Dalen et al., 2016; Fransson et al., 2017). It could be concluded that the activity profile of elite football players highly depends on their tactical roles and positions, especially regarding high-velocity activities as presented in Figure 16 (Bradley et al., 2018a; Dalen et al., 2016; Ju et al., 2023b).

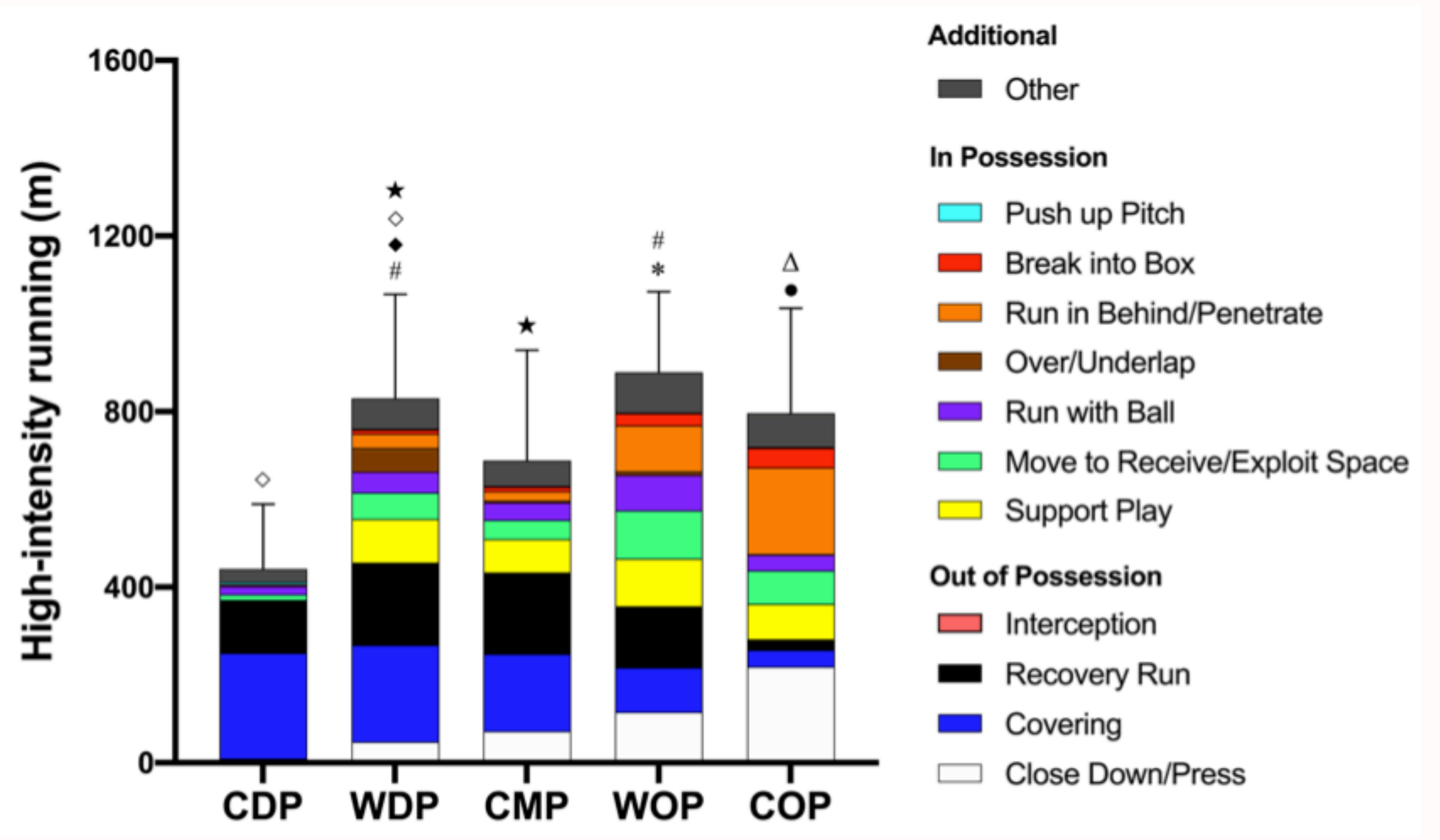

Figure 16. High intensity running during contextualized periods covered by general positions: Central Defensive Players (CDP), Wide Defensive Players (WDP), Central Midfield Players (CMP), Wide Offensive Players (WOP), Central Offensive Players (COP). Adopted from Ju et al. (2023b).

GPS devices and in-built accelerometery used in training and match play alike other tracking systems might be useful to identify players' activity profile, physical output differences between positions, assess the peak match demands, detect neuromuscular fatigue, compare workload of training to matches and compare different playing levels (Akenhead et al., 2013; Aughey et al., 2011; Buchheit et al., 2018; Castillo et al., 2021; Clemente et al., 2019b; Dalen et al., 2016; Gabbett et al., 2012). Many studies used GPS systems to track weekly and annual workloads employed in elite players, which could be used as a reference value for coaches and practitioners when planning training load for football sessions (Buchheit et al., 2018; Clemente et al., 2020a; Malone et al., 2015; Martín-García et al., 2018). Generally, studies using GPS and LPS systems showed that loads in days preceding the match play are decreased (MD-2 and MD-1), while the midweek loading block (MD-4 and MD-3) generated the highest count of high-intensity accelerations/decelerations and high-speed distances, which could indicate the tapering concept in football (Kelly et al., 2020; Martín-García et al., 2018; Stevens et al., 2017). GPS technology has also been used extensively to determine the impact of various game formats and number of players on physical demands on elite football players. Small-sided (SSG) or large-sided games (LSG) are often used to mimic the football-specific match demands including technical skills, tactical awareness, speed, acceleration/deceleration qualities and endurance performance (Riboli et al., 2020). The manipulation of different variables such as pitch size, the number of players, goalkeeper presence, and technical rules alter the football-specific demands depending on the session objectives (Hill-Haas et al., 2011; Rampinini et al., 2007). Studies found that large formats produced more high-intensity accelerations and decelerations as well as generate more high-speed actions and sprints (Abbott et al., 2018c; Castellano et al., 2013; Clemente et al., 2019b; Gaudino et al., 2014). Figure 17 shows that as the pitch size and the number of players increases, the sprinting activities may be more reflective of the true competition demands displaying positional differences (Beato et al., 2023a; Beato et al., 2023b Clemente et al., 2019b). Different game formats might be suggested to players based on their positional demands, which shows how useful research using GPS technology has become for practitioners and coaches (Abbott et al., 2018c).

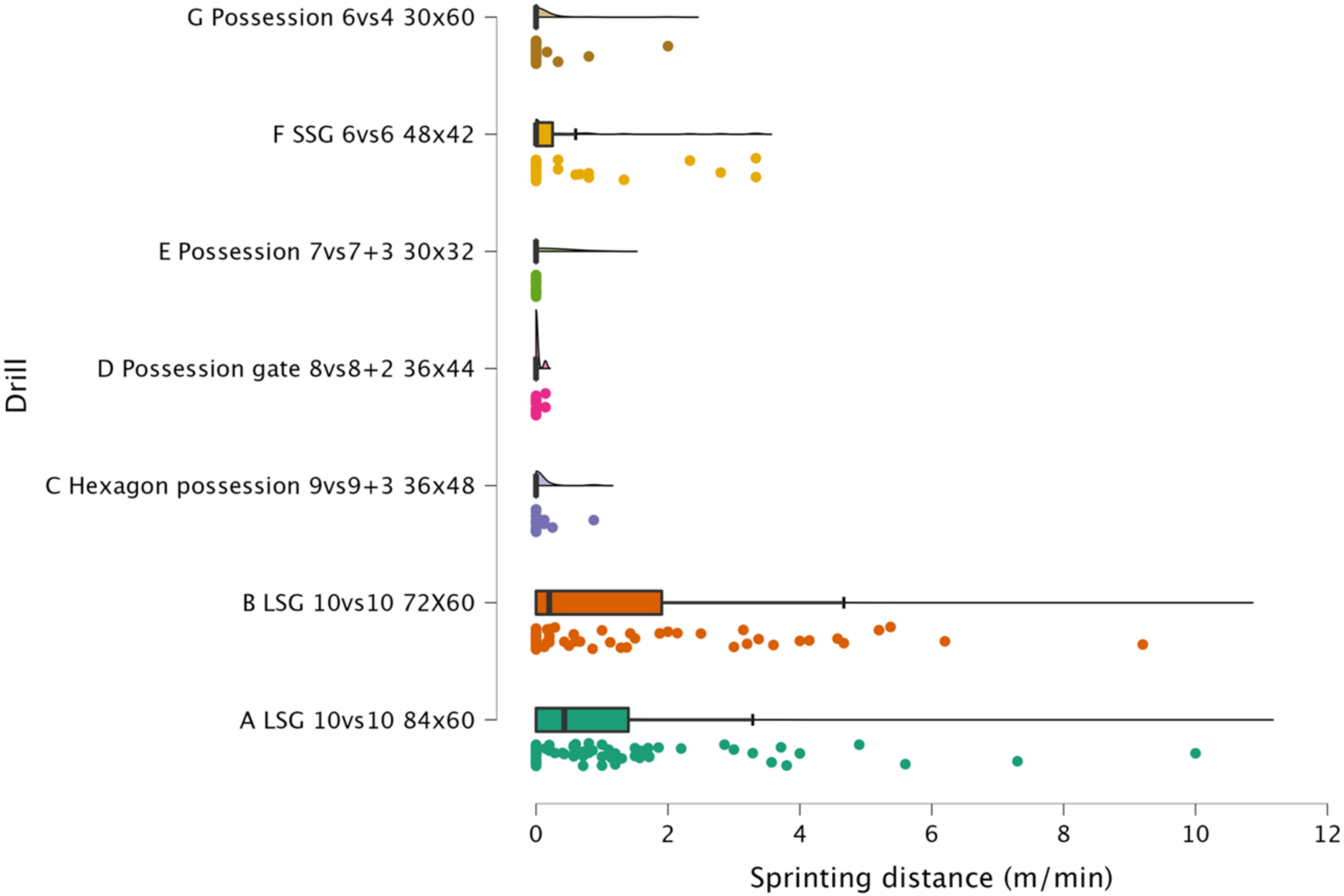

Figure 17. Comparison of sprinting distance per minute between different football-specific drills. The data distributions indicate, mean, standard deviation, 95% CI, and individual data points. Adopted from Beato et al. (2023b).

2.4 External Load and Injury

Training load has been considered a modified risk factor for injury in football (Gabbett et al., 2016b; Malone et al., 2018). Monitoring and understanding workloads could improve not only training adaptations and reduce risk of injury through the prescription of appropriate loads to athletes (Bowen et al., 2017; Gabbett et al., 2012). Banister et al. (1975) originally proposed a statistical model to determine training-performance relationship, which claims that each training session “dose” produces a positive fitness and negative fatigue response (Figure 18). The author suggests that at any given time athletes’ performance could be determined from a difference between fatigue as negative function and fitness as positive function (Banister et al., 1975). According to Gabbett (2016a) the best practice to model the training-injury relationship is to use acute:chronic ratio approach (ACWR), in which acute workload represents 1-week cumulative load and chronic load is the rolling average of workload in 3-6 previous weeks (Gabbett et al., 2016b). Most studies however used 7 days acute to 28 days chronic to calculate the ratio (Griffin et al., 2020). ACWR between 0.8 to 1.3 might be considered the training “sweet spot”, while ratios above 1.5 depict “the danger zone” that could increase a risk of soft-tissue injury (Blanch & Gabbett, 2016). In fact, values below the recommended range could lead to under-preparedness, potentially leave players unable to withstand the physical match demands and hinder performance (Ehrmann et al., 2016). Thus, it has been suggested to aim for “the sweet spot” for both internal- and external-intensity indicators in professional football (Jaspers et al., 2018; Malone et al., 2017b). Yet various sports might have different training load-injury relationships, and this knowledge should still be used with caution (Gabbett, 2016a). To support that approach, Bowen et al. (2020) shown that ACWR could be a better non-contact injury predictor than accumulated load analysed in isolation. Nevertheless, the evident link between ACWR and non-contact injury in professional settings does not translate into the ability to predict injury (Griffin et al., 2020). In practical settings, there might be many athletes on numerous occasions across the season with ACWR outside of the recommended range (0.8 to 1.3) for various external-intensity metrics, yet these players never get injured. Practitioners could still manage these athletes accordingly. First, to ensure they are properly conditioned and optimally prepared for the competition demands by gradually increasing volume and “smartly” imposing intensity over a certain period of time as depicted in Figure 19 (e.g. pre-season, return to play, etc.) relative to the positional demands and second, to “wisely” de-load those athletes whose ratio surpassed 1.5 value, especially for high-intensity locomotor and mechanical metrics (Abbott et al., 2018c; Malone et al., 2017b; Piggott et al., 2009).

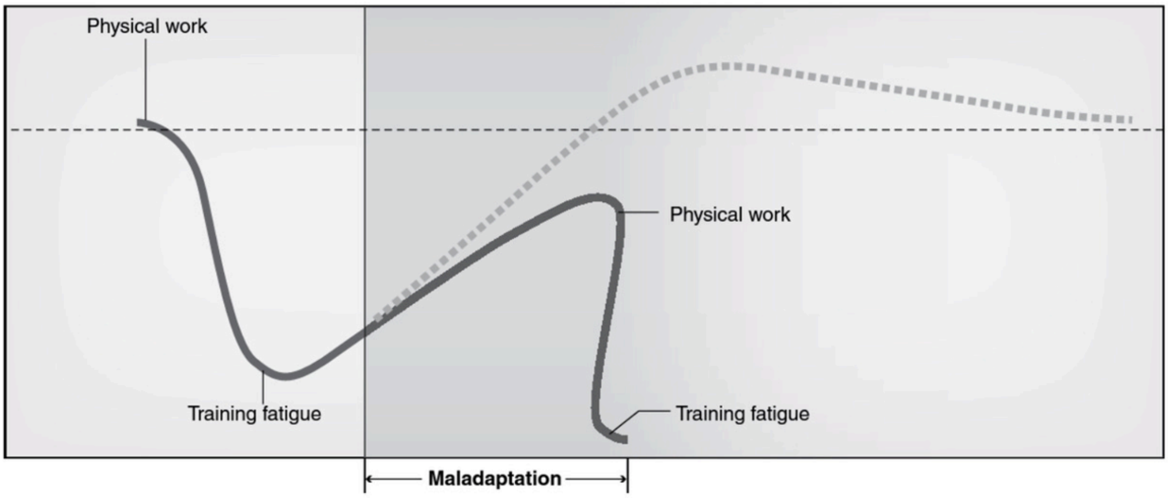

Figure 18. Maladaptive training response due to insufficient recovery after a training dose. Adopted from Banister et al. (1975).

Team sport athletes including football players with high chronic loads might possess enhanced abilities to cope with the increased physical demands and workload, which might ultimately protect them against subsequent injury (Hulin et al, 2016; Lovell et al., 2006). Recently, English Premier league players with low chronic load and a rapid spike in load (ACWR > 2.0) experienced 5 to 7 times greater risk of non-contact soft-tissue injury (Bowen et al., 2020). Ehrmann et al. (2016) concluded that when spikes in workload occurred, the risk of non-contact soft tissue injuries in Australian professional football players also increased. In addition, elite rugby players with excessive session sprint distance were 2,7 times more likely to suffer non-contact soft tissue injury, alternatively, the risk was reduced when greater distances were covered in low-intensity bands (Gabbett et al., 2012). The U-shaped relationship between sprinting and soft-tissue injury in elite Gaelic footballers and football players was also identified (Malone et al., 2017b; Malone et al., 2018), which highlights the importance of adequate exposure to high-velocity running and sprinting within elite athletes in terms of preparation for competition demands, avoidance of under-preparedness, and injury reduction concept (Bowen et al., 2017). Football players with higher intermittent aerobic fitness could be able to cope better with high increases in workload and/or sudden spikes in week-to-week load with lower chances of injury, indicating the importance of developing robust players (Malone et al., 2017c; Malone et al., 2018). Piggott et al. (2009) showed in elite Australian footballers that low weekly training monotony could have implications on reduced injury rate and that weekly training load changes (10% increase) might also influence the risk of injury in the following week.

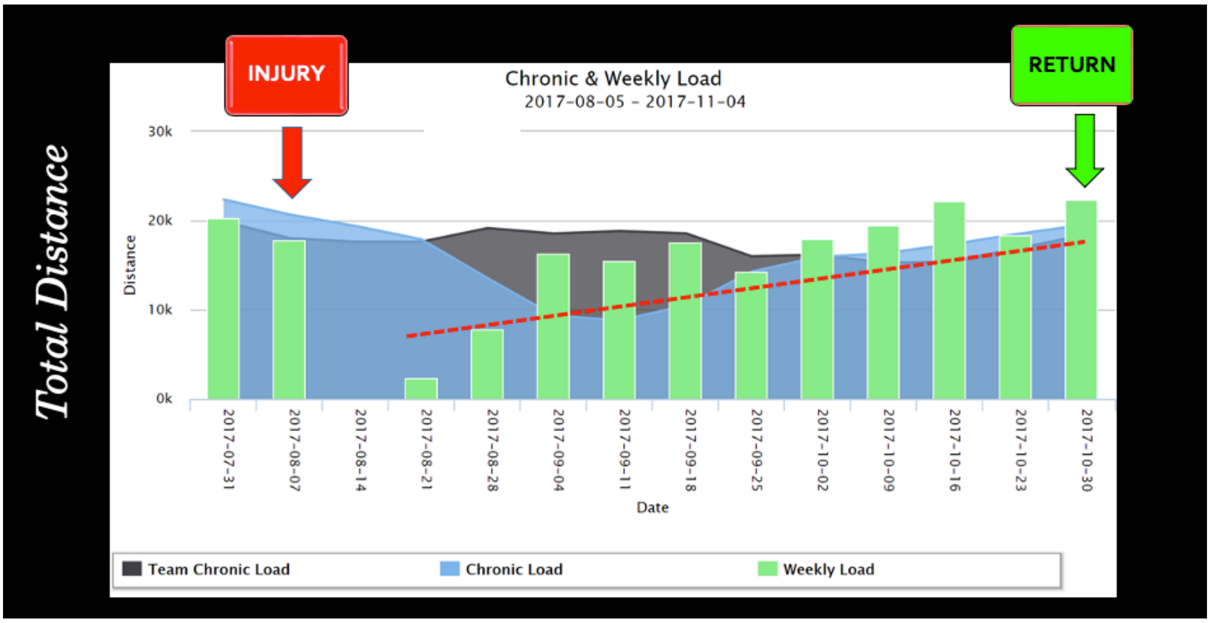

Figure 19. Example of using ACWR (7:21) to track and guide players' return to play after a serious injury. Unpublished data.

Therefore, based on current literature it could be stated that high training loads might have protective properties, yet excessive and sudden spikes in workload could predispose athletes to non-contact and soft-tissue injuries. Nevertheless, it is noteworthy not to oversimplify the dynamic, multifactorial, and contextual injury process to one single factor, which is a workload-injury relationship (Windt et al., 2017). According to Buchheit (2017b), injury prevention in football should not be limited only to one metric such as the ACWR mentioned above. Furthermore, Williams et al. (2017) proposed a new model called 'exponentially weighted moving averages' (EWMA) to alleviate limitations inherent to the ACWR approach such as not addressing the decaying effect of fatigue and fitness nor accounting for variations in accumulated load over time. The newly proposed EWMA model could be more sensitive to identify the risk of injury, especially at high ACWR values during pre-season and in-season training in elite field-based athletes (Griffin et al., 2020; Murray et al., 2017). More work should be done in that sensitive area. Yet, coaches and practitioners should be aware that knowing athletes' needs, understanding their activity profiles, and logically planning workloads are probably equally important concepts (Buchheit et al., 2017b), especially considering that no specific workload profile exist prior to injury in professional football players (Lu et al., 2017). Finally, fitness professionals should know that the mismatch between training and match workloads, especially inadequate volumes of high-speed and sprint activities, could lead to undertraining and higher injury risk (Abbott et al., 2018c; Gabbett et al., 2012; Gabbett et al., 2016b).

2.5 Future Perspectives for Monitoring Football Performance

2.5.1 Introduction to The Integrated Approach

Analysing physical data in isolation might be described as a shortcoming in contemporary football match analysis, because contextual factors (e.g., match location, standard of opposition, result) as well as technical and tactical aspects determine physical output of the players (Bradley et al., 2018a; Bush et al., 2015b; Malone et al., 2019). There is no doubt that modern approach in football training requires to contextualise sessions to implement a position-specific program integrating all aspects into one content (the integrated approach in Figure 20) (Bradley et al., 2018b; Harper et al., 2019; Ju et al., 2022a; Martín-García et al., 2018). Conditioning drills should never isolate tactical requirements and technical skills nor prescribe intensity based on average game demands, otherwise players would end up underprepared for match play and their performance could suffer (Abbott et al., 2018c; Gabbett et al., 2016b; Malone et al., 2019).

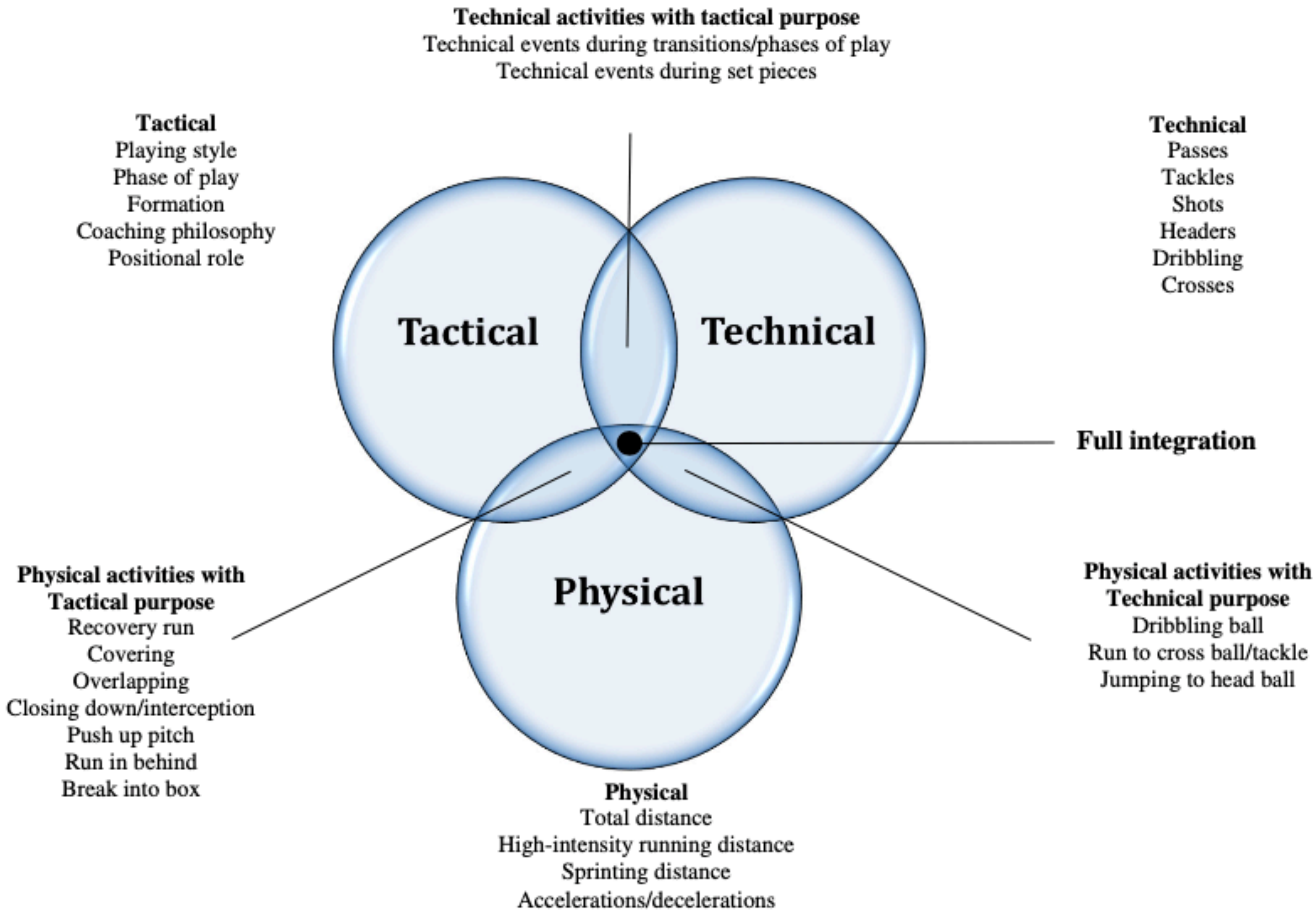

Figure 20. A Venn diagram displaying an integrated approach to measuring and interpreting the physical football match performance. Adopted from Ju (2022c) and Bradley (2018a).

2.5.2 Transitional Play and High-Pressure Activities

It has been suggested that current traditional match analysis data might not be very applicable in today's practice, since most studies reported physical data as full match and/or half-by-half averages of mainly locomotor categories (Bradley et al., 2018b). Entire match averages do not show how running performance and match intensity fluctuates during the game, which clearly underestimates physical, technical-tactical density in competition (Wass et al., 2020). Studies in elite football have recently shifted towards the peak match demands, also called worst case scenarios (WCS), most demanding scenarios (MDS), and most demanding passages (Garcia et al., 2022; Pollard et al., 2018; Riboli et al., 2021a; Riboli et al., 2021b; Whitehead et al., 2018). According to Wass et al. (2020) understanding the maximal physical demands during specific and short-lasting periods of match play, might allow coaches to prepare players more precisely for these high intensities.

It has been determined that a shorter duration WCS generated higher intensity, raising questions regarding the physical preparation of players for these increased demands in competition (Doncaster et al., 2020; Martin-Garcia et al., 2018). Different methods have been used to measure WCS and the rolling average has been found superior compared to the fixed length methods (Fereday et al., 2020; Martin-Garcia et al., 2018; Olizano et al., 2021a). Regardless of the substantially increased body of knowledge regarding the most demanding passages and its distribution within the contemporary game, more information is needed surrounding the technical-tactical context and pattern of occurrence. Increasing this knowledge would better equip coaches and practitioners to optimise pitch specific conditioning and football specific training (small-sided games, technical, tactical, and positional drills) and more closely replicate the competition demands (Carling et al., 2018; Novak et al., 202; Riboli et al., 2021a).

WCS studies used durations from 10 seconds to 10 minutes and interestingly, shorter duration-specific periods have not been widely investigated (Whitehead et al., 2018). One of those short-duration specific actions are offensive and defensive transitions, which have been identified among the key five moments of play in football (Lago-Peñas et al., 2018; González-Rodenas et al, 2020; Wass et al., 2020). Analysis of transitions within elite football have shown increased physical demands when compared to match averages (Novak et al., 2021), often elicited when the ball is in play (BIP) (Pollard et al., 2018). Transitional play in football presents actions in and out of ball possession and represents offensive / defensive tactical behaviours and movements (Table 2 and 3). Offensive transitions (defence-to-attack) are characterised by high-speed actions with the goal to outnumber opponents, whereas defensive transitions (attack-to-defence) by very quick reorganisation of defensive shape, which could lead to conceived goals if remained imbalanced (Hewitt et al., 2016; Tenga et al., 2010). These phases called counter-attacks, occur in play during rapid changes from defensive and offensive actions. They happen at high tempo with the ball circulation more in depth, often surprising opponents and giving minimum chances for defensive forces to be well prepared and organised (González-Rodenas et al, 2021; Sarmento et al., 2013).

Conversely, other transition periods referred to as fast attacks occur when possession has been regained in play or the game restarted (change of possession = transition). They involve more passing sequences in both width and depth, but still with the intention to rapidly surprise opponent when opportunity arises (González-Rodenas et al, 2021; Sarmento et al., 2013). In addition, high-pressure activities have been found an effective playing style to create more goals scoring chances (Tenga et al., 2010) and have been linked to greater physical demands and higher levels of fitness in football (Wright et al., 2011). They occur in match play during transitional phases when ball possession has been lost (counter-press) as well as during an open play when a team attempts to win the ball back aggressively and applies pressure on the opposition high up the pitch (Low et al., 2020; Nigel, 2023). Compared to counter-attacks and fast attacks, high pressures are more difficult to be identified and captured as they revealed reduced inter-observer reliability (Chapter 3). In contrast to other sports such as futsal (Spyrou et al., 2020) and basketball (Ferioli et al., 2020) that stop a game clock, there is lack of studies in football that investigate BiP match demands in relation to positional roles, different formations as well as phases of play (transition to attack, transition to defend) and styles of play (e.g., high press and counter-attack), which clearly points out direction for future research (Wass et al., 2020). In this regard, understanding how these transitional activities present within competition might be essential to optimise the physical preparation of players to enhance performance and contribute to reducing injury risk.

2.5.3 Future Research Regarding Contextualised High-intensity Periods

Research comparing match play and training peak intensity periods (Objective 6) is strongly required to deem usability of the peak match demands for conditioning drills prescription (Carling et al., 2019). Nowadays, identifying peak match demands is useful mainly for isolated high-intensity drills as well as return to play training, but still there is lack of knowledge how this information could be used for team physical conditioning purposes (Carling et al., 2019). It is noteworthy that technical-tactical metrics should not be omitted in the analysis to optimally translate match demands into training and integrate sport-specific movement with technical skills (Carling et al., 2019; Bradley et al., 2018a; Bush et al., 2015b). Lack of information about the context is still a huge limitation when analysing physical performance in modern match play. Coaches and practitioners should know not only 'HOW' but also 'WHY' players produce high-intensity efforts in football (Bradley et al., 2018b), how long they last, how many times they occur in match play and how long is a recovery rest between them (Figure 2). More detailed approach integrating technical-tactical aspects into overall players performance analysis during blocks of maximum physical outputs is necessary today to better understand true competition demands and optimally transfer that knowledge into practical settings (Objective 2 and 7).

In contrast to match average physical metrics (Bradley et al., 2013; Dalen et al., 2016), research exploring the effect of contextual variables (match location, match half, and match outcome) on contextualised peak intensity periods in elite football is scarce (Objective 3 and 4), and future bodies of work should look into that area (Casamichana et al, 2019; Fereday et al., 2020; Oliva-Lozano et al., 2020a; Oliva-Lozano et al., 2020b; Riboli et al., 2021b). Future studies could investigate offensive and defensive transitions and compare them to the most intense periods during football match play (Objective 2). It would be valuable to identify whether physical outputs during these short and specific high-intensity blocks change across different phases of the game and during congested fixtures to detect the possible effect of transient and accumulated fatigue on these moments of play (Objective 3). Finally, by comparing physical efforts between substitute players and starters could be an added value for professionals (Objective 5) and increase the current body of knowledge related to the physical demands during transitions and high-pressure scenarios in elite football (Objective 7).

Chapter 3: The Mean and Peak Physical Demands During Transitional Play and High-pressure Activities in Elite Football

This chapter comprises the following manuscript published in Biology of Sport:

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The mean and peak physical demands during transitional play and high pressure activities in elite football

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ABSTRACT: The aim of the present study was to establish the effect of transitional activities (TA) on physical metrics. Global Positioning System technology was utilized on 23 elite outfield footballers over 10 games to quantify absolute metrics per minute such as total distance (TD; m·min^{-1}), sprint distance (SD; m·min^{-1}), the number of high-intensity accelerations and decelerations (A+D; n·min^{-1}), and high-speed running distance (HSRD; m·min^{-1}). TD – total distance; HSRD – high-speed running distance; SD – sprint distance and high-intensity acceleration distance (Acc B3 Dist) were also quantified. Metrics were observed in relation to 4 TA's commonly observed in football matches. Positive Transitions (PT), Negative Transitions (NT), Fast Attacks (FA) and High Pressure Activities (HP). Main effects for transition and game were observed. Comparisons were also made between 90 minute averages and transitional mean scores. NT displayed the highest TD (m·min^{-1}) when compared to other TA's ($p \leq 0.05$). Observation of SD (m·min^{-1}) for all transitions highlighted higher outputs when in PT ($p \leq 0.05$). HP TA displayed the lowest output in all metrics ($p \leq 0.05$), except high-intensity accelerations and decelerations A+D (n·min^{-1}). The mean average and peak average outputs for TA and 90min average detailed elevated physical outputs across all metrics. Absolute physical metrics are increased when observing transitional play, representing the maximum physical exposure that athletes experience in games. This knowledge should be utilized when implementing high-velocity exposures within a weekly microcycle, to best prepare players for match play.

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Transitions
Counterattacks
High pressure
Peak demands
Worst-case-scenario

3.1 Chapter Overview

Despite a high tactical value and undoubted importance of transitional play and high-pressure activities in a modern football strategic approach, there are no previous studies that attempt to provide physical and technical-tactical insights about these crucial periods (Nassis et a., 2020; Wass et al., 2020). Current literature describes the effect of different playing styles including counter-attacks on physical, technical, and success-related metrics, merely depicting 90-min totals and fails to contextualise these variables into transitions (Forcher et al., 2023). Moreover, there are no studies to the authors knowledge that distinguish physical output differences between offensive and defensive transitional actions nor identify their frequency and density, pattern of occurrence, duration, recovery period and positional differences. Not to mention, comparing training to official matches and analysing the effect of various contextual factors on physical performance during transitional activities referred to as the maximum-intensity periods in elite football. Therefore, the initial objective of the present body of work and represented in Chapter 3 is to capture physical performance during crucial moments of modern football game, whereupon coaches and practitioners could gain more insights about decisive transitional phases, high-pressure activities, and short maximum-intensity periods relative to the positional demands (Lago-Penas et al., 2018; Maneiro et al., 2019). It is hoped that measuring high-intensity actions during critical offensive and defensive activities commonly used by elite teams to win games, would significantly add to the existing body of knowledge, and most importantly, effectively transfer new evidence to practical applied settings (Aranda et al., 2019; Forcher et al., 2023). The following text has been taken directly from the manuscript published in Biology of Sport (Bortnik et al., 2022).

3.2 Abstract

The aim of the present study was to establish the effect of transitional activities (TA's) on physical metrics. Global Positioning System technology was utilised on 23 elite outfield footballers over 10 games to quantify absolute metrics per minute such as total distance (TD; $m \cdot min^{-1}$), sprint distance (SD; $m \cdot min^{-1}$), the number of high-intensity accelerations and decelerations (A+D; $n \cdot min^{-1}$), and high-speed running distance (HSRD; $m \cdot min^{-1}$). TD: total distance; HSRD: high-speed running distance; SD: sprint distance and high-intensity acceleration distance (Acc B3 Dist) were also quantified. Metrics were observed in relation to 4 TA's commonly observed in football matches. Positive Transitions (PT), Negative Transitions (NT), Fast Attacks (FA) and High Pressure Activities (HP). Main effects for transition and game were observed. Comparisons were also made between 90-minute averages and transitional mean scores. NT displayed the highest TD ($m \cdot min^{-1}$) when compared to other TA's ($p \leq 0.05$). Observation of SD ($m \cdot min^{-1}$) for all transitions highlighted higher outputs when in PT ($p \leq 0.05$). HP TA displayed the lowest output in all metrics ($p \leq 0.05$), except high-intensity accelerations and decelerations A+D ($n \cdot min^{-1}$). The mean average and peak average outputs for TA's and 90min average detailed elevated physical outputs across all metrics. Absolute physical metrics are increased when observing transitional play, representing the maximum physical exposure that athletes experience in games. This knowledge should be utilised when implementing high-velocity exposures within a weekly microcycle, to best prepare players for match play.

3.3 Introduction

Football match play consists of short bouts of high intensity linear and multidirectional activities, interspersed with longer recovery breaks at lower intensity (Barnes et al., 2014). It has been shown that both physical and technical demands within the game of football have evolved substantially over the past decade (Barnes et al., 2014; Harper et al., 2019). Training design should integrate physical, technical and tactical aspects collectively (Stolen et al., 2005) and reflect increased overall demands to successfully prepare players for high-intensity periods, which are crucial for the game outcome (Anderson et al., 2016a; Pollard et al., 2018). Modern wearable technology, including global positioning systems, offers a valid, reliable, practical and time-efficient solution for practitioners to quantify players' external load and measure athletes' movements in team sports (Scott et al., 2016). Quantifying load during match play, provides a valuable reference for training load prescription (Anderson et al., 2016a). Literature currently focuses on whole game data with limited evidence analysing transitional play that often exposes players to the highest external loads within the modern game (Novak et al., 2021).

Observing game play identifies changes in running performance and match intensity during the game. Training design based on whole game data underestimates the physical and technical-tactical demands of high-intensity periods experienced by players (Delaney et al., 2015; Lacome et al., 2016). These periods will exhibit changing demands on specific positions within the team. Thus, posing the question as to whether prescribing training based on whole game data best prepares our athletes for the highest demands experienced during game play. Despite different terms being utilised in literature, the most intense periods during match play are described "worst case scenarios" (WCS) (Novak et al., 2021; Pollard et al., 2018; Whitehead et al., 2018). Understanding the maximal physical demands during specific and short-lasting periods of match play, might allow coaches to prepare players more precisely for these high intensities (Wass et al., 2020).

WCS studies used durations from 10 seconds to 10 minutes and interestingly, shorter duration-specific periods have not been widely investigated (Whitehead et al., 2018). The shorter the duration of the WCS the higher the intensity achieved in high-speed running, sprinting and high-intensity accelerations and decelerations (Martin-Garcia et al., 2018; Riboli et al., 2021b). Different methods for quantification of WCS exist and the rolling average method has been considered more accurate than fixed length method for measuring peak intensity during the periods of 1-, 3-, 5-, 10-minutes in professional football (Fereday et al., 2020; Martin-Garcia et al., 2018; Oliva-Lozano et al., 2021a). Another alternative and important approach to quantify WCS is to analyse actions when the ball is in play (BiP) (Pollard et al., 2018) and/or quantify periods of repeated high-intensity efforts such as transitional activities (Aranda et al., 2019). In all available methods to measure WCS, the idea is the same, to identify the most intense periods of match play to recreate the same physical stimulus in training and reach positive physiological outcome (McCall et al., 2020). WCS or peak intensity demands is a multivariate concept, which must be properly addressed in practical settings. It rather represents an unstable benchmark today that is very difficult to be applied in practice and hence, it has been questioned (Novak et al., 2021).

It has been shown that players don't achieve peak physical demands for different metrics simultaneously, which occur in different phases of the game (Novak et al., 2021). There is lack of knowledge how the WCS information could be used for team physical conditioning purposes (small-sided games, technical-tactical drills, positional and running-based drills) such as volume/sets/duration and it is a challenge for practitioners to fully replicate and/or overload these match play intense periods in training (Carling et al., 2019; Riboli et al., 2021b). There still remains a lack of knowledge of several of the most intense passages in match play (Oliva-Lozano et al., 2021a) as well technical-tactical actions that inevitably occur during these passages, and which should not be omitted in the WCS analysis and training (Bradley et al., 2018a; Carling et al., 2019). Riboli and colleagues (2021a) described the distribution of the time spent at varied percentages of 1-min_{peak} for different physical metrics and identified that most match activities overloaded average match demands, especially high-velocity activities. Despite new insights on match peak demands distribution, further insight is needed with regards what happens during these peak intensity passages considering a technical-tactical perspective. This would enable coaches and practitioners to understand how to best integrate physical and tactical aspects in training design to prepare players for maximal physical outputs in modern football game. Unfortunately, the current body of scientific research has focused on how to prescribe training based on only one physical variable (i.e. total distance per minute), which could limit specificity and consequently not fully reflect high physical stress players are exposed to in short and specific high-intensity passages (Martin-Garcia et al., 2018).

It is proposed that analysing transitions in play and high pressing in more detail and further exploring a multivariate meaning of the complex WCS concept (Wright et al., 2011). Offensive (defence-to-attack) transitions and defensive (attack-to-defence) transitions are short-duration specific actions that have been identified among the key five moments of play in football (Hewitt et al., 2016; Lago-Penas et al., 2018; Wass et al., 2020). Elite football teams in top leagues characterise a high tempo and fast attacking actions that last below 20 seconds (González-Rodenas et al., 2020). Offensive transitions are characterised by high-speed actions with the goal to outnumber opponents, whereas defensive transitions by quick reorganisation of defensive shape (Hewitt et al., 2016; Tenga et al., 2010). Rapid transitions from defensive to offensive in play moments of the game are counter-attacks (Riboli et al., 2021b) that surprise opposition's imbalanced and disorganised defence (González-Rodenas et al., 2020). This tactical style of play has been found to be the most effective for scoring goals (Lago-Ballesteros et al., 2012). Moreover, other phases referred to as fast attacks fall into a transitional play category, since they occur during defence-to-attack change of possession in play. Yet these periods could also happen when a game is restarted and hence, are characterised by a higher number of passes when compared to counter-attacks (González-Rodenas et al., 2021; Sarmento et al., 2013). Transitions are crucial phases of the game, since most goals and risks take place during these moments (Lago-Penas et al., 2018) and for this reason, they should be explored in more detail and analysed in relation to high-intensity and high-velocity activities that occur during these phases. In addition, high pressing in the offensive third was found to generate seven times more goals and create more goalscoring opportunities (Tenga et al., 2010). High pressure has been believed to be linked to high levels of fitness, teamwork, and tactical awareness (Nigel, 2023; Wright et al., 2011). It might represent an individual- and sub-group or team-level tactical behaviours depending on other tactical factors and be mentally as well as physically demanding (Low et al., 2020).

Regardless of the significance of TA's within football match play and the fact that they could be easily replicated in training, there are no studies that investigate physical demands during these phases (Wass et al., 2020), compare them to the 90-min demands and treat them as peak intensity periods as well as inform practice about specific physical targets to improve teams performance during their offensive and defensive activities. In contrast to WCS concept, TA's have been well defined and directly linked to technical-tactical activities that occur simultaneously with other physically demanding activities within a modern football match play (Armatas et al., 2005; Hewitt et al., 2016; Tenga et al., 2010). In addition, TA's include a high context within as they represent moments when ball is in play, describe phases when team is either in (offensive actions) or out of the ball possession (defensive actions), and relates to tactical aspects such as offensive activities (counter-attack and fast attack) and defensive actions (attack-to-defence transition and high pressure). Therefore, the current study aims to determine the physical demand (total distance, high-speed running distance, sprint distance and high-intensity accelerations/decelerations) and frequency of transitional activities in games, comparing them to 90-minute match demands.

3.4 Materials and Methods

3.4.1 Participants

Twenty-three elite footballers from the Polish premier league were included in the study. Anthropometric data in not shared here as this was irrelevant to the purpose of the study inquiry. Players were classified according to the following playing position: center backs (*n* = 4), full backs (*n* = 5), central defensive midfielders (*n* = 2), central attacking midfielders (*n* = 2), central midfielders (*n* = 2), wingers (*n* = 5), and attackers (*n* = 3). Each game only included data from those players who played at least 60 min, since substitutes can have higher outputs than starting players likely as a result of pacing strategies (Lacome et al., 2016; Wass et al., 2020). All players were competing in the 1st Polish Division (Ekstraklasa) in season 2020–21 (Appendix 9). Players were presented with information of the project protocol and provided informed consent for the use of match data, in accordance with the Helsinki Declaration (2013). All data was anonymised prior to data analysis to ensure player confidentiality. Ethical approval was provided by the University of Central Lancashire (HEALTH 0104) (Appendix 8).

3.4.2 Procedures & Experimental Design

Data was collected between August and November 2020, during which a total of ten official matches including one UEFA CL qualifier and nine Polish domestic league (Ekstraklasa) games were analysed. Players' movements were captured by MEMS (10 Hz; Vector S7, Catapult Sports, Melbourne, Australia), which were worn in each game between the scapulae and contained within the playing jersey inside a pocket. The players were familiar with the use of these devices, wearing them usually in training and games. Devices were turned on 15 minutes before the start of the match to get a better connection to the satellites. Each data was screened for satellite coverage and horizontal dilution of precision (HDOP) using an inclusion criterion of > 6 satellites and ≤ 1.0 respectively, in accordance with previous guidelines for acceptable GPS coverage (Malone et al., 2017a). Players wore the same device during each game to reduce the inter-unit variations. The reliability and validity of such technology has been previously presented (Johnston et al., 2014; Scott et al., 2016).

Variables analysed were selected based on previous publications (Pollard et al., 2018; Riboli et al., 2021b; Wass et al., 2020). Absolute distances covered per minute ($m \cdot min^{-1}$) in the following categories: total distance (TD), high-speed running distance (HSRD, > 19.8 $km \cdot h^{-1}$), sprint distance (SD, > 25.2 $km \cdot h^{-1}$), as well as the number of high-intensity accelerations and decelerations (A+D, > 3 $m \cdot s^{-2}$; $n \cdot min^{-1}$) were observed. Additional observed variables were absolute distances covered in the following categories: total distance (TD), high-speed running distance (HSRD), sprint distance (SD) and acceleration distance (Acc B3 Dist, distance with variations in running speed > 3 $m \cdot s^{-2}$). Following each match, transitions were identified and manually generated in the Catapult Vision video analysis system (Catapult Sports Ltd, Melbourne, Australia) by the club's analysis team (Robinson et al., 2024).

To integrate physical data with video footage, the kick off time stamp was identified through video analysis, and then manually matched with a visible velocity change (team collective movement initiation) through GPS data (velocity graph) (Buchheit et al., 2024). Transitions were categorised as followed: positive transition (PT), negative transition (NT), fast attack (FA), and high pressure (HP). Identification of these transitional actions by the analysis team was completed utilising the observational methodology REOFUT theoretical framework (Aranda et al., 2019). All analysts involved in the present study had previously completed training on the use of the REOFUT instrument and as part of the club's game analysis protocols implemented this as part of their daily work. The inter- and intra-observer reliability of these methods has been previously well described in literature, identifying a good to high intra-inter reliability (Aranda et al., 2019; Armatas et al., 2005; González-Rodenas et al., 2020; Tenga et al., 2010). Inter-observer and intra-observer analysis indicated adequate levels of reliability for the phases analysed in the study based on Cohen's Kappa calculations (PT: 0.819, 0.964; NT: 0.815, 0.818; FA: 0.959, 0.962; HP: 0.775, 0.896, for inter- and intra-observer reliability, respectively). High levels of objectivity are detailed for OT, DT and FA, and reduced objectivity for HP (Cobb et al., 2018; Landis et al., 1977). Prior to the analysis of the ten games reliability and objectivity checks between the two analysts were completed. Both analysts were asked to utilise the REOFUT methodology to analyse two 11 v 11 training matches which were separated by 7 days, with each game consisting of two 30-minute halves. For each of the observed transition periods within the two 11v11 games an agreement of >85% was noted between the two analysts. Any agreement above 80-85% would be deemed as acceptable inter-rater reliability (Robinson et al., 2024). Definitions of PT, NT, FA and HP are provided in Table 2 and 3 on the following pages and Appendix 10.

Table 2. Descriptions and definitions of transitions including PT = Positive transition; NT = Negative transition; FA = Fast attack and HP = High Pressure activities.

Tactical phase	Definition
Positive Transition (PT)	A counter-attack (defence-to-attack) or offensive transition (OT) (González-Rodenas et al., 2020): a) the possession starts by winning the ball in play, b) the progression towards the goal attempts to utilise the degree of imbalance right from start to the end with high tempo (Tenga et al., 2010), c) the circulation of the ball takes place more in depth than in width and the intention of the team is to exploit the space left by the opponent when they were attacking; the number of short and penetrative passes is reduced, d) the opposing team does not have the opportunity to minimise surprise, reorganise their system and be prepared defensively.
Negative Transition (NT)	A reversed counter-attack (transition from attack-to-defence) or defensive transition (DT) that describes defensive actions of the team against an opposition counter-attack defined above (González-Rodenas et al., 2020).
Fast Attack (FA)	Fast attack has the following characteristics: a) started by winning the ball in play or restarting the game (González-Rodenas et al., 2020), b) the progression towards the goal had a high number of penetrative and short passes, c) the circulation of the ball during fast attacks took place in width and depth, (in contrast to counter-attacks), but the intention of the team was still to disorder the opponent with a reduced number of passes and high tempo (Sarmento et al., 2013; González-Rodenas et al., 2021), d) contrary to the counter-attack, the opposing team had the opportunity to minimise surprise, reorganise his system and be prepared defensively.
High Pressure (HP)	A high-risk, high-reward strategy that has the following characteristics: a) occurs when one or several offensive (attacking) players press the opposing team aggressively close to their penalty area (attacking third) to regain the ball, cut off passing lanes, or block off spaces, b) involves an “individual-level” tactical behaviour when the closest player puts pressure on the ball carrier (offensive player), which is followed by remaining players (mid-block and low-block) that either directly apply pressure or adjust their position by marking the opponent and pushing up to prevent counter-attacks (sub-group or team-level) (Low et al., 2020), c) follows a change in possession representing “counter-pressing” (attack-to-defence transition), d) occurs in open play aiming to win ball possession aggressively (transition), force opposition into making mistakes, create turnovers and goalscoring opportunities (Armatas et al., 2005; Nigel, 2023).

Table 3. End time of transitions including PT = Positive transition; NT = Negative transition; FA = Fast attack and HP = High Pressure activities.

Tactical phase	End time
Positive Transition (PT) **Fast Attack (FA)**	Offensive transitions (PT and FA) ended when the following occurred: a) loss of ball possession (ball of out play and/or cleared by opposition), b) shot on goal, c) decreased tempo of attack due to an effective defence by opposition (goalkeeper catch/save, interception, clearance, header, tackle and block) (Fernandez-Navarro et al., 2019).
Negative Transition (NT)	NT ended if the following events took place: a) possession re-gained, b) ball out of play, c) shot on goal, d) decreased tempo of attack due to an effective defence by opposition (goalkeeper catch/save, interception, clearance, header, tackle and block) (Fernandez-Navarro et al., 2019).
High Pressure (HP)	HP activities terminated when: a) possession regained, b) ball kicked forward by team in possession, c) ball out of play.

Data from the Catapult vision software was then downloaded and integrated into the manufacturer's software package (*Openfield*, version 3.2.0) and finally exported into Microsoft Excel (Microsoft Corporation, USA) to calculate relative distances in selected categories for each transitional play. In addition to obtaining the mean average and peak average of each given metric per minute during TA's. The transition mean average for selected metrics was calculated as the sum total of all TA's, divided by their number. To obtain the transition peak average value for each metric, the highest values in 10 games were identified, and their average was calculated as the sum of all peak values during transitions, divided by their number.

3.4.3 Statistical analysis

A descriptive analysis was performed, and the results are presented as mean ± standard deviation (SD). Between-matches coefficient of variation (CV) values were calculated for transitions and the whole match (90-min) demands for total distance ($m \cdot min^{-1}$), high-speed running distance ($m \cdot min^{-1}$), sprint distance ($m \cdot min^{-1}$), and number of accelerations/decelerations ($n \cdot min^{-1}$). Statistical analyses were conducted using IBM Statistical Package for the Social Sciences (SPSS, Version 27.0, IBM Corporations, New York, USA) with the statistical significance accepted at the 0.05 level. A univariate analysis of variance (ANOVA) was conducted to quantify main effects for games and transitions. Interaction effects were quantified, and any significant main effects associated with games and transitions were explored using post hoc pairwise comparisons. The assumptions associated with the statistical model were assessed to ensure model adequacy. To assess residual normality for each dependent variable, q-q plots were generated using stacked standardised residuals. Scatterplots of the stacked unstandardised and standardised residuals were utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity was completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. Partial eta squared (η^2) were calculated to estimate effect sizes for all significant main effects and interactions. As previously recommended by Cohen (1988), partial eta squared was classified as small (0.01–0.059), moderate (0.06–0.137), and large (> 0.138).

3.5 Results

Table 4 highlights the mean number of transitions that occur per game, accompanied with the standard error, min, max and confidence interval (CI). The frequency of each transition across the games analysed is displayed in Table 5. Within Table 5 detailed is the percentage that each transition accounts for, the mean and standard deviation of each transition type and the peak duration of each transition across all games analysed.

Table 4. Mean ± SD, minimum and maximum count of transitions PT = Positive transition; NT = Negative transition; FA = Fast attack; HP = High pressure for each game at 95% confidence interval of difference (CI).

TRANSITIONS	
Mean ± SD	**50 (11.1)**
Standard Error	**3.52**
Minimum	**32**
Maximum	**68**
CI	**7.97**

Table 5. Frequency of transitions PT = Positive transition; NT = Negative transition; FA = Fast attack; HP = High pressure depicted as a count and percent, and duration of transitions expressed as a mean ± SD and peak value across 10 official matches.

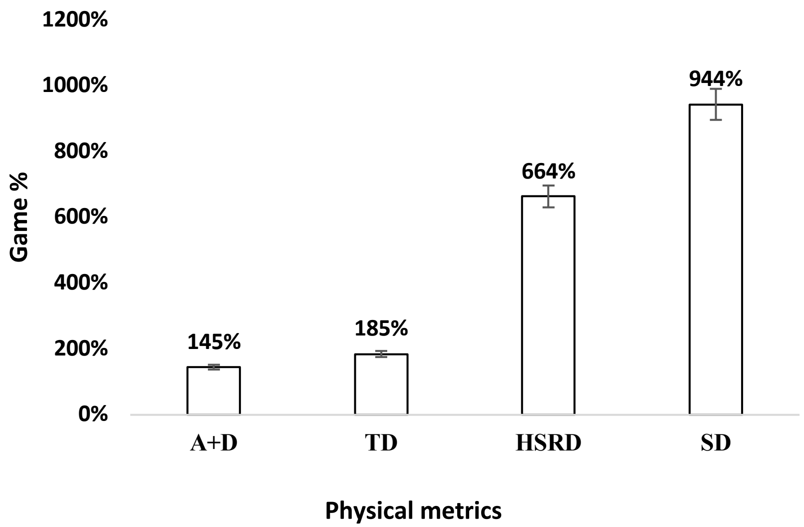
Frequency			**Duration (s)**	
Transition	**Count**	**Percent (%)**	**Mean (s)**	**Peak (s)**
PT	137	27.6	10.9 ± 3.9^{bcd}	24
NT	152	30.7	9.3 ± 3.4^{a}	23
FA	130	26.2	10.0 ± 3.1^{ad}	22
HP	77	15.5	9.8 ± 3.7^{ac}	27

Displayed in Table 6 is the mean, standard deviations and CI for total distance: TD ($m \cdot min^{-1}$), high speed running distance: HSRD ($m \cdot min^{-1}$), sprint distance: SD ($m \cdot min^{-1}$), and number of accelerations/decelerations: A+D ($n \cdot min^{-1}$) for mean and peak transitions and 90-minute averages for each of the listed metrics. Figure 21 displays transitions as a percentage of the whole-match demands and details the match-to-match variability for transitions and 90 min game averages. Figure 22 represents total physical output during 4 transitions as percentage of the whole-match output and highlights sprint distance during transitions. Comparisons between all transitions in total distance: TD ($m \cdot min^{-1}$), high speed running distance: HSRD ($m \cdot min^{-1}$), sprint distance: SD ($m \cdot min^{-1}$), and number of accelerations/decelerations: A+D ($n \cdot min^{-1}$) can be seen in Figure 23.

Table 6. Team mean ± SD and 95% confidence intervals for total distance: TD ($m \cdot min^{-1}$), high-speed running distance: HSRD ($m \cdot min^{-1}$), sprint distance: SD ($m \cdot min^{-1}$), and number of accelerations/decelerations: A+D ($m \cdot min^{-1}$), across whole-match vs mean and peak transitions demands.

	TD		HSRD		SD		A+D	
	Mean ± SD	**95%CI**	**Mean ± SD**	**95%CI**	**Mean ± SD**	**95%CI**	**Mean ± SD**	**95%CI**
90-min	109.7 ± 3.7	107.1 – 112.3	7.7 ± 0.9	7.0 – 8.4	1.6 ± 0.5	1.2 – 2.0	0.76 ± 0.1	0.71 – 0.81
Transitions (mean)	203.0 ± 12.2	194.3 – 211.7	51.1 ± 9.1	44.6 – 57.6	15.1 ± 4.0	12.2 – 18.0	1.1 ± 0.2	1.0 – 1.2
Transitions (peak)	290.3 ± 30.8	241.2 – 339.4	164.7 ± 61.2	67.4 – 262.0	84.0 ± 41.8	17.5 – 150.5	4.7 ± 0.8	3.4 – 6.0

A)



B)

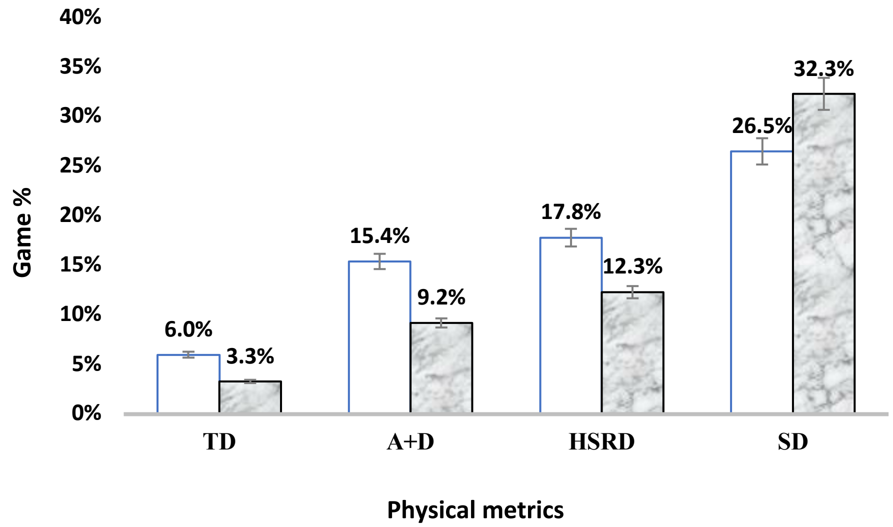


Figure 21. Transitions as percentage of the average-match demands (90-min) (A) and the match-to-match variability for both transitions (white) and 90 min (marble) (B) are shown for total distance: TD, high-speed running distance: HSRD, sprint distance: SD in m·min^{-1} and number of accelerations/decelerations: A+D in n·min^{-1}.

A) B)

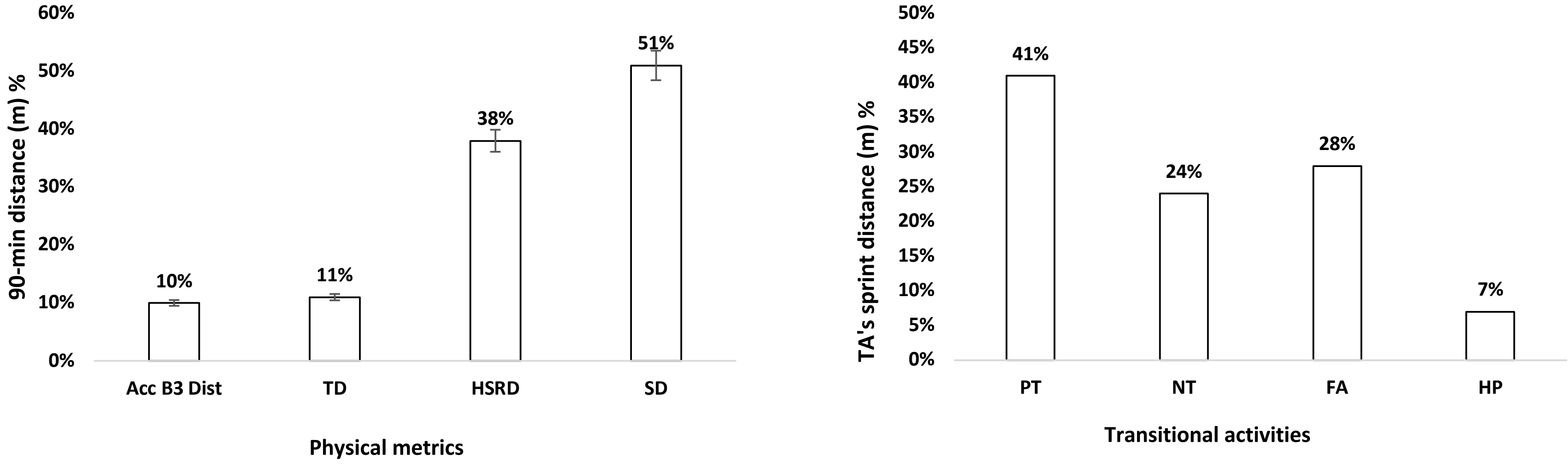


Figure 22. Total physical output during transitions as percentage of the whole-match output (90-min) (A) and sprint distance as percentage of the whole-transitions sprint distance (B) are shown for total distance (TD), high-speed running distance (HSRD), sprint distance (SD) and acceleration distance (Acc B3 dist).

Note: PT = Positive transition; NT = Negative transition; FA = Fast attack; HP = High pressure.

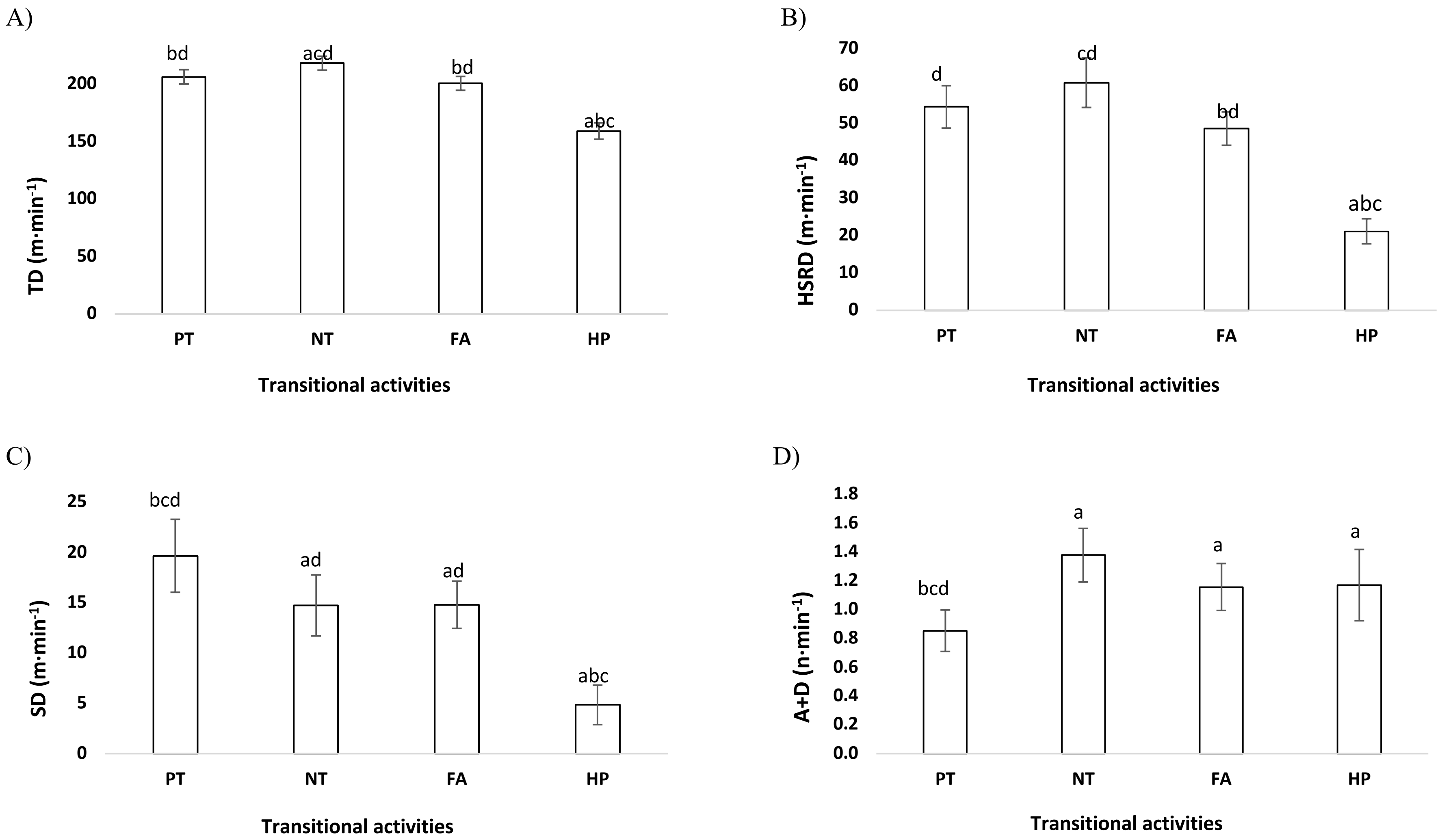


Figure 23. Comparisons between all transitions in a) mean total distance per minute (TD), b) mean high-speed running distance per minute (HSRD), c) mean sprint distance per minute (SD), and d) mean number of accelerations/decelerations per minute (A+D). **Significant difference ($p < 0.05$) compared to the PT (a), NT (b), FA (c), and HP (d).

Note: PT = Positive transition; NT = Negative transition; FA = Fast attack; HP = High pressure.

3.5.1 Duration

There was a main effect of transitions on duration, $F(3,456) = 9.997$, $p < 0.0005$, partial $\eta^2 = 0.062$. Negative transition (NT) duration displayed no difference in relation to fast attacks (FA) and high pressure (HP) ($p = .142$ and $p = .198$, respectively). Positive transitions (PT) duration was higher than all other transitions ($p \leq 0.05$).

3.5.2 Total distance (TD; m · min^{-1})

There was a main effect of transitions, $F(3,456) = 26.628$, $p < 0.005$, partial $\eta^2 = 0.149$ as well as games, $F(9,456) = 2.010$, $p = 0.037$, partial $\eta^2 = 0.038$ for total distance. Negative transitions (NT) had higher m · min^{-1} than PT, FA and HP ($p \leq 0.05$). High pressure (HP) showed lower distance than all transitions ($p \leq 0.05$). See Figure 23 (Panel A).

3.5.3 High-speed running distance (HSRD; m · min^{-1})

There was a main effect of transitions, $F(3,456) = 12.244$, $p < 0.005$, partial $\eta^2 = 0.075$ for high speed running distance. Post hoc analysis showed that high pressure (HP) revealed difference from all other transitions ($p \leq 0.05$). See Figure 23 (Panel B).

3.5.4 Sprint distance (SD; m · min^{-1})

There was a main effect of transitions, $F(3,456) = 5.488$, $p = 0.001$, partial $\eta^2 = 0.035$ for sprint distance. Multiple comparisons show that negative transitions (NT) were nearly equal to fast attacks (FA) ($p = 0.974$). Positive transitions (PT) showed difference from negative transitions (NT) and fast attacks (FA) ($p = 0.014$ and $p = 0.019$, respectively). Furthermore, PT were higher than high pressure (HP) ($p \leq 0.05$). High pressure (HP) was the lowest from all other transitions ($p \leq 0.05$). See Figure 23 (Panel C).

3.5.5 Accelerations and Decelerations (A+D; n · min^{-1})

There was an interaction between games and transitions for high-intensity accelerations and decelerations, $F(27,456) = 1.606$, $p = 0.029$, partial $\eta^2 = 0.087$. High pressures (HP) were nearly equal to fast attacks (FA) ($p = .927$). Positive transitions (PT) were lower than NT, FA and HP ($p \leq 0.05$). See Figure 23 (Panel D).

3.6 Discussion

The aim of this chapter was to determine the physical demand (total distance, high-speed running distance, sprint distance and high-intensity accelerations/decelerations) and frequency of transitional activities in games, comparing them to 90-minute match demands. Main findings revealed that transitions occurred on average 50 times across ten official games, with a range of 32 to 68. Negative transitions (NT) were most frequent, followed by positive transitions (PT), fast attacks (FA), and high pressure (HP) activities. It is suggested that transitional strategy of the team and opponent affect the number and type of transition seen in game play. Future research should consider tactical strategy of the team and opponent, which the present study failed to do. Positive transitions (PT) lasted significantly longer than other periods (around 11 seconds), while mean duration of transitions was around 10 seconds. Peak duration of all transitions lasted between 22–27 seconds. Findings consistent with previous work detailing that most transitions performed were shorter than 20 seconds (Gonzalez-Rodenas et al., 2020).

Negative transitions (NT) accumulated higher TD ($m \cdot min^{-1}$), while positive transitions (PT) generated highest SD ($m \cdot min^{-1}$). This has implications on performance, particularly when considering previous literature detailing the importance of this metric in creating chances and scoring goals (Faude et al., 2012; Tenga et al., 2010). Counter-attacks have been demonstrated to display high physical outputs often associated with high-velocity movements into space with the objective of getting to the opponents box to create goalscoring opportunities (Faude et al., 2012; Gonzalez-Rodenas et al., 2020; Hughes et al., 2019; Lago et al., 2010; Schulze et al., 2021). The context of these findings is important, and practitioners need to consider the volume of exposure to high-velocity activities such as sprinting, accelerations, decelerations and high-speed running within training. That said, the present work doesn’t consider high-velocity distances covered and average time between transition in games in relation to these transitional activities. Analysis of this would enhance training design. Findings showed that mean transition performance demonstrated around 16% match-to-match variability and transitions’ sprinting activities (SD; $m \cdot min^{-1}$) exhibited lower variability compared to the 90-min sprinting demands, findings consistent with literature (Gregson et al., 2010; Rampinini et al., 2007; Riboli et al., 2021b). Thus, demonstrating the complexity of training design for footballers, due to the unpredictability of game play.

High pressure (HP) activities generated lower physical output in all metrics, except for A+D ($n \cdot min^{-1}$). It has been shown that defensive activities require players to actively engage in regaining the possession of the ball, squeeze space and block forward passes, which demands high-intensity actions such as high-intensity accelerations and decelerations (Zhou et al., 2020). Often these actions are initiated by the opposing teams movement, so become reactive high velocity actions (accelerations and decelerations) to put pressure on the ball quickly. Pressing high in the offensive zone (opposition half) is essential as nearly half of all winning ball turnovers, across various European leagues, are shown to create goalscoring opportunities (Armatas et al., 2005; Hughes et al., 2019; Kubayi et al., 2020; Vogelbain et al., 2014). Coaches could apply football-specific drills that utilise high pressure to induce a higher number of accelerations and decelerations in training without accumulating higher distances in different velocity bands. These rapid changes of speed are crucial in elite football and efficient and quick ability to accelerate, decelerate, change of direction have been linked to success in field-sport teams (Delaney et al., 2015; Harper et al., 2019) and football match result (Rhodes et al., 2021).

A novel concept in the present study was to directly compare players physical output during transitions directly to the 90-min demands. To the authors knowledge, this is the first research thesis that investigates the mean and peak physical demands during TA's. Considering a shorter than usually investigated time epochs for the WCS analysis, comparisons to other studies could be difficult. Findings detailed that transitions exceeded the 90-min physical demands in all variables, especially in high-velocity activities (SD; m·min^{-1}) in both mean and peak transitions. High-velocity activities were 7–9-fold greater than the 90-min demands and nearly half of the game SD and HSRD occurred during TA's. Presenting practitioners with considerations of how these demands are replicated in training to best prepare their athletes.

Interestingly, offensive actions such as positive transitions (PT) and fast attacks (FA) mostly contributed to sprint distance accumulated during transitional periods (41% and 28%, respectively) and high pressure (HP) activities accumulated the lowest sprint distance equal to only 7%. Contextually, how players are prepared during training would depend on the tactical focus of the teams approach to games. Over 90 minutes, players cover TD of around 119 m·min^{-1}, HSRD of 7.5 m·min^{-1} and SD of 1.5 m·min^{-1} [(Rico-Gonzalez et al., 2022; Vazquez et al., 2023), which is consistent with these findings, especially regarding high-velocity metrics. Physical output during 1-min peak passages (WCS) has been shown to be higher during which elite players cover TD (m·min^{-1}) ranging from 167 to over 190, HSRD (m·min^{-1}) from 38.3 to 60, and SD (m·min^{-1}) around 10.6 (Casamichana et al., 2019; Fereday et al., 2020; Lacome et al., 2016; Martin-Garcia et al., 2018; Riboli et al., 2021b). In addition, a previous analysis of ball in play (BiP) short-lasting WCS window (30–60 s) showed that elite youth players cover a total distance of 200.9 (m·min^{-1}), high-speed running distance of 68.3 (m·min^{-1}) as well as perform 5 accelerations and 5.1 decelerations (n·min^{-1}) (Wass et al., 2020). These values are very similar to the current findings across all mean metrics, yet still lower compared to peak variables during this specific and short-lasting maximum outputs. Thus, contextualising high-intensity metrics that occur in relation to short-duration blocks through a 90-minute period is crucial for understanding training needs and best preparing athletes to minimise injury risk and increase performance (Gabbett 2016a; Malone et al., 2017b).

Well-defined short-lasting passages (transitions) might offer new multivariate insights on high-intensity periods in modern football and allow practitioners to understand their impact on performance. High-intensity periods (high-velocity) with a clear tactical objective (i.e. transition from defence to offence) should be replicated in training to ensure specificity. It has been demonstrated that maximum speed activities over longer distances have not been adequately used in football (Vazquez et al., 2023). In addition, tailoring training in a similar manner and utilising principles of overload within a weekly training block has been shown to induce desired physiological adaptations in football players (Ade et al., 2021; Mohr et al., 2016; Stolen et al., 2005).

Due to the peak demands displayed in the present chapter a key objective of training would be to reach maximum speed and generate higher sprint distances, practitioners could use offensive position-specific exercises as well as transitional games to do this. The main target during these games would be a very quick attack after the ball possession was recovered. The important condition, which should be applied, would be to create large spaces behind the defenders. Enabling the attacking team to exploit it and generate high-velocity movements with a tactical objective to enter the penalty area. Transitions could be effectively used to overload average match play intensity concurrently in different physical metrics. Practitioners could use isolated transitional drills (offensive and defensive) as well as conditioning transitional games (large-, medium-, and small-sided) in MD-4 and/or MD-3 sessions (midweek) to overload locomotor and mechanical demands and increase high-velocity stress on players (Martin-Garcia et al., 2018; Oliva-Lozano et al., 2021b; Vazquez et al., 2023). It has been shown that large-sided games (LSG10) were the most appropriate mode of football-specific training (midweek) to reach similar intensity in many physical metrics and even over-stimulate (125%) sprint demands in relation to the 5- and 10-min peak match demands. In contrast, small-sided games (SSG5 and SSG6) were found to over-stimulate (150%) high-intensity accelerations/decelerations, but under-stimulate locomotive variables such as distance, high speed running, and sprinting (Martin-Garcia et al., 2019). Therefore, well balanced transitions to replicate the high-intensity / high-velocity demands of competition during team, individual and/or end-stage rehabilitation sessions could better prepare athletes for the game demands, increase performance and reduce the risk of injury. Consideration should be given to recovery taken after and before match play for such high-intensity activities, which have been linked to muscle fatigue and higher injury risk (Ade et al., 2021; Maffulli et al., 2021; Rhodes et al., 2019). Further work in this area is required, however. Furthermore, it is equally important to acknowledge that these demands would change in relation to positional requirements and individual player physical capability, willingness to run, coach style, opposition level, and other contextual factors (Bradley et al., 2011; Carling et al., 2011; Castellano et al., 2011; Gregson et al., 2010; Lago et al., 2010).

The activity profile of elite football players within 90-min match play has been found to be highly dependent on the tactical role and playing position (Bradley et al., 2018b; Dalen et al., 2016). Similar to the 90-min demands, positional differences in physical output have been found among different positions during varied WCS periods (Martin-Garcia et al., 2018; Martin-Garcia et al., 2019; Oliva-Lozano et al., 2021a; Rico-Gonzalez et al., 2022; Riboli et al., 2021b). The present Chapter 3 did not analyse positional differences in physical demands across different TA's. Future work should consider these positional differences. Research analysing the impact of contextual variables (match location, match half, and match outcome) on WCS within a football match is scarce (Fereday et al., 2020; Oliva-Lozano et al., 2021a; Riboli et al., 2021b). Contextual factors such as changes on the tactical and technical requirements of the match play most likely determine the physical output experienced by players during the most intense passages in modern football, especially for near maximum velocity activities (Gregson et al., 2010).

3.6.1 Limitations

It is important to note the present study was completed with one club over ten games (small sample), therefore future research should consider a larger sample across a number of teams across the league in a season, investigate physical differences between positions, identify impact of substitutes on transitions, compare training to match play transitional demands, and include additional contextual factors, such as formation, to enable individualisation. This would allow conclusions to be drawn in relation to game demands in modern day football. It is important to note that a potentially subjective view of the analyst regarding identification of transitional phases and high-pressure actions, is a limitation of this study. Moreover, the observational methodology REFOUT also presents the limitations and future research should identify better analytical tools to accurately capture tactical periods in competition. This body of work analysed only absolute metrics, and it is noteworthy to emphasise the importance of monitoring players relative to their physical performance capacities. Absolute zones/metrics enable practitioners to compare players physical outputs, however do not show individual physical characteristics (Akenhead et al., 2016b; Harper et al., 2019). Particularly regarding high-velocity activities such as high-speed running and sprinting. Relative locomotor zones might be more appropriate to analyse players' true workload during the most demanding passages of match play (Carling et al., 2016). Hence, future work should consider analysing transitional play using individual velocity and accelerations thresholds.

3.7 Conclusions

Understanding of the frequency, duration and type of transition that generates the highest physical absolute outputs is important to practitioners. Present literature describes and highlights the use of 90-min average data to inform how to best prepare athletes for modern game play within training. Yet, the present chapter demonstrates that these metrics are largely increased when contextualised into transitional play, representing the maximum physical exposure that these athletes experience in games. Consideration of these maximal outputs informs practitioners of the physical demands footballers will face within given time frames during offensive and/or defensive activities. This knowledge should be utilised when implementing high-velocity / high-intensity exposures within a weekly microcycle to best prepare players for these high-intensity periods in match play. Caution should be taken as these findings are representative of one team within the Polish top league and therefore transferability may be tempered by the use of elite football players in ecologically valid conditions.

3.8 Practical implications

- Transitions exceed 90-min physical demands in all metrics and expose players to maximum physical outputs.
- Coaches should develop training strategies that replicate these demands by placing conditions in training drills, manipulating pitch size and selecting appropriate number of players in order to best prepare athletes for competition, increase players performance and reduce injury risk.
- Since playing position/formation (e.g., 4-4-2, 4-3-3, 3-5-2) /playing style would most likely generate different physical metrics during TA's, coaches and practitioners are encouraged to assess these differences to design and deliver optimal training programmes for all players according to their tactical roles and individual abilities.
- Offensive actions (counter-attacks and fast attacks) expose players to maximum velocity activities (sprint distance) and could be used in the midweek overload block for conditioning purposes.
- High pressure activities increase mechanical load on players and might be used to increase accelerations and decelerations demands in team raining, top-up sessions and end-stage rehabilitation programmes.

3.9 Chapter Summary & Link to Chapter 4

The current Chapter 3 analysed physical metrics and described frequency, type, duration of short and specific high-intensity passages in an elite football team. It was found that team running performance was increased when contextualised into transitional play and high-pressure activities. The findings raised another question whether physical performance would differ between various playing positions during these phases. Therefore, the next chapter will explore absolute and relative physical match demands across different playing positions and investigate these differences in relation to four previously used tactical phases (offensive and defensive transition, fast attack, and high-pressure). This knowledge regarding the physical output of each playing position in Chapter 4 would enable coaches and practitioners to design and prescribe more accurate training sessions considering specific needs in attack and/or defence to improve performance and better prepare players for their technical-tactical tasks during the key phases of football game.

Chapter 4: Physical Demands Across Different Playing Positions During Transitional Play and High-pressure Activities in Elite Football

This chapter comprises the following manuscript published in Biology of Sport:

Bortnik, L., Bruce-Low, S., Burger, J., Alexander, J., Harper, D., Morgans, R., Carling, C., McDaid, K., & Rhodes, D. (2024). Physical match demands across different playing positions during transitional play and high-pressure activities in elite soccer. *Biology of Sport*, 41(2), 73-82. https://doi.org/10.5114/biolsport.2024.131815. A synthesis of this study is demonstrated in Table 19**.**

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Physical match demands across different playing positions during transitional play and high-pressure activities in elite soccer

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ABSTRACT: This study explored physical match demands across different playing positions during transitional play, to inform the need for position-specific training interventions. Data was collected using 10 Hz GPS units from 10 competitive matches including 23 elite soccer players of the 1st Polish Division (Ekstraklasa) in season 2020–21. A total of 4249 positional observations were made; center backs ($n = 884$), full backs ($n = 972$), central defensive midfielders ($n = 236$), central attacking midfielders ($n = 270$), central midfielders ($n = 578$), wingers ($n = 778$), and attackers ($n = 531$). Match data reflected distances covered per minute ($m \cdot min^{-1}$): total distance (TD), high-speed running distance (HSRD, $> 19.8\ km \cdot h^{-1}$), sprint distance (SD, $> 25.2\ km \cdot h^{-1}$), and the frequency of high-intensity accelerations and decelerations (A+D, $> 3\ m \cdot s^{-2}$; $n \cdot min^{-1}$). Total absolute sprint distance (SD, $> 25.2\ km \cdot h^{-1}$) and total relative sprint distance (Rel B5) were also quantified. A univariate analysis of variance revealed position-specific differences. Significant effects of position were found for all analysed metrics during transitional play (large ESs; $p < .001$). Central attacking midfielders displayed higher TD ($m \cdot min^{-1}$), fullbacks covered highest SD ($m \cdot min^{-1}$) and wingers achieved the highest A+D ($n \cdot min^{-1}$) ($p \leq 0.05$). Centre backs displayed the lowest physical outputs when compared to all other positions, except in A+D ($n \cdot min^{-1}$) during defensive transitions ($p \leq 0.05$). Attackers displayed the highest physical metrics during high pressure activities ($p \leq 0.05$). Coaches should carefully consider positional transitional demands to better inform training design. With specific attention paid to drills that replicate game play.

Key words:
Soccer
Transitions
High pressure
Peak demands
Worst-case-scenario
Positions

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4.1 Chapter Overview

Despite a high tactical value and significance of transitional play and high-pressure activities in a modern football strategic approach, there are no previous studies that attempt to provide physical and technical-tactical insights about these crucial periods nor deliver detailed information about positional differences (Nassis et a., 2020; Wass et al., 2020). Current literature describes the effect of different playing styles including counter-attacks on physical, technical, and success-related metrics, merely depicting 90-min totals and fails to contextualise these variables into transitions (Forcher et al., 2023). Moreover, there are no studies to the authors knowledge that distinguish physical output differences between offensive and defensive transitional actions nor identify their frequency and density, pattern of occurrence, duration and recovery period. Not to mention, comparing training to official matches and analysing the effect of various contextual factors on physical performance during transitional activities referred to as the maximum-intensity periods in elite football. Therefore, the main objective of the present body of work and represented in Chapter 4 is to capture physical performance during crucial moments of modern football game, whereupon coaches and practitioners could gain more insights about decisive transitional phases, high-pressure activities, and short maximum-intensity periods relative to the positional demands (Lago-Penas et al., 2018; Maneiro et al., 2019). It is hoped that measuring high-intensity actions during critical offensive and defensive activities commonly used by elite teams to win games, would significantly add to the existing body of knowledge, and most importantly, effectively transfer new evidence to practical applied settings (Aranda et al., 2019; Forcher et al., 2023). It is worth noting that these short and highly contextual periods could easily be applied and replicated in training, possibly giving practitioners powerful ammunition to holistically prepare footballers for the most demanding passages in modern match play (Martin-Garcia et al., 2018; Oliva-Lozano et al., 2021b; Rochael et al., 2023a). The following text has been taken directly from the manuscript published in Biology of Sport (Bortnik et al., 2024).

4.2 Abstract

This study explored physical match demands across different playing positions during transitional play, to inform the need for position-specific training interventions. Data was collected using 10 Hz GPS units from 10 competitive matches including 23 elite football players of the 1st Polish Division (Ekstraklasa) in season 2020-21. A total of 4249 positional observations were made; center backs (n = 884), full backs (n = 972), central defensive midfielders (n = 236), central attacking midfielders (n = 270), central midfielders (n = 578), wingers (n = 778), and attackers (n = 531). Match data reflected distances covered per minute ($m \cdot min^{-1}$): total distance (TD), high-speed running distance (HSRD, > 19.8 $km \cdot h^{-1}$), sprint distance (SD, > 25.2 $km \cdot h^{-1}$), and the frequency of high-intensity accelerations and decelerations (A+D, > 3 $m \cdot s^{-2}$; $n \cdot min^{-1}$). Total absolute sprint distance (SD, > 25.2 $km \cdot h^{-1}$) and total relative sprint distance (Rel B5) were also quantified. A univariate analysis of variance revealed position-specific differences. Significant effects of position were found for all analysed metrics during transitional play (large ESs; $p < .001$). Central attacking midfielders displayed higher TD ($m \cdot min^{-1}$), full backs covered highest SD ($m \cdot min^{-1}$) and wingers achieved the highest A+D ($n \cdot min^{-1}$) ($p \leq 0.05$). Center backs displayed the lowest physical outputs when compared to all other positions, except in A+D ($n \cdot min^{-1}$) during defensive transitions ($p \leq 0.05$). Attackers displayed the highest physical metrics during high-pressure activities ($p \leq 0.05$). Coaches should carefully consider positional transitional demands to better inform training design. With specific attention paid to drills that replicate game play.

4.2 Introduction

Football match play is characterised by short linear high-velocity actions and multidirectional accelerations and decelerations, mixed with lower intensity recovery breaks of longer duration (Barnes et al., 2014). With the most decisive and crucial moments involving explosive actions (high-speed running and sprinting) combined with varied technical skills (Barnes et al., 2014; Harper et al., 2019; Stølen et al., 2005). Thus, emphasising the need to carefully consider the inclusion of physical, technical, and tactical demands within modern training design, optimally preparing players for high-intensity passages experienced within game play (Pollard et al., 2018). Modern microtechnology such as Global Positioning Systems (GPS) has become commonplace in professional football allowing quantification of team and individual external loads. GPS has been shown to be a valid and reliable method of quantifying team and positional demands, albeit commonly utilised to display maximum and average outputs over the duration of a session or game (Scott et al., 2016). This approach fails to quantify the isolated physical demands experienced by players during transitional play, where short bouts of high-intensity actions are performed (Novak et al., 2021).

Although average session data provides valuable information about the volume of the activity, it does not represent fluctuations in physical, technical, and tactical intensity. Thus, potentially underestimating the most demanding periods within a modern game and importantly providing no accurate differentiation of these high-intensity passages in relation to individual positional demands (Lacome et al., 2016). Literature details that distances covered at varied intensities would differ between positional groups (Barnes et al., 2014). Many studies have reported that midfield players cover the most total distance, whilst wide players (full backs, wingers) and forwards complete more high-intensity running (Di Salvo et al., 2009; Di Salvo et al., 2012). Research surrounding peak intensity passages, with specific reference to technical and tactical activities, is limited in elite football (Carling et al., 2019; Ju et al., 2022a; Riboli et al., 2021a). Understanding positional differences during crucial high-intensity transitional periods, would provide definitive insight of how to best prepare the players for game demands. Allowing practitioners to contextualise the physical outputs required in specific drills, ensuring the physical demand complements the tactical requirements placed on players by the coaches (Bortnik et al., 2022; Martín-García et al., 2018; Wass et al., 2020).

Offensive (defence-to-attack) and defensive (attack-to-defence) transitions represent key moments of play in football, that directly influence match outcome (Carling et al., 2019; Lago-Peñas et al., 2018). During these critical phases of match play goalscoring opportunities are created, with teams taking risks to capitalise quickly on the opposition conceding possession (Lago-Peñas et al., 2018). The main objective of offensive transitional activities (counter-attack and fast attack) is to achieve numerical superiority in the opponent's half by performing high speed actions. Contrastingly, the defensive transition is characterised by reshaping an imbalanced defence to effectively slow down the opposition attack (Tenga et al., 2010). It is noteworthy that elite football teams attack at a very high tempo that lasts below 20 seconds (Bortnik et al., 2022; González-Rodenas et al., 2020). Counter-attacks have been shown to be the most productive playing style for scoring goals (Lago-Ballesteros et al., 2012) often influenced by a number of contextual factors (Fernandez-Navarro et al., 2019). High-pressure activities were identified as an effective strategy to score goals and create more goalscoring opportunities (Tenga et al., 2010). These actions have been associated with high fitness levels and high physical demands (Wright et al., 2011). TA's have been well described in the literature and directly connected with technical and tactical activities occurring concurrently with other physically stressful moments (Tenga et al., 2010). Moreover, TA's have a deep context within since it encompasses moments when the ball is in and out of possession (offense and defence, respectively) as well as describing periods of high tactical component such as offensive activities (counter-attack and fast attack) and defensive actions (attack-to-defence transition and high-pressure).

It is hypothesised that physical outputs would differ across playing positions during transitions. Moreover, it is suggested that defensive players (center backs, full backs, and central defensive midfielders) would therefore be exposed to higher physical stress during defensive phases, with offensive players (wingers, central attacking midfielders, and attackers) within attacking moments of game play. Wide players (full backs and wingers) would accumulate greater high-velocity distances during transitional activities. Consequently, the aims of Chapter 4 were, 1) investigate physical match demands across different playing positions during transitional play in elite football; and 2) identify positional differences in different relative and absolute physical metrics (total distance, high-speed distance, sprint distance, and accelerations/decelerations) during specific short-duration actions such as offensive transitions (counter-attacks), defensive transitions, fast attacks and high-pressure activities.

4.3 Materials and Methods

4.3.1 Participants

Twenty three male elite football players participated in this investigation. Players belonged to a leading team of the 1st Polish Division (Ekstraklasa) in season 2020-21 and they were classified according to playing position with the following number per position present: center backs (*n* = 4), full backs (*n* = 5), central defensive midfielders (*n* = 2), central attacking midfielders (*n* = 2), central midfielders (*n* = 2), wingers (*n* = 5), and attackers (*n* = 3). Anthropometric data in not shared here as this was irrelevant to the purpose of the study inquiry. Only players who completed at least 60 minutes were included in this investigation, due to pacing strategies utilised by substitutes potentially generating higher outputs than starting players (Lacome et al., 2016; Wass et al., 2020). Players received all information about the project protocol and provided informed consent for the use of match data, in accordance with the Helsinki Declaration (2013). To ensure player confidentiality, all data was anonymised prior to analysis. Ethical approval was provided by the University of Central Lancashire (HEALTH 0104) (Appendix 8).

4.3.2 Procedures & Experimental Design

Data from a total of ten official games including one UEFA CL qualifier and nine Polish domestic league (Ekstraklasa) games (6 wins, 1 draw, and 3 losses) were collected and analysed in the 2020-2021 season. The CL qualifier was included due the opposing team competing at a comparable level, in terms of budget and league position, within another eastern European country. A low number of analysed matches were observed due to a manager change, could have skewed the results due to tactical differences. A total of 4249 individual observations were extracted including 1164 offensive transitions, 1269 defensive transitions, 1120 fast attacks, and 696 high pressure activities. The following number of observations per position were recorded: center backs (*n* = 884), full backs (*n* = 972), central defensive midfielders (*n* = 236), central attacking midfielders (*n* = 270), central midfielders (*n* = 578), wingers (*n* = 778), and attackers (*n* = 531) (Appendix 9).

The activity profile of players was captured by MEMS (10 Hz; Vector S7, Catapult Sports, Melbourne, Australia). The GPS model used in this study was worn in each game between the scapulae and contained within the playing jersey inside a mini pocket and thus not affecting mobility of the upper limbs. The players wore these devices in training and games and thus, were familiar with the entire procedure. To get an optimal connection to the satellites, the devices were turned on 15 mins before the start of the game. In accordance with previous guidelines for acceptable GPS coverage, each data was screened for satellite coverage and horizontal dilution of precision (HDOP) using an inclusion criterion of > 6 satellites and ≤ 1.0 respectively (Malone et al., 2017a). To avoid the inter-unit variations, each player used the same device in matches. The accuracy of this technology has been previously presented in detail (Johnston et al., 2014; Scott et al., 2016).

All variables selected for this study have been previously utilised within research (Pollard et al., 2018; Riboli et al., 2021b; Wass et al., 2020). Displaying ICC values between 0.77 (95% CI: 0.62-0.89) (very large) to 1.0 (95% CI: 0.99-1.0) (nearly perfect) for the measurement of distances at different velocity bands, indicating excellent intra-unit reliability (Johnston et al., 2014; Scott et al., 2016). For mechanical load, acceptable reliability was found for accelerations (CV = 1.4 ± 1.5% to 4.2 ± 1.5%), and acceptable to poor reliability for decelerations (CV = 2.5 ± 1.5% to 10.9 ± 1.5%) (Johnston et al., 2014; Scott et al., 2016). These variables reflected absolute distances covered per minute ($m \cdot min^{-1}$) in the following categories: total distance (TD), high-speed running distance (HSRD, > 19.8 $km \cdot h^{-1}$), sprint distance (SD, > 25.2 $km \cdot h^{-1}$), as well as the number of high-intensity accelerations and decelerations (A+D, > 3 $m \cdot s^{-2}$; $n \cdot min^{-1}$). Furthermore, the variables reflected total absolute sprint distance (SD, > 25.2 $km \cdot h^{-1}$) and total relative sprint distance (Rel B5), which was proposed previously by other authors to represent the functional limits of endurance and sprint locomotor capacities (Mendez-Villanueva et al., 2012). Relative sprint distance (Rel B5) was set above maximum aerobic speed (MAS) and plus 30% for anaerobic speed reserve (ASR) (Mendez-Villanueva et al., 2012). An incremental running treadmill test was conducted by the club physiologist to measure VO_2max and MAS. The test was performed in the gym environment with a normal ambient temperature and took place on a mechanical treadmill (Technogym, Italy). It began with an initial speed of 10 km/h^{-1} and each stage was increases by 1.5 km/h^{-1}. Five stages were set. Each stage lasted 4 minutes and it was separated by 1 minute passive break (Manzi et al., 2022). The inclination was set at 1.5%. Polar heart rate monitors (Polar, Norway) and Polar M400 were used to record HR data. Expired gases were analysed breath-by-breath using an online automated gas analysis system (MetaLyzer® 3b-R2; Cortex Biophysik Gmbh, Leipzig, Germany) and accompanying software (MetaSoft® 3). Maximum oxygen uptake (VO_2max) was defined as the highest 15-s average oxygen uptake (Bortnik et al. 2023a). Velocity ($km \cdot h^{-1}$), during the maximum oxygen uptake (VO_2max) was recorded and set as the maximum aerobic speed (MAS).

TA's were identified and manually created by the club's analysis team in the Catapult Vision video analysis system (Catapult Sports Ltd, Melbourne, Australia) after each match was completed. Phases of play were classified into the following categories: offensive transition (counter-attack) (OT), defensive transition (opposition's counter-attack) (DT), fast attack (FA), and high pressure (HP), which were previously defined in Chapter 3 (Table 2 and 3) and analysed by others (Tenga et al., 2010). Offensive transitions and fast attacks ended when the following occurred: a) loss of ball possession (ball of out play and/or cleared by opposition), b) shot on goal, c) decreased tempo of attack due to an effective defence by opposition. Defensive transitions ended if the following events took place: a) possession re-gained, b) ball out of play, c) shot on goal, d) decreased tempo of attack due to an effective defence by opposition. High-pressure activities ended when: a) possession re-gained, b) ball kicked forward by team in possession, c) ball out of play (Table 3) (Appendix 10).

The theoretical framework of observational methodology called REndimiento Ofensivo en FUTbol (REOFUT; in English: offensive performance in football) was used to identify these actions by one member of the club's analysis team (Aranda et al., 2019; Collins et al., 2006) and checked by an independent analyst working for the club's software supplier. The analysis procedure using the REOFUT instrument involved in the current body of work was part of the club's analysis protocols implemented daily by the analysis team. Previous literature has demonstrated good to high intra- and inter-observer reliability of this analysis method (Aranda et al., 2019; Tenga et al., 2010). Inter-observer and intra-observer analysis indicated adequate levels of reliability for the phases analysed in the study based on Cohen's Kappa calculations (OT: 0.819, 0.964; DT: 0.815, 0.818; FA: 0.959, 0.962; HP: 0.775, 0.896, for inter- and intra-observer reliability, respectively). High levels of objectivity are detailed for OT, DT and FA, and reduced objectivity for HP (Cobb et al., 2018). Both analysts had 8 years plus experience of working as part of an analysis team within elite football. Prior to the analysis of the ten games reliability and objectivity checks between the two analysts were completed. Both analysts were asked to utilise the REOFUT methodology to analyse two 11 v 11 training matches which were separated by 7 days, with each game consisting of two 30-minute halves.

Data from the Catapult vision software was then downloaded and integrated into the manufacturer's software package (*Openfield*, version 3.2.0) and finally exported into Microsoft Excel (Microsoft Corporation, USA) to make additional calculations for each transitional play. The transition mean average for selected metrics was calculated as the sum of all TA's and divided by their number. For each of the observed transition periods within the two 11v11 games an agreement of >85% was noted between the two analysts.

4.3.3 Statistical Analysis

A descriptive analysis was used, and the results are shown as mean ± standard deviation (SD). Between-matches coefficient of variation (CV) values were computed for transitions for absolute and relative sprint distance (SD and Rel B5, respectively). Statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS, Version 27.0, IBM Corporations, New York, USA) with the statistical significance accepted at the 0.05 level. A univariate analysis of variance (ANOVA) was used to quantify main effects for games, transitions, and positions. Interaction effects were also calculated, and any significant main effects associated with games, transitions, and positions were examined using post hoc pairwise comparisons. The assumptions linked to the statistical model were examined to ensure model adequacy. To establish residual normality for each dependent variable, q-q plots were created using stacked standardised residuals. Scatterplots of the stacked unstandardised and standardised residuals were also used to examine the error of variance associated with the residuals. Mauchly's test of sphericity was applied for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. A *priori* power calculations were conducted using familiarisation trials and pilot data completed by participants matching the criteria described above. Across all isokinetic and stabilometery measures considered within the thesis, a sample size ≥ 14 players was required to evaluate the interactions associated with all independent variables (for statistical power > 0.8; $p < 0.05$). Partial eta squared (η^2) were computed to estimate effect sizes for all significant main effects and interactions. Partial eta squared was classified as small (0.01–0.059), moderate (0.06-0.137), and large (>0.138) as suggested previously (Cohen, 1998).

4.4 Results

Figure 24 depicts how players were assigned to their general and specialized playing position in accordance with their tactical roles and responsibilities (Aalberts & Van Van Haaren, 2019). Table 7 highlights the mean for selected physical variables for each playing position during transitions that occurred across all 10 analysed matches. Statistically significant interactions between game, transition and position were found for TD ($m \cdot min^{-1}$) and HSRD ($m \cdot min^{-1}$) (TD: $F(131,4010) = 1.506$, $p < .001$, partial $\eta^2 = .047$; HSRD: $F(131,4010) = 1.223$, $p = .045$, partial $\eta^2 = .038$). A significant interaction between transition and position were identified for SD ($m \cdot min^{-1}$), A+D ($n \cdot min^{-1}$), Absolute SD and Relative SD (Rel B5) (SD: $F(18,4010) = 6.385$, $p < .001$, partial $\eta^2 = .028$; A+D: $F(18,4010) = 9.227$, $p < .001$, partial $\eta^2 = .040$; Absolute SD: $F(18,4010) = 6.211$, $p < .001$, partial $\eta^2 = .027$; Relative SD (Rel B5) $F(18,4010) = 16.337$, $p < .001$, partial $\eta^2 = .068$). Removal of the CL game for analysis indicated negligible change to the observed interactions for game, transition and position (TD: $F(131,4010) = 1.514$, $p < .001$, partial $\eta^2 = .044$ and HSRD: $F(131,4010) = 1.293$, $p = .02$, partial $\eta^2 = .038$) and for transition and position (Rel B5) (SD: $F(18,4010) = 6.672$, $p < .001$, partial $\eta^2 = .031$; A+D: $F(18,4010) = 9.081$, $p < .001$, partial $\eta^2 = .041$; Absolute SD: $F(18,4010) = 6.826$, $p < .001$, partial $\eta^2 = .031$; Relative SD (Rel B5) $F(18,4010) = 16.907$, $p < .001$, partial $\eta^2 = .074$). There was a statistically significant main effect of transitions on duration ($F(3,456) = 9.997$, $p < .0005$, partial $\eta^2 = .062$). Offensive transitions (OT) duration was significantly higher than all other transitions ($p \leq 0.05$).

Post hoc tests for all ten games revealed that central attacking midfielders (CAM) had higher TD ($m \cdot min^{-1}$) compared to other positional groups ($p \leq 0.001$). Wingers (W), fullbacks (FB) and central attacking midfielders (CAM) ran higher HSRD ($m \cdot min^{-1}$) and relative sprint distance (Rel B5) from other positions ($p \leq 0.05$). Fullbacks (FB) covered highest SD ($m \cdot min^{-1}$) and Absolute SD ($p \leq 0.05$). Wingers (W) had the highest number of A+D ($n \cdot min^{-1}$) compared to other groups ($p \leq 0.05$). In contrast, center backs (CB) showed lower TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$), A+D ($n \cdot min^{-1}$), and Relative SD (Rel B5) compared to other positions ($p \leq 0.05$). Also, they had lower Absolute SD than fullbacks (FB), wingers (W), central midfielders (CM), and central attacking midfielders (CAM) ($p \leq 0.05$).

No statistical significance was found between central midfielders (CDM and CM) and wingers (W) for TD ($m \cdot min^{-1}$) ($p > 0.05$). Wingers (W), fullbacks (FB), central attacking midfielders (CAM), and attackers (A) detailed no significant difference positionally for HSRD ($m \cdot min^{-1}$) and relative SD (Rel B5) ($p > 0.05$), however for these metrics these positions were higher than all other positions ($p \leq 0.05$). No difference between wingers (W) and fullbacks (FB) for SD ($m \cdot min^{-1}$) and Absolute SD ($p > 0.05$). Center backs (CB) and central defensive midfielders (CDM) had lowest SD ($m \cdot min^{-1}$) ($p \leq 0.05$), A+D ($n \cdot min^{-1}$) and Absolute SD, a no statistically significant difference between them ($p > 0.05$). No statistically significant difference was found for Fullbacks (FB), wingers (W), and central attacking midfielders (CAM) for Relative SD (Rel B5) ($p > 0.05$).

Table 8 displays the mean absolute and relative sprint distance for each playing position during all analysed transitions accompanied by match-to-match variability for these physical metrics. Figure 25 displays differences in all playing positions for mean absolute and relative sprint distance across all transitions. Figure 26 depicts differences between all playing positions in mean distances covered per minute ($m \cdot min^{-1}$) for TD, HSRD, SD and mean number of accelerations/decelerations - A+D ($n \cdot min^{-1}$) across all transitional activities.

Analysis of positional effect identified that center backs (CB) had the lowest TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$), and A+D ($n \cdot min^{-1}$), a statistically significant difference from all other positions ($p \leq 0.05$) during offensive phases such as offensive transitions (OT) and fast attacks (FA). In contrast, they achieved highest A+D ($n \cdot min^{-1}$) during defensive transitions (DT), a statistically significant difference with offensive players such as attackers (A), wingers (W), and central attacking midfielders (CAM) ($p \leq 0.05$).

Detailed positional analysis also revealed that SD ($m \cdot min^{-1}$) was highest for fullbacks (FB) ($p \leq 0.05$) during defensive transitions (DT) and fast attacks (FA). Similarly, central midfielders (CM) had high SD ($m \cdot min^{-1}$), a statistically significant difference with attackers (A) and wingers (W) ($p \leq 0.05$) during defensive transitions (DT). Central attacking midfielders (CAM) revealed significantly higher TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$) from other groups ($p \leq 0.05$) during offensive transitions (OT) and fast attacks (FA).

Wingers (W) showed statistically higher TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$), SD ($m \cdot min^{-1}$), and A+D ($n \cdot min^{-1}$) ($p \leq 0.05$) during offensive transitions (OT). Also, this positional group revealed highest output in A+D ($n \cdot min^{-1}$) during fast attacks (FA), a statistically significant difference with other positions ($p \leq 0.05$). Attackers (A) had significantly lower TD ($m \cdot min^{-1}$) and HSRD ($m \cdot min^{-1}$) compared to all other positions ($p \leq 0.05$) during defensive transitions (DT). However, this positional group had highest TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$), and SD ($m \cdot min^{-1}$) from other positions ($p < .001$) and were statistically higher in A+D ($n \cdot min^{-1}$) from all defenders (CB, FB) ($p \leq 0.05$) during high pressure (HP). No other significant positional differences were identified for any other physical metrics ($p > 0.05$).

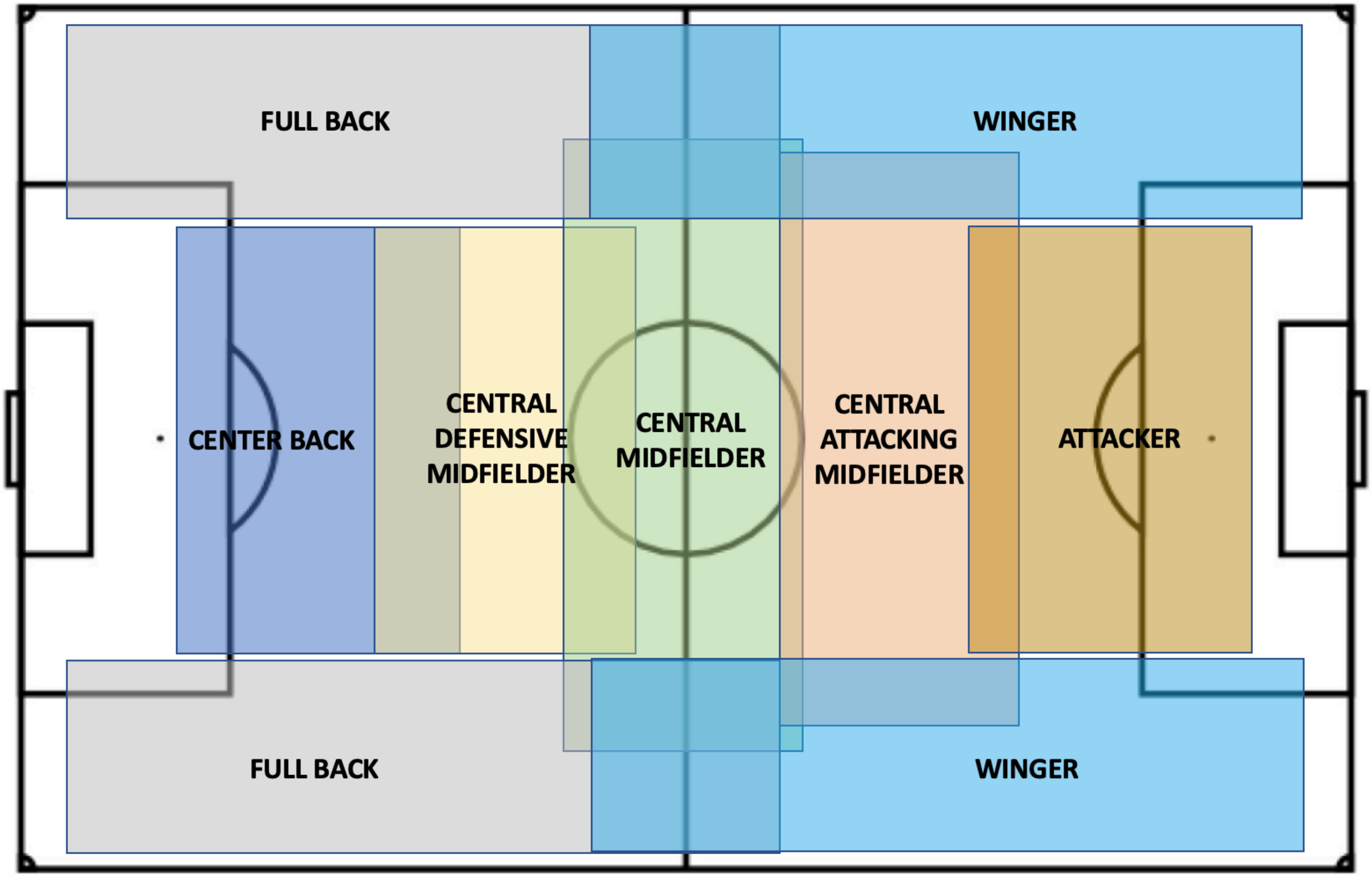

Figure 24. General and specialised tactical roles based on game analyses. Adapted from Aalberts & Van Haaren (2019).

Table 7. Mean ± SD for TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$), SD ($m \cdot min^{-1}$), A+D ($n \cdot min^{-1}$) for each playing position CB (Center Back), FB (Full Back), CDM (Central Defensive Midfielder), CM (Central Midfielder), CAM (Central Attacking Midfielder), W (Winger), and A (Attacker) during transitional activities across 10 official matches.

	All (n=4249)	CB (n=884)	FB (n=972)	CDM (n=236)	CM (n=578)	CAM (n=270)	W (n=778)	A (n=531)
TD	206.2 ± 19.0	166.8 ± 63.7 [b,c,d,e,f,g]	204.2 ± 81.4 [a,e]	214.9 ± 59.2 [a,e]	212.3 ± 66.6 [a,e]	234.4 ± 58.6 [a,b,c,d,f,g]	211.7 ± 72.6 [a,e]	203.6 ± 73.7 [a,e]
HSRD	50.1 ± 11.6	21.7 ± 57.1 [b,c,d,e,f,g]	61.2 ± 94.2 [a,c,d]	44.5 ± 70.4 [a,b,e,f]	45.6 ± 81.9 [a,b,e,f]	67.4 ± 87.2 [a,c,d]	63.4 ± 87.7 [a,c,d]	53.0 ± 77.3 [a]
SD	13.2 ± 7.0	5.0 ± 26.7 [b,d,f]	24.2 ± 62.2 [a,c,d,e,g]	5.5 ± 26.2 [b,f]	12.9 ± 42.8 [a,b]	13.5 ± 38.8 [b]	20.0 ± 54.1 [a,c,g]	10.9 ± 37.2 [b,f]
A+D	1.1 ± 0.3	0.7 ± 2.3 [b,d,f,g]	1.1 ± 2.9 [a,f]	0.9 ± 2.7 [f]	1.1 ± 3.0 [a,f]	1.1 ± 2.6 [f]	1.7 ± 3.5 [a,b,c,d,e]	1.3 ± 2.9 [a]

Table 8. Mean ± SD and match-to-match variability as CV (%) for absolute sprint distance (SD; m) and relative sprint distance (Rel B5; m) for each playing position CB (Center Back), FB (Full Back), CDM (Central Defensive Midfielder), CM (Central Midfielder), CAM (Central Attacking Midfielder), W (Winger), and A (Attacker) during transitional activities across 10 official matches.

	All (n=4249)	CB (n=884)	FB (n=972)	CDM (n=236)	CM (n=578)	CAM (n=270)	W (n=778)	A (n=531)	CV (%)
SD	2.2 ± 1.2	0.8 ± 4.1 [b,d,e,f]	4.0 ± 10.6 [a,c,d,e,g]	1.0 ± 4.7 [b,f]	2.1 ± 7.1 [a,b]	2.4 ± 6.8 [a,b]	3.3 ± 8.6 [a,c,f]	1.7 ± 5.6 [b,f]	53.8
Rel B5	6.1 ± 2.0	2.6 ± 8.1 [b,c,d,e,f,g]	7.2 ± 13.7 [a,d]	5.3 ± 9.8 [a,f]	5.1 ± 11.5 [a,b,e,f]	8.2 ± 13.3 [a,c,d,g]	8.2 ± 13.1 [a,c,d,g]	5.8 ± 10.2 [a,f]	32.7

Note: Significant differences [a] CB, [b] FB, [c] CDM, [d] CM, [e] CAM, [f] W, and [g] A ($p < 0.05$).

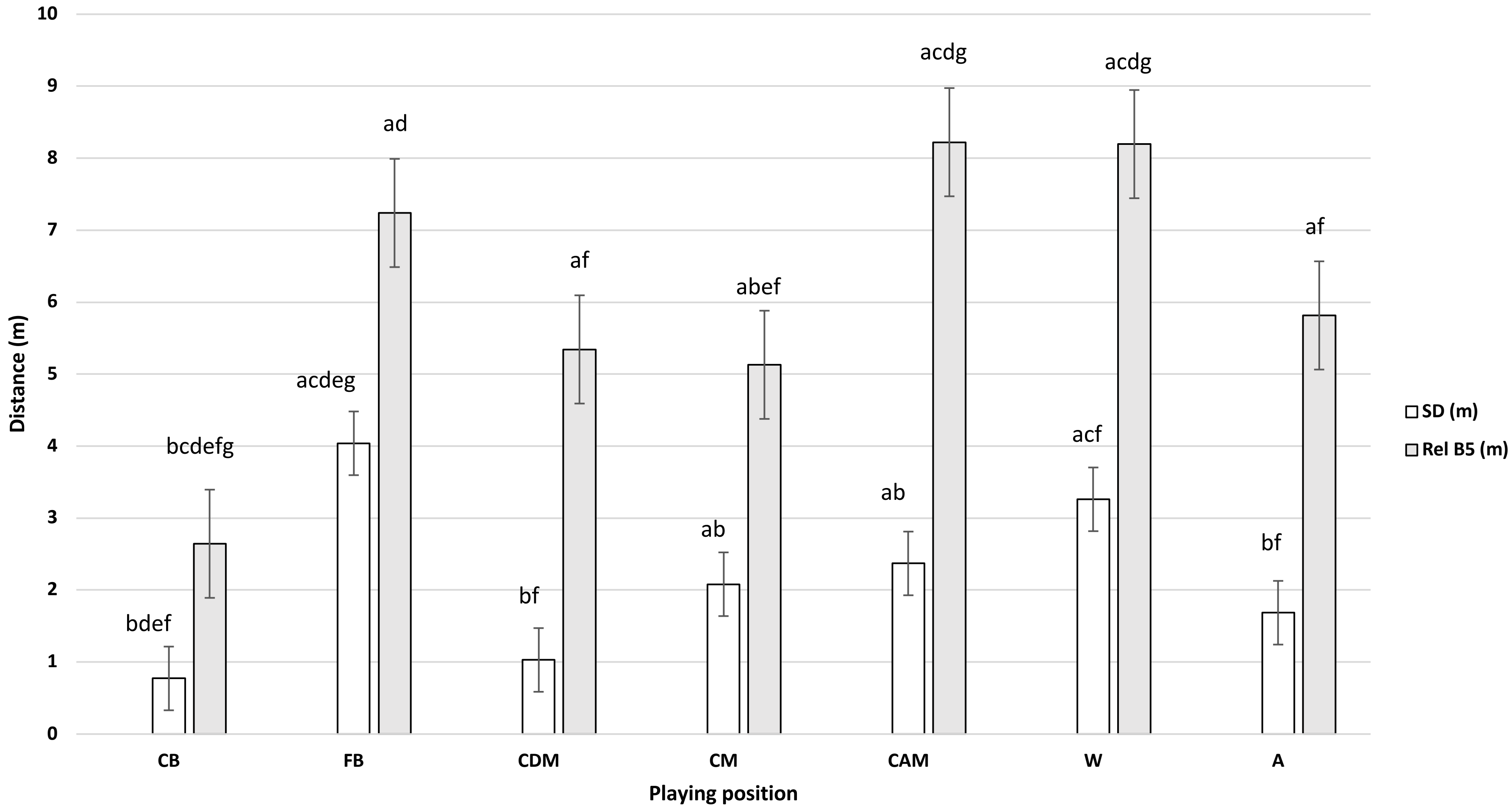

Figure 25. Comparisons between all playing positions CB (Center Back), FB (Full Back), CDM (Central Defensive Midfielder), CM (Central Midfielder), CAM (Central Attacking Midfielder), W (Winger), and A (Attacker) in mean absolute sprint distance – SD (m) (> 25.2 km·h^{-1}) and mean relative sprint distance - Rel B5 (m) (MAS + 30% ASR) during transitional activities (offensive transitions; defensive transitions; fast attacks; high pressures) across 10 official matches.***Significant differences [a] CB, [b] FB, [c] CDM, [d] CM, [e] CAM, [f] W, and [g] A ($p < 0.05$).***

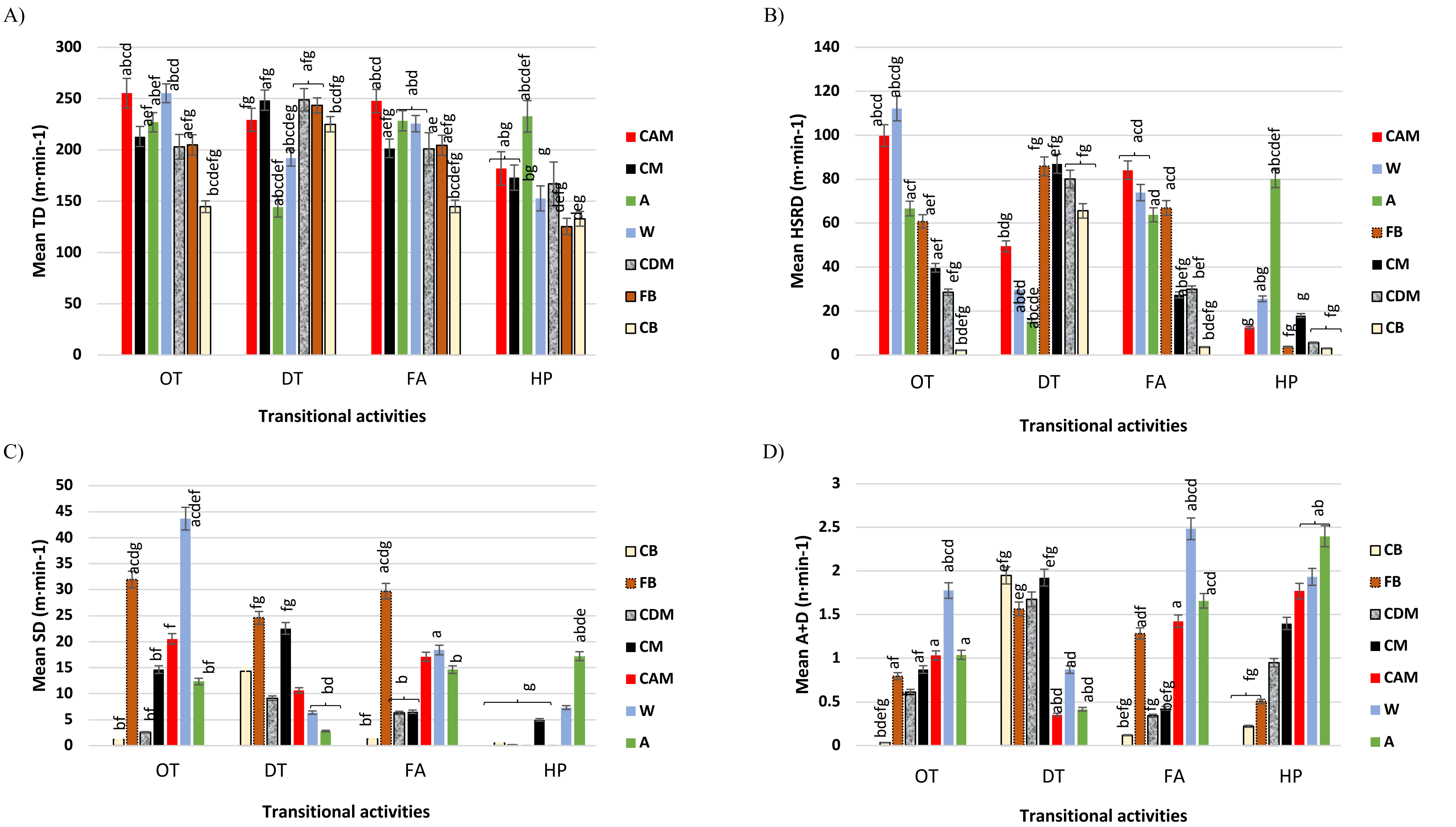

Figure 26. Comparisons between playing positions CB (Center Back), FB (Full Back), CDM (Central Defensive Midfielder), CM (Central Midfielder), CAM (Central Attacking Midfielder), W (Winger), and A (Attacker) in a) mean TD ($m \cdot min^{-1}$) b) mean HSRD (> 19.8 $km \cdot h^{-1}$; $m \cdot min^{-1}$), c) mean SD (> 25.2 $km \cdot h^{-1}$; $m \cdot min^{-1}$), and d) mean A+D (> 3 $m \cdot s^{-2}$; $n \cdot min^{-1}$) during different transitions: OT = Offensive transition; DT = Defensive transition; FA = Fast attack; HP = High pressure. **Significant differences [a] CB, [b] FB, [c] CDM, [d] CM, [e] CAM, [f] W, and [g] A ($p < 0.05$).

4.5 Discussion

The aims of the present Chapter 4 were to 1) investigate physical match demands across different playing positions during transitional play in elite football; and 2) identify positional differences in different relative and absolute physical metrics during offensive transitions (counter-attacks), defensive transitions, fast attacks and high-pressure activities. The main findings indicated that physical performance during transitions varied between different playing positions. The activity profile of elite football players within 90-min match play has been found to be highly dependent on the tactical role and playing position (Barnes et al., 2014; Bradley et al., 2018a; Clemente et al., 2020b). Previous research has identified midfielders covering the longest average distance followed by forwards and defenders (Di Salvo et al., 2009). Full backs, midfielders, and offensive midfielders were found to cover a greater high-speed distance, whilst central defenders and attackers did more high acceleration movements (Altavilla et al., 2017).

In the current body of work, center backs (CB) experienced the lowest absolute and relative physical demands. This finding is consistent with previous research investigating whole and peak match demands in elite football (Martín-García et al., 2018; Oliva-Lozano et al., 2021a). This positional group was found to be less active in offensive transitions (ball possession) but achieved highest number of accelerations and decelerations (A+D; $n \cdot min^{-1}$) during defensive transitions (DT) (out of possession). It is noteworthy to acknowledge that accelerations and decelerations are more physically demanding than speed-based activities (Akenhead et al., 2016b; Delaney et al., 2018a) and have been linked to match result in modern football (Rhodes et al., 2021). Therefore, it is considered that center back positions should be regularly exposed to adequate acceleration/deceleration stimuli in training to be optimally prepared for high mechanical demands during collective defensive actions in matches. It is revealed in previous research that this positional group's locomotor metrics were raised when a team was out of ball possession (Riboli et al., 2021b). In this body of work, center backs (CB) along with central defensive midfielders (CDM) had the lowest SD ($m \cdot min^{-1}$), absolute SD, and A+D ($n \cdot min^{-1}$). Interestingly, these two positional groups showed very similar patterns for high-intensity metrics such as HSRD ($m \cdot min^{-1}$), SD ($m \cdot min^{-1}$), and A+D ($n \cdot min^{-1}$) during all transitions, suggesting similarities within parts of their training content. Similar training modes could be applied to best prepare them for high physical demands during transitional play, especially when the ball possession is lost and a rapid transition from offense to defence required.

In contrast, full backs (FB) covered the highest sprint distance in all transitions and near-maximum velocity actions. Predominantly displaying this during defensive transitions (DT) and fast attacks (FA), which is consistent with previous work (Martín-García et al., 2018; Martín-García et al., 2019; Riboli et al., 2021b). It has been shown that maximum speed activities over longer distances were not adequately used in football training (Vázquez et al., 2023). Consequently, our findings support the need for such activities to be considered when planning training for full backs. They often link defensive and offensive responsibilities, resulting in them accumulating high speeds over longer distances (Ju et al., 2022a). Prompting the need for them to be provided with regular high-velocity exposures during a weekly microcycle. It is important to remember high-velocity distances were found to be directly related to the training status (Krustrup et al., 2003) and recognised as one of the key indicators of the physical performance in professional football (Mohr et al., 2003). Full backs should be conditioned to cope with higher sprint distance exposure to best prepare them for competition. Allowing them to deliver high performance, meet their positional requirements and importantly keep them free from injury. Due to the fatiguing nature of these repeated high-velocity actions coaches should consider employing appropriate and individualised recovery strategies post training and game play. This is due to their link to increased injury risk (Ade et al., 2021; Rhodes et al., 2019). Future research should consider analysing the effectiveness of recovery strategies following increased exposure to these high-velocity demands (Alexander et al., 2022).

Additionally, central attacking midfielders (CAM) exhibited higher TD ($m \cdot min^{-1}$) and HSRD ($m \cdot min^{-1}$) than other positions. Interestingly, wingers (W) demonstrated the highest number of accelerations and decelerations per min: A+D ($n \cdot min^{-1}$) during offensive actions while in possession of the ball such as counter-attacks and fast attacks. These findings are consistent with previous studies (Martín-García et al., 2018; Oliva-Lozano et al., 2021b). These rapid changes of speed are crucial in elite football and the ability to accelerate, decelerate and change direction quickly has been linked to success in field sport teams (Akenhead et al., 2016b; Harper et al., 2019) and football match result (Rhodes et al., 2021). Interestingly, during counter-attacks wingers (W) showed the highest output in other variables per minute ($m \cdot min^{-1}$) such as TD, HSRD and SD, which indicated the importance of this positional group during rapid changes from defensive to offensive transitions. Previous literature detailed the importance of high-velocity metrics for creating opportunities and scoring goals, which has very strong implications on performance (Tenga et al., 2010). Counter-attacks demonstrated the need to generate high-velocity outputs to exploit opponents, open space and create goalscoring opportunities (Hughes et al., 2019; Schulze et al., 2021).

It is acknowledged that offensive midfielders covered the greatest locomotor distance per minute: TD ($m \cdot min^{-1}$) (Martin Garcia et al., 2019), while wide midfielders (wingers) accumulated the highest A+D ($n \cdot min^{-1}$) in 4-4-3 formation (Riboli et al., 2021b). Findings are consistent with the present thesis. Attackers (A) experienced lower physical output in defensive transitions (DT) but reached higher metrics during high-pressure activities (HP), again consistent with conclusions drawn within recent literature (Oliva-Lozano et al., 2021b; Riboli et al., 2021b). Activities that require players to regain possession, squeeze space and block penetrating forward passes, have been shown to generate a greater frequency of high-intensity accelerations and decelerations as shown in Chapter 3 (Zhou et al., 2020). These actions are very reactive to the opposition movement to apply immediate pressure on the ball. It has been shown that nearly half of all ball winning turnovers across different European leagues, were a result of high pressing in the offensive (opposition) half. Resulting in more goals scored (Hughes et al., 2019; Kubayi, 2020). Thus, demonstrating how crucial it is to use attackers as the first line of defence, aiming to win the ball back and apply high pressure when out of possession.

Finally, mean transition performance for each playing position demonstrated higher match-to-match variability for absolute sprint distance (SD) than for relative sprint distance (Rel B5) (53.8% vs 32.7%, respectively). Indicating the high unpredictability of contemporary football matches and the complexity of modern training design for practitioners (Abbott et al., 2018a; Gregson et al., 2010). Global zones widely adopted in football enable workload comparisons to be made between athletes, but don't reflect players' individual physical characteristics (Abbott et al., 2018b; Harper et al., 2019; Oliva-Lozano et al., 2021a; Rago et al., 2019a). Relative speed zones could be more appropriate in elite football players analysis to assess true workload, detect fatigue and/or adaptation within a game (Carling et al., 2016) and therefore, should be explored more in future research.

Prescribing training based on whole/average match data (Lacome et al., 2016), utilising one physical variable (i.e. distance per min), while neglecting other contextual factors like position, limits specificity. Consequently, not fully reflecting the high physical stress players are exposed to in short and specific high-intensity passages within a football match (Martín-García et al., 2018; Rico-González et al., 2022; Wass et al., 2020; Vázquez et al., 2023). It is therefore critical for coaches to contextualise football specific short lasting blocks, that expose players to maximum physical outputs. Describing the tactical phase of play and positional role to best prepare athletes for competition, decrease the injury risk and improve performance (Malone et al., 2017b). Previous research has shown that utilising principles of overload of short lasting maximum intensity activities within a training block, are beneficial to football players in impacting their performance and causing various physiological adaptations (Ade et al., 2021; Mohr et al., 2016; Stølen et al., 2005). According to Chapter 3, if transitions were well described in relation to positional high-intensity and high-velocity metrics, they could offer new multivariate insights into the physical demands of the modern game. Thus, allowing managers and fitness practitioners to plan a clearer contextualised plan for training prescription for the team and individual position (Martín-García et al., 2018). To the author's knowledge, this body of work is the first to explore and describe physical demands and positional differences in detail during the key phases of a football game (transitions).

The findings of this Chapter 4 can be used to inform training intensity to ensure that sessions reflect different physical requirements among varied positional groups. Utilising this approach within varying tactical drills (offensive and defensive) when in or out of possession. For instance, during the midweek overload block (MD-4 and/or MD-3), coaches could use specific drills which encompass transitional activities (defence-to-offense transitions, offense-to-defence transitions, and fast attacks) as well as transitional games (large-, medium-, and small-sided) to over-stimulate locomotor and mechanical demands, increasing the high-velocity stress placed on players (Martín-García et al., 2018; Oliva-Lozano et al., 2021b; Vázquez et al., 2023). Alternatively, practitioners could utilise different SSG's to apply high pressure without the ball (defensive) and mimic high-intensity periods with the ball (offensive). By changing the number of players, size of the pitch and introducing a goalkeeper, the locomotor demands could be over- or under-stimulated relative to the WCS periods (Martín-García et al., 2019). Large-sided games and small-sided games have been found to be the most appropriate mode of football specific training (midweek) to over-stimulate different physical variables in relation to the 5- and 10-min peak match demands (125% sprint demands, and 150% high-intensity accelerations/decelerations, respectively) (Martín-García et al., 2019). SSG's could potentially however under-stimulate locomotive variables such as distance, high speed, and sprinting (Martín-García et al., 2019). Thus, emphasising the importance of utilising transitional activities to replicate the position specific maximum physical demands experienced by the team or individuals during competition. This approach should be replicated within end-stage rehabilitation sessions to increase performance and reduce the risk of future injury. Importantly, these physical demands would change in relation to individual physical capacity, willingness to compete, coaching style, level of opposition, and other situational and contextual factors (Bradley et al., 2011; Carling et al., 2011; Gregson et al., 2010).

4.5.1 Limitations

Studies investigating the impact of contextual variables (match location, match half, and match outcome) on WCS within a football match are limited (Bortnik et al., 2023a; Oliva-Lozano et al., 2021b; Riboli et al., 2021b). Contextual factors most likely determine the physical stress players are exposed to during the most demanding passages in modern match play, particularly for the high-velocity activities. We agree that this area should be further explored (Gregson et al., 2010). The present body of work did not analyse effective playing time. Previous research has recently shown that physical demand increases with greater playing time (<65 min) regardless of the playing position (Altmann et al., 2023). This study analysed ten games (small sample) of only one club. Thus, future research should investigate a larger sample across a higher number of teams in a season. Moreover, consideration should be given to analysis of the impact of substitutions on physical metrics during TA's, comparing training to game play and determine the impact of additional contextual factors such as system of play, formation, venue, score, to gain deeper knowledge about the true physical demands of the modern football game. The present study compared absolute to relative sprint distance across different positions during TA's, but future research should consider analysing peak intensity periods using acceleration thresholds to better relate to the players individual physical capacities during these actions.

4.6 Conclusions

Understanding differences in physical absolute and relative outputs across different playing positions during peak intensity periods is important to practitioners. The present investigation shows that the key physical metrics are largely increased compared to the 90-min averages when contextualised into transitions. Furthermore, differences exist in physical outputs across positions during these highest physical demands players are exposed to in match play. This study consequently provides guidance for coaches and practitioners on how to prescribe short and specific high intensity activities in training that integrates physical and technical-tactical aspects (offensive and defensive) to mimic maximum physical demands of competition in relation to different positional groups. This knowledge has direct implications for training prescription in relation to high-intensity and high-velocity activities within a weekly microcycle to best prepare each positional group for peak intensity passages in football match.

4.7 Practical implications

- Transitional activities largely increased physical demands across all positions compared to the 90-minute averages.
- Coaches could use strategies that mimic these physical demands and replicate the positional specificity by designing appropriate drills in training, selecting offensive/defensive activities in/out of the ball possession, manipulating pitch size and the number of players to best prepare athletes for their position specific role in the modern game and reduce their risk of injury (underprepardness).
- Center backs experienced the lowest physical metrics during all TA's but achieved the highest number of high-intensity accelerations and decelerations in defensive transitions.
- Full backs covered the highest sprint distance during all transitions, which was most evident in defensive transitions and fast attacks.
- Central attacking midfielders ran higher total distance and high-speed running distance from other positions during offensive transitions (counter-attacks) and fast attacks.
- Wingers had the highest number of high-intensity accelerations and decelerations, especially during offensive activities (counter-attacks) and fast attacks.
- Attackers experienced lower physical demands during defensive activities, while reaching higher physical metrics during high pressure activities.

4.8 Chapter Summary & Link to Chapter 5

Previous two Chapters (3 & 4) aimed to describe in detail the physical demands in crucial and highly contextualised phases of football match play, exploring not only team metrics but also emphasising and highlighting positional differences. This enabled coaches and practitioners to gain deeper insights into true physical match demands, giving them tools to transfer this knowledge to practical settings, which could potentially allow players to cope more effectively with maximum-intensity periods they experience in matches. These chapters led to another question whether various contextual factors such as match outcome (win / draw / loss) and match half (1st half / 2nd half) would impact the physical demands during these passages and if transitions would occur repeatedly over a short period of time with limited recovery, which could increase metabolic stress and potentially lead to acute and transient fatigue across 90 minutes. This specific knowledge could guide coaches and practitioners to adequately condition footballers and mimic high density of repeated actions in training to improve match performance, minimise fatigue, and reduce the risk of injury. Hence, Chapter 5 will determine the impact of match outcome and match half on physical metrics during transitions and introduce the novel concept of repeated transitional activities (CTA) in elite football.

Chapter 5: The Effect of Match Outcome and Match Half on Transitional Activities in Elite Football and the Novel Concept of Clusters

This chapter comprises the following manuscript published in Research & Investigations in Sports Medicine:

Bortnik, L., Bruce-Low, S., Burger, J., Alexander, J., Harper, D., Carling, C., & Rhodes, D. (2023a). Transitional Activities in Elite Football: Frequency, Type, Effect on Match Outcome and the Novel Concept of Clusters. *Research & Investigations in Sports Medicine*, 9(5), 872–886. https://doi.org/10.31031/RISM.000721.2023. A synthesis of this study is demonstrated in Table 20.

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Research Article

Transitional Activities in Elite Football: Frequency, Type, Effect on Match Outcome and the Novel Concept of Clusters

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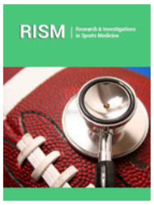

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Abstract

The aims of this study were to analyze the effect of contextual variables on physical metrics during transitions and investigate repeated transitional activities during transitions. Data was collected from 10 matches (23 elite soccer players). A total of 4249 individual observations were recorded including 1164 positive transitions (defense-to-attack), 1269 negative transitions (attack-to-defense), 1120 fast attacks, and 696 high pressure activities. Metrics per minute ($m \cdot min^{-1}$) as well as absolute variables: Total Distance (TD), high-speed running distance (HSRD, >19.8$km \cdot h^{-1}$), sprint distance (SD, >25.2$km \cdot h^{-1}$), relative high-speed running distance (VelB4), relative sprint distance (VelB5), acceleration distance (AccB3 Dist., distance with variations in running speed >3$m \cdot s^{-2}$), the number of high-intensity accelerations (HI Acc, >3$m \cdot s^{-2}$) and decelerations (HI Dec, >3$m \cdot s^{-2}$) were quantified. Significant effects of match half were found for TD (p <.001; ES =.03), HSRD (p = .023; ES = .012), VelB4 (p < .001; ES = .04), and HI Dec (p = .037; ES = .010). Match outcome had a relation to TD (m), HSRD (m) (p < .001), SD (m) and VelB4 (m) (p = .011) as well as VelB5 (m), and AccB3 Dist. distance (m) (p = .002 and p = .020, respectively). Performance in lost matches was lower in the 2nd half (p≤0.05). This study indicates that players are exposed to repeated short and intermittent high velocity actions together, highlighting the need to move away from 90min averages and pay more attention to transitional activities in modern training design.

Keywords: Soccer; Transitions; High pressure; Peak demands; Match outcome; Repeated activities

Introduction

Soccer match play demands are well defined within literature [1,2], and the increasing demands highlighted on players continually evolves [3]. A deeper understanding of the physical demands placed on athletes during competition better informs coaches and physical performance staff of the appropriate physical and technical stimuli needed in training to better prepare players [4,5]. Modern wearable technology, which has been deemed valid, reliable, and practical has been used to measure team/individual training and match locomotor and mechanical metrics in team sports [6]. However, most studies have provided whole and average match physical metrics describing the volume of activity, yet not truly reflecting fluctuations in physical, technical, and tactical intensity, which inevitably underestimates the most demanding periods of football match play [7,8]. Recent literature in elite football has focused more attention on peak match demands, also referred to as Worst-Case-Scenarios (WCS) [9-11]. Importantly, it has been established that a shorter duration WCS generated higher intensity, raising questions regarding the physical preparation of players for these repeated increased demands in game play [7,8]. Various methods have been utilized to

5.1 Chapter Overview

Despite a high tactical value and significance of transitional play and high-pressure activities in a modern football strategic approach, there are no previous studies that attempt to provide physical and technical-tactical insights about these crucial periods, deliver detailed information about positional differences nor explore density of transitional activities in modern match play (Nassis et a., 2020; Wass et al., 2020). Current literature describes the effect of different playing styles including counter-attacks on physical, technical, and success-related metrics, merely depicting 90-min totals and fails to contextualise these variables into transitions (Forcher et al., 2023). Moreover, there are no studies to the authors knowledge that distinguish physical output differences between offensive and defensive transitional actions nor identify their frequency, pattern of occurrence, duration and recovery period. Therefore, the main objective of the present body of work and represented in Chapter 5 is to better understand the impact of different contextual factors (match half and match outcome) on physical demands during transitions and explore density of transitional activities in official games. It is hoped that measuring high-intensity actions during critical offensive and defensive activities commonly used by elite teams to win games, would significantly add to the existing body of knowledge, and most importantly, effectively transfer new evidence to practical applied settings (Aranda et al., 2019; Forcher et al., 2023). It is worth noting that these short and highly contextual periods could easily be applied and replicated in training, possibly giving practitioners powerful ammunition to holistically prepare footballers for the most demanding passages in modern match play (Martin-Garcia et al., 2018; Oliva-Lozano et al., 2021b; Rochael et al., 2023a). The following text has been taken directly from the manuscript published in Research & Investigations in Sports Medicine (Bortnik et al., 2023a).

5.2 Abstract

The aim of this study were to analyse the effect of contextual variables on physical metrics during transitions and investigate repeated transitional activities during transitions. Data was collected from 10 matches (23 elite football players). A total of 4249 individual observations were recorded including 1164 positive transitions (defence-to-attack), 1269 negative transitions (attack-to-defence), 1120 fast attacks, and 696 high pressure activities. Metrics per minute ($m \cdot min^{-1}$) as well as absolute variables: total distance (TD), high-speed running distance (HSRD, > 19.8 $km \cdot h^{-1}$), sprint distance (SD, > 25.2 $km \cdot h^{-1}$), relative high-speed running distance (VelB4), relative sprint distance (VelB5), acceleration distance (AccB3 Dist, distance with variations in running speed > 3 $m \cdot s^{-2}$), the number of high-intensity accelerations (HI Acc, > 3 $m \cdot s^{-2}$) and decelerations (HI Dec, > 3 $m \cdot s^{-2}$) were quantified. Significant effects of match half were found for TD (small ES*s*; $p < .001$), HSRD (small ES*s*; $p = .023$), VelB4 (small ES*s*; $p < .001$), and HI Dec (small ES*s*; $p = .037$). Match outcome had a relation to TD (m), HSRD (m) ($p < .001$), SD (m) and VelB4 (m) ($p = .011$) as well as VelB5 (m), and AccB3 Dist distance (m) ($p = .002$ and $p = .020$, respectively). Performance in lost matches was lower in the 2nd half ($p \leq 0.05$). This study indicates that players are exposed to repeated short and intermittent high velocity actions together, highlighting the need to move away from 90min averages and pay more attention to transitional activities in modern training design.

5.3 Introduction

Football match play demands are well defined within literature (Carling, 2013; Castellano et al., 2014), and the increasing demands highlighted on players continually evolves (Barnes et al., 2014). A deeper understanding of the physical demands placed on athletes during competition better informs coaches and physical performance staff of the appropriate physical and technical stimuli needed in training to better prepare players (Stevens et al., 2017; Wass et al., 2020). Modern wearable technology, which has been deemed valid, reliable, and practical has been used to measure team/individual training and match locomotor and mechanical metrics in team sports (Scott at al., 2016). However, most studies have provided whole and average match physical metrics describing the volume of activity, yet not truly reflecting fluctuations in physical, technical, and tactical intensity, which inevitably underestimates the most demanding periods of football match play (Bortnik et al., 2022; Martin-Garcia et al., 2018).

Recent literature in elite football has focused more attention on peak match demands, also referred to as worst-case-scenarios (WCS) (Pollard et al., 2018; Riboli et al., 2021a; Riboli et al., 2021b). Importantly, it has been established that a shorter duration WCS generated higher intensity, raising questions regarding the physical preparation of players for these repeated increased demands in game play (Martin-Garcia et al., 2018). Various methods have been utilised to quantify the peak demands in football and the rolling average has been found superior over fixed length methods (Martin-Garcia et al., 2018; Oliva-Lozano et al., 2021a). Regardless of the substantially increased body of knowledge regarding the most demanding passages and its distribution within the contemporary game, more information is needed surrounding the technical-tactical context and pattern of occurrence. Increasing this knowledge would inform practitioners of the need to adapt pitch specific conditioning and football specific training (small-sided games, technical, tactical and positional drills) to better replicate competition and positional demands (Novak et al., 2021; Riboli et al., 2021a).

Analysis of transitions within elite football (Chapter 3 and 4) has detailed increased high velocity demands when compared to 90-minute game averages (Novak et al., 2021), often elicited when the ball is in play (BIP) (Pollard et al., 2018). Transitional activities present as a broad context within game play, as they represent actions in/out of ball possession (ball in play) as well as depict tactical offensive and defensive team collective movements and behaviours in modern football (Chapter 3). Offensive (defence-to-attack) and defensive (attack-to-defence) transitions have been previously claimed as the key phases of play in football, during which many goals are scored, and risks taken (Tenga et al., 2010; Wass et al., 2020). In addition, high-pressure activities have been found an effective playing style to create more goals scoring chances and have been linked to greater physical demands and higher levels of fitness in football (Wright et al., 2011). Understanding how these transitional activities present within competition is essential to optimise the physical preparation of players to enhance performance and contribute to reducing injury risk.

Previous authors have investigated match average physical metrics taking into consideration various contextual factors such as match half (Bradley et al., 2013), match location (Oliva-Lozano et al., 2020a), and match outcome (Oliva-Lozano et al., 2020b; Rhodes at al., 2021). However, research exploring the effect of contextual variables on peak intensity periods is scarce (Riboli et al., 2021b; Oliva-Lozano et al., 2021a). To the author's knowledge, there are no studies exploring the effect of match half and match outcome on physical metrics during transitions in professional football. Moreover, there has been lack of research related to the number of clusters of transitional activities, which would represent repeated high-intensity specific efforts in attack and defence during the key phases of play in football (Aranda et al., 2019). The ability to repeatedly perform high-intensity actions has been found crucial for successful performance in elite football due its intermittent nature (Carling et al., 2012). A better understanding of a team's collective performance during intensified blocks of activity might have a significant practical impact on coaches and practitioners to optimally design football specific team and individual sessions integrating physical and technical-tactical aspects (Ju et al., 2022a). Therefore, Chapter 5 aims to 1) analyse the effect of match half (1st vs 2nd) and match outcome (win vs draw vs loss) on different absolute and relative physical metrics during TA's; 2) explore the effect of match outcome on the second half physical performance; and 3) investigate repeated TA's (clusters) within contemporary match play.

5.4 Materials and Methods

5.4.1 Participants

GPS and accelerometery data was captured from a total of twenty-three elite football players (n = 23), which were part of a leading team of the 1st Polish Division (Ekstraklasa) in season 2020-21. Players represented the following playing positions: center backs (n = 4), full backs (n = 5), central defensive midfielders (n = 2), central attacking midfielders (n = 2), central midfielders (n = 2), wingers (n = 5), and attackers (n = 3). Substitutions were excluded from this investigation because they could generate greater physical demands compared to starters likely because of pacing strategies present on modern football (Wass et al., 2020). Players who completed a minimum of 60 mins were analysed. Players received all information about the project protocol and provided informed consent for the use of match data, in accordance with the Helsinki Declaration (2013). To ensure player confidentiality, all data was anonymised prior to its analysis. Ethical approval was provided by the University of Central Lancashire (HEALTH 0104) (Appendix 8).

5.4.2 Procedures & Experimental Design

Ten competitive games from Polish domestic top division league (Ekstraklasa), were investigated between August and November of 2020. A total of 4249 individual observations were recorded including 1164 positive transitions (defence-to-attack), 1269 negative transitions (attack-to-defence), 1120 fast attacks, and 696 high pressure activities. The activity profile of players was monitored during each game using portable MEMS (10 Hz; Vector S7, Catapult Sports, Melbourne, Australia). The GPS device used in this investigation was worn in each game in a purpose-designed vest, inside a mini pocket positioned between the scapulae, and thus not affecting mobility of the upper limbs. The players were familiar with this entire procedure since they wear these devices regularly in training and games. To have an optimal connection to the satellites, the GPS units were turned on 15 minutes before the start of the game. In accordance with previous guidelines for acceptable GPS coverage, the data was screened for satellite coverage and horizontal dilution of precision (HDOP) using an inclusion criterion of > 6 satellites and ≤ 1.0 respectively (Malone et al., 2017a). In order to avoid inter-unit error, each player wore the same unit for the whole study period (Appendix 9). The accuracy of this technology has been previously reported (Johnston et al., 2014; Scott et al., 2016).

All metrics analysed in this study were previously used by other authors (Pollard et al., 2018; Riboli et al., 2021b; Wass et al., 2020). They depicted absolute distances covered per minute ($m \cdot min^{-1}$) in the following categories: total distance (TD), high-speed running distance (HSRD, > 19.8 $km \cdot h^{-1}$), sprint distance (SD, > 25.2 $km \cdot h^{-1}$), as well as the number of high-intensity accelerations and decelerations (A+D, > 3 $m \cdot s^{-2}$; $n \cdot min^{-1}$). In addition, the metrics represented absolute distanced covered in the following categories: total distance (TD), high-speed running distance (HSRD), sprint distance

(SD), the number of high-intensity accelerations (HI Acc, > 3 $m \cdot s^{-2}$), the number of high-intensity decelerations (HI Dec, > -3 $m \cdot s^{-2}$), and acceleration distance (AccB3 Dist, distance with variations in running speed > 3 $m \cdot s^{-2}$). Further, the variables reflected total relative high-speed running distance (VelB4) and relative sprint distance (VelB5), which was proposed previously by other authors to represent the functional limits of endurance and sprint locomotor capacities (Mendez-Villanueva et al., 2012). As previously recommended (Mendez-Villanueva et al., 2012), relative high-speed running distance (VelB4) and relative sprint distance (VelB5) was set as 100% maximal aerobic speed (MAS) – 30% (anaerobic speed reserve) ASR, and above MAS + 30% ASR, respectively. An incremental running treadmill test was conducted by the club physiologist to measure VO_2max and MAS. The test was performed in the gym environment with a normal ambient temperature and took place on a mechanical treadmill (Technogym, Italy). It began with an initial speed of 10 km/h^{-1} and each stage was increases by 1.5 km/h^{-1}. Five stages were set. Each stage lasted 4 minutes and it was separated by 1 minute passive break. The inclination was set at 1.5%. Polar heart rate monitors (Polar, Norway) and Polar M400 were used to record HR data. Expired gases were analysed breath-by-breath using an online automated gas analysis system (MetaLyzer® 3b-R2; Cortex Biophysik Gmbh, Leipzig, Germany) and accompanying software (MetaSoft® 3). Maximum oxygen uptake (VO_2max) was defined as the highest 15-s average oxygen uptake. Velocity (km/h^{-1}) during the maximum oxygen uptake (VO_2max) was recorded and set as the MAS (Bortnik et al., 2023a).

After each game was completed, TA’s were identified and manually tagged by the club’s analysis team in the Catapult Vision video analysis system (Catapult Sports Ltd, Melbourne, Australia). The analysis staff utilized the observational methodology REOFUT theoretical framework to identify these phases (Aranda et al., 2019) , which was part of the club’s analysis protocols implemented daily by the analysis team. Previous literature has shown good to high intra- and inter-observer reliability of the current analysis method (Aranda et al., 2019; Gonzalez-Rodenas et al., 2020; Tenga et al., 2010). Data from the Catapult vision software were then downloaded and integrated into the manufacturer’s software package (*Openfield*, version 3.2.0) and finally exported into Microsoft Excel (Microsoft Corporation, USA) to make additional calculations for each transitional play and clusters. Clusters were defined as two or more transitional activities that occurred within a period shorter than 61 secs (Buchheit et al., 2010; Carling et al., 2012). The transition mean average for selected metrics and cluster frequencies was calculated as the sum total of all TA’s, divided by their number. To get the transition/cluster peak average value, the highest values in 10 games were found, and their average was calculated as the sum of all peak values during transitions/clusters, divided by their number. Transitional activities were classified into the following categories: positive transition (PT), negative transition (NT), fast attack (FA), and high pressure (HP), which were described in Chapter 3 (Table 2 and 3) and previously defined by other authors (Tenga et al., 2010; González-Rodenas et at., 2020).

5.4.3 Statistical analysis

A descriptive analysis was used, and the results are shown as mean ± standard deviation (SD). Statistical analyses were conducted using IBM Statistical Package for the Social Sciences (SPSS, Version 27.0, IBM Corporations, New York, USA) with the statistical significance accepted at the 0.05 level. A univariate analysis of variance (ANOVA) was conducted to quantify main effects for games, transitions, and positions. Interaction effects were quantified, and any significant main effects associated with games, transitions, and positions were explored using post hoc pairwise comparisons. The assumptions associated with the statistical model were assessed to ensure model adequacy. To assess residual normality for each dependent variable, q-q plots were generated using stacked standardised residuals. Scatterplots of the stacked unstandardized and standardised residuals were also utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. Across all isokinetic and stabilometery measures considered within the thesis, a sample size ≥ 14 players was required to evaluate the interactions associated with all independent variables (for statistical power > 0.8; $p < 0.05$). Partial eta squared (η^2) were calculated to estimate effect sizes for all significant main effects and interactions. As previously recommended (Cohen, 1988), partial eta squared was classified as small (0.01–0.059), moderate (0.06-0.137), and large (>0.138).

5.5 Results

Analysis of TD (m) identified significant effects for game (F = 4.590, p < .001, partial η^2 = .071) and transition type (F = 17.097, p < .001, partial η^2 = .109). There were significant effects of HSRD (m), SD (m), VelB4 (m), and VelB5 (m) for a transition type (HSRD: F = 15.298, p < .001, partial η^2 = .099; SD: F = 9.916, p < .001, partial η^2 = .066; VelB4: F = 15.471, p < .001, partial η^2 = .100; VelB5: F = 12.614, p < .001, partial η^2 = .083). There was a game x time interaction for HI Acc (n) (F = 3.511, p = .001, partial η^2 = .055). No interactions of game, transition type, result, and time were discovered for TD (m), HSRD (m), SD (m), VelB4 (m), VelB5 (m), HI Dec (n), and AccB3 distance (m) (p > .05). Moreover, analysis of TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$), SD ($m \cdot min^{-1}$), and A+D ($n \cdot min^{-1}$) revealed significant effects for a transition type (TD: F = 29.754, p < .001, partial η^2 = .176; HSRD: F = 14.441, p < .001, partial η^2 = .094; SD: F = 6.248, p < .001, partial η^2 = .043; A+D: F = 4.453, p = .004, partial η^2 = .031). There was a game x time interaction for A+D ($n \cdot min^{-1}$) (F = 2.178, p = .035, partial η^2 = .035). No interactions of game, transition type, result, and time were discovered for TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$), SD ($m \cdot min^{-1}$) (p > .05).

5.5.1 1st vs 2nd half

Statistically significant effects of time (1st vs 2nd half) were found for absolute metrics such as TD (m), HSRD (m), relative high-speed running distance (VelB4) (m), and high-intensity decelerations - HI Dec ($n \cdot min^{-1}$) (TD: $F(1,419)$ = 12.823, p < .001, partial η^2 = .030; HSRD: $F(1,419)$ = 5.244, p = .023, partial η^2 = .012; VelB4: $F(1,419)$ = 17.572, p < .001, partial η^2 = .040; HI Dec: $F(1,419)$ = 4.430, p = .037, partial η^2 = .010). No significant effects of time (1st vs 2nd half) were revealed for any metrics per minute (p > .05).

Table 9 highlights the effect of time (0-45' and 45-90') on absolute physical metrics that occur during transitions, accompanied with the confidence interval (CI), p-value and effect size (η^2). The effect of time (0-45' and 45-90') on metrics per minute in all transitions across the games analysed, accompanied with the confidence interval (CI), p-value and effect size (η^2) is displayed in Table 10. Table 11 highlights the mean frequency of transitional activities in clusters that occur per game, accompanied with the confidence interval (CI), min and max.

Table 9. Effects of time (0-45' and 45-90') on total distance (m): (TD), high-speed running distance (m): (HSRD, > 19.8 km·h^{-1}), sprint distance (m): (SD, > 25.2 km·h^{-1}), relative high-speed running distance (m): (VelB4), relative sprint distance (m): (VelB5), high-intensity accelerations count (n): (HI Acc, > 3 m·s^{-2}), high-intensity decelerations count (n): (HI Dec, > 3 m·s^{-2}) and HI acceleration distance (m): (AccB3 Dist, distance with variations in running speed > 3 m·s^{-2}) during transitional activities across 10 official matches. Data are shown as team mean ± SD and 95% confidence intervals.

	0-45'		45-90'			
	Mean ± SD	95%CI	Mean ± SD	95%CI	p - Value	Effect size η^2
TD (m)	306.0 ± 41.0	276.7 – 335.3	257.7 ± 45.2	225.4 – 290.0	< .001	0.30
HSRD (m)	78.1 ± 16.6	66.2 – 90.0	64.5 ± 17.1	52.3 – 76.7	.023	0.12
SD (m)	22.3 ± 6.6	17.6 – 27.0	20.0 ± 7.6	14.6 – 25.4	.235	0.001
VelB4 (m)	60.3 ± 11.3	52.2 – 68.4	45.8 ± 11.1	37.8 – 53.8	< .001	0.40
VelB5 (m)	56.8 ± 13.6	47.1 – 66.5	47.4 ± 13.1	38.0 – 56.8	.091	0.007
HI Acc (n)	0.7 ± 0.3	0.5 – 0.9	0.7 ± 0.4	0.6 – 0.8	.648	0.000
HI Dec (n)	1.1 ± 0.4	0.8 – 1.4	0.8 ± 0.2	0.6 – 0.9	.037	0.010
AccB3 distance (m)	3.3 ± 1.0	2.6 – 4.0	3.0 ± 0.7	2.4 – 3.5	.121	0.006

Table 10. Effects of time (0-45' and 45-90') on metrics per min: total distance: TD (m·min^{-1}), high-speed running distance: (HSRD > 19.8 km·h^{-1} (m·min^{-1}), sprint distance: SD > 25.2 km·h^{-1} (m·min^{-1}), and number of high-intensity accelerations/decelerations: A+D, > 3 m·s^{-2} (n·min^{-1}) during transitional activities across 10 official matches. Data are shown as team mean ± SD and 95% confidence intervals.

	0-45'		45-90'			
	Mean ± SD	95%CI	Mean ± SD	95%CI	p - Value	Effect size η^2
TD (m·min^{-1})	208.2 ± 11.2	200.0 – 216.2	199.4 ± 17.4	187.0 – 211.8	.174	0.004
HSRD (m·min^{-1})	52.6 ± 9.5	45.8 – 59.4	50.5 ± 12.0	41.9 – 59.1	.394	0.002
SD (m·min^{-1})	14.8 ± 3.6	12.2 – 17.4	15.9 ± 5.5	11.9 – 19.9	.495	0.001
A+D (n·min^{-1})	1.2 ± 0.3	1.0 – 1.4	1.2 ± 0.2	1.0 – 1.4	.627	0.001

Table 11. Mean ± SD, 95% confidence intervals and minimum/maximum frequency of transitional activities (TA's) in clusters across 10 official matches.

FREQUENCY (n)	Mean ± SD	95%CI	Minimum	Maximum
Total clusters	12.2 ± 3.2	9.9 – 14.5	8.0	18.0
Mean TA's in cluster	2.6 ± 0.4	2.3 – 2.9	2.0	3.3
Peak TA's in cluster	4.5 ± 1.4	3.5 – 5.5	2.0	7.0
Total TA's as clusters	32.7 ± 11.5	24.5 – 40.9	16.0	52.0
Total TA's (all games)	50.0 ± 11.1	41.6 – 57.6	32.0	68.0

5.5.2 Match performance outcomes (loss, draw, win)

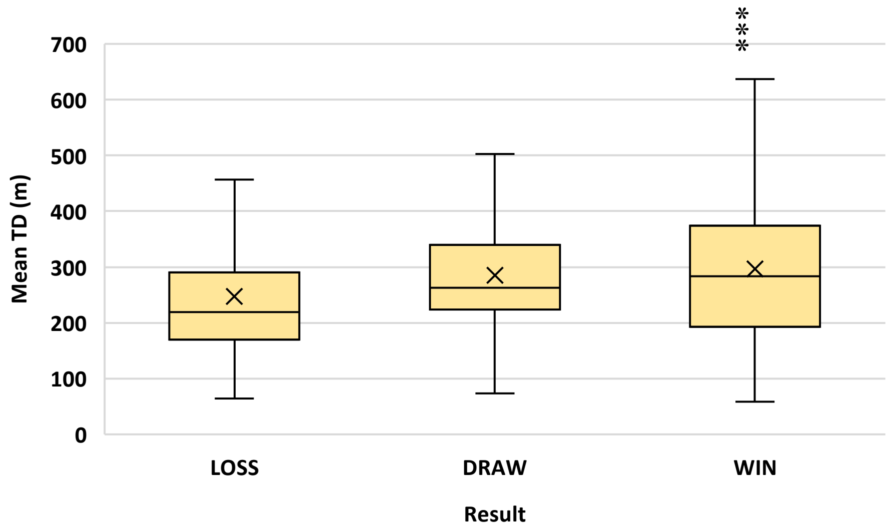
Significant difference was found during TA'a for absolute metrics such as TD (m) and HSRD (m) ($p < .001$), SD (m) and VelB4 (m) ($p = .011$) as well as VelB5 (m) and HI Acc distance (m) ($p = .002$ and $p = .020$, respectively) between matches with a win and loss performance outcomes. Number of HI accelerations and decelerations (n) revealed no significant impact on the match outcome (result) ($p > .05$). No significant difference during TA'a was found for TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$), SD ($m \cdot min^{-1}$), A+D ($n \cdot min^{-1}$) between different match performance outcomes (win vs draw vs lost) ($p > .05$).

Comparisons between matches with a loss, draw, and win performance outcomes in absolute and per minute physical metrics during all transitions and high-pressure activities can be seen in Figure 27 and Figure 28, respectively.

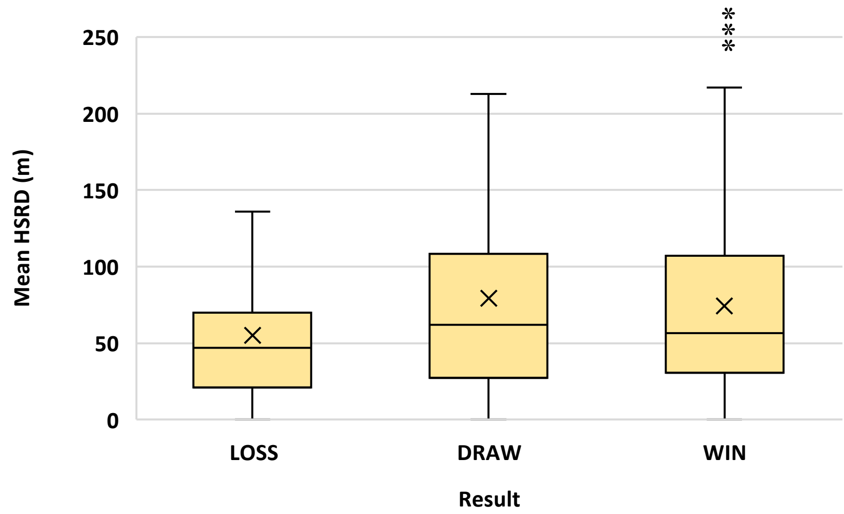
Pairwise comparisons showed that TA's volume in absolute metrics such as TD ($p = .023$), HSRD ($p = .017$), VelB4 ($p = .006$), VelB5 ($p = .028$) in lost matches (Loss) was lower in the 2nd half compared to the first half. Other absolute metrics did not reveal any significant differences ($p > .05$). In addition, 2nd half performance significantly decreased for TD ($m \cdot min^{-1}$) ($p = .003$). Match result revealed no difference between both halves in other metrics per minute ($p > .05$).

Figure 29 depicts differences between matches with a loss, draw, and win match results in half 1 vs. half 2 in absolute metrics. Figure 30 represents the same differences for metrics for minute such as total distance – TD ($m \cdot min^{-1}$), high-speed running distance – HSRD ($m \cdot min^{-1}$), sprint distance - SD ($m \cdot min^{-1}$), and number of accelerations/decelerations - A+D ($n \cdot min^{-1}$).

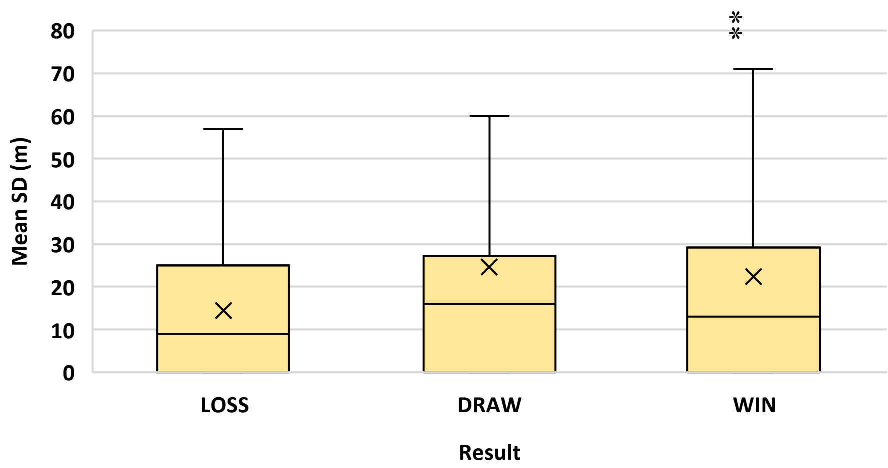
A)


***
700
600
500
400
300
200
100
0
Mean TD (m)
LOSS
DRAW
WIN
Result

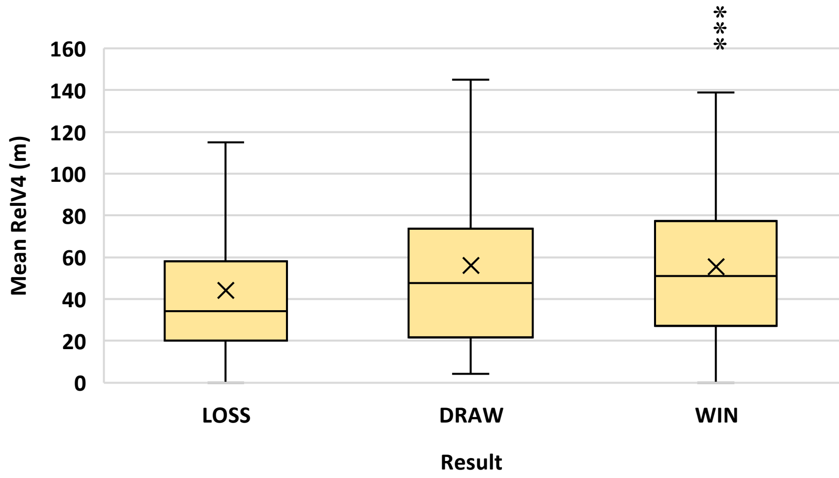
B)


***
250
200
150
100
50
0
Mean HSRD (m)
LOSS
DRAW
WIN
Result

C)


**
80
70
60
50
40
30
20
10
0
Mean SD (m)
LOSS
DRAW
WIN
Result

D)


***
160
140
120
100
80
60
40
20
0
Mean RelV4 (m)
LOSS
DRAW
WIN
Result

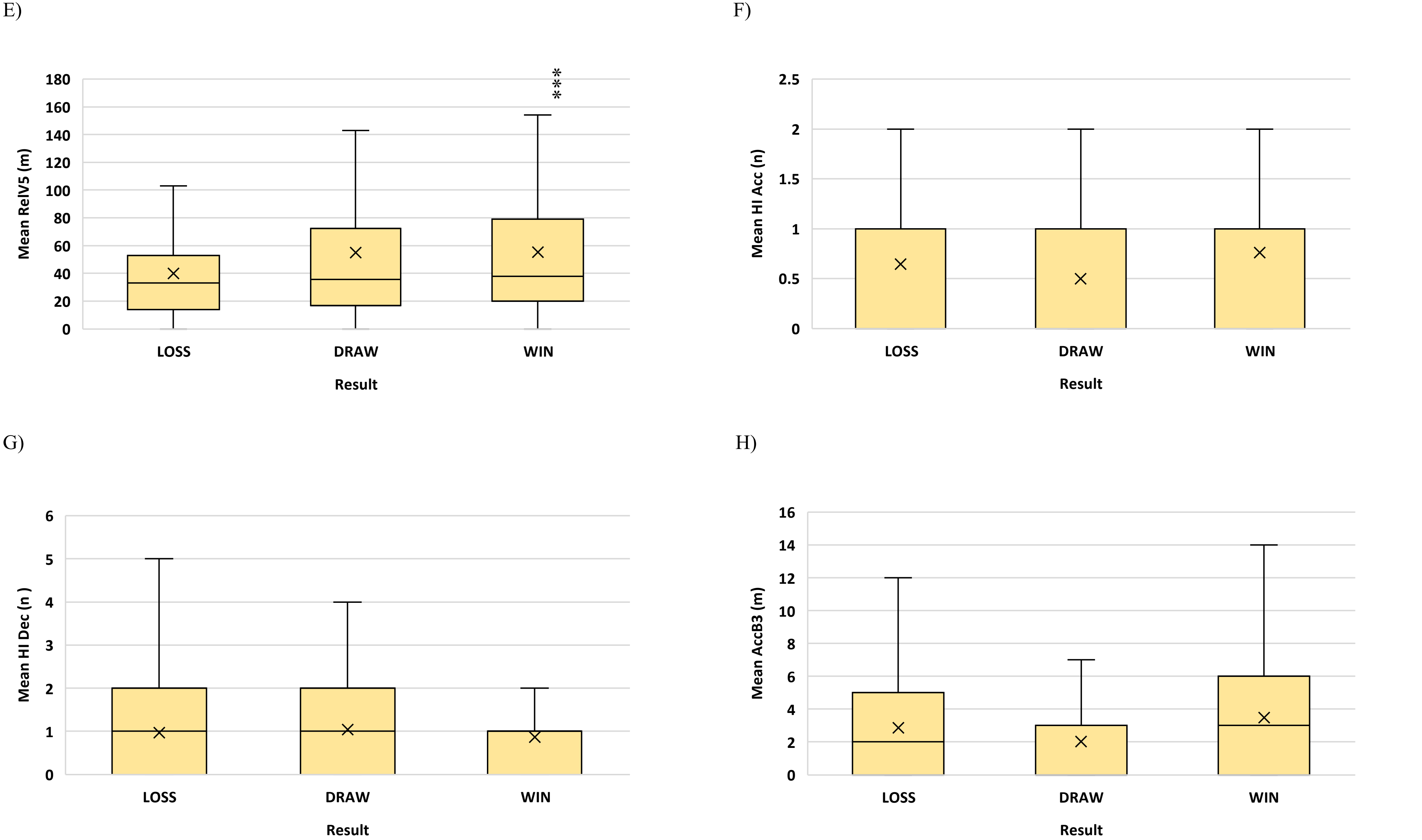


Figure 27. Comparisons between matches with loss, draw and win performance outcomes during transitions and high pressure activities in a) mean total distance (TD), b) mean high-speed running distance (HSRD), c) mean sprint distance (SD), d) mean relative high-speed running distance (RelV4), e) mean relative sprint distance (RelV5), f) mean number of high-intensity accelerations (HI Acc), g) mean number of high-intensity decelerations (HI Dec), and h) mean high-intensity acceleration distance (AccB3).
Note: Different from WIN * p < 0.05; ** p < 0.01; *** p < 0.001

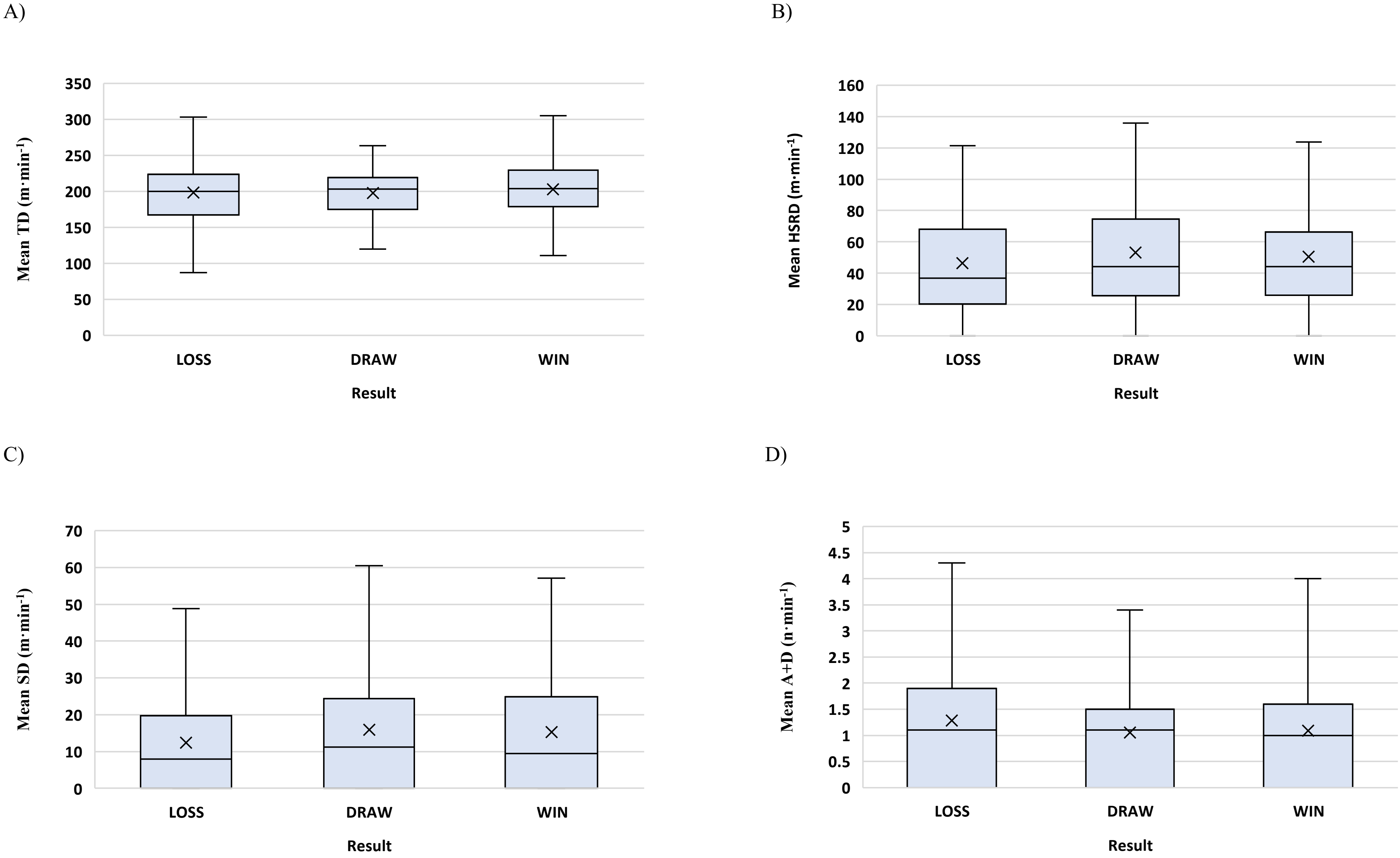
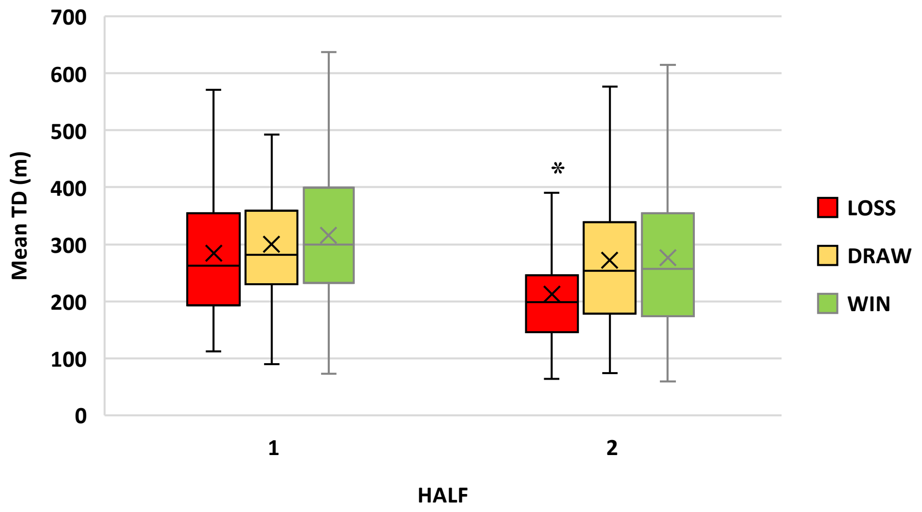


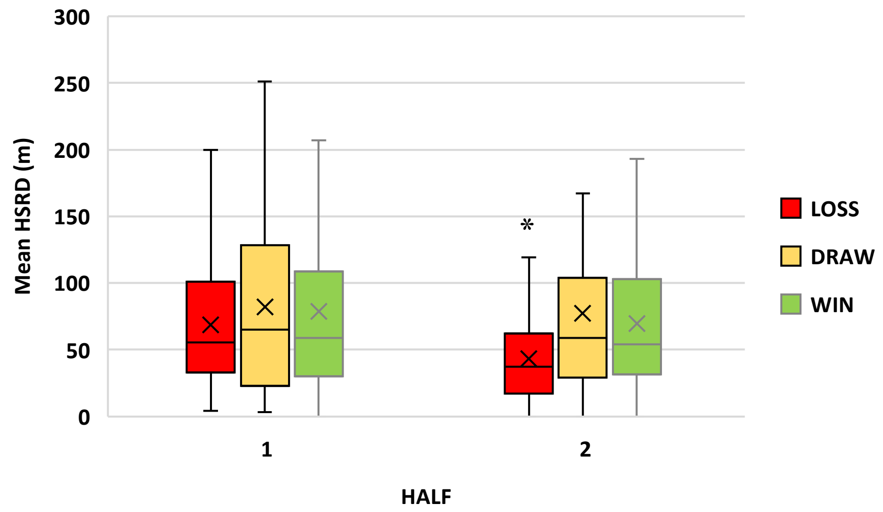
Figure 28. Comparisons between matches with loss, draw and win performance outcomes during transitions and high-pressure activities across 10 matches in a) mean TD (m·min-1), b) mean HSRD (m·min-1), c) mean SD (m·min-1), and d) mean A+D (n·min-1).

Note: Different from WIN * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

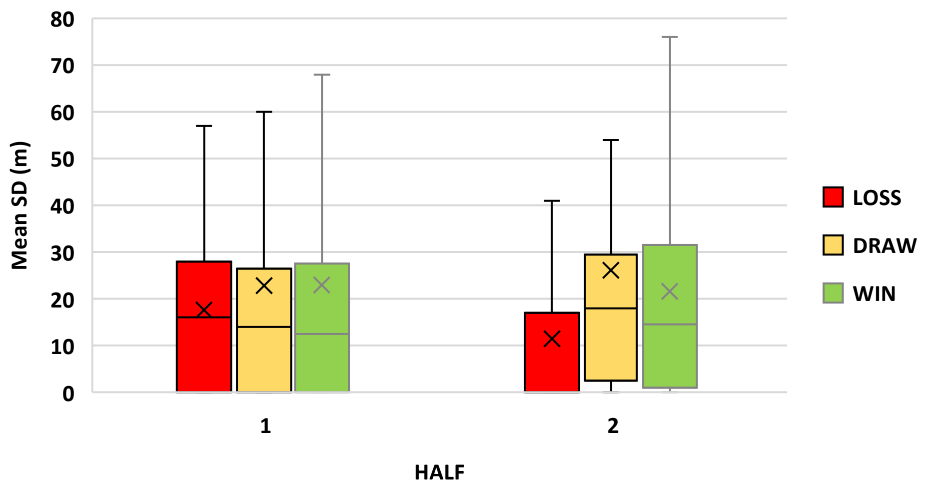
A)


700
600
500
400
300
200
100
0
Mean TD (m)
*
LOSS
DRAW
WIN
1
2
HALF

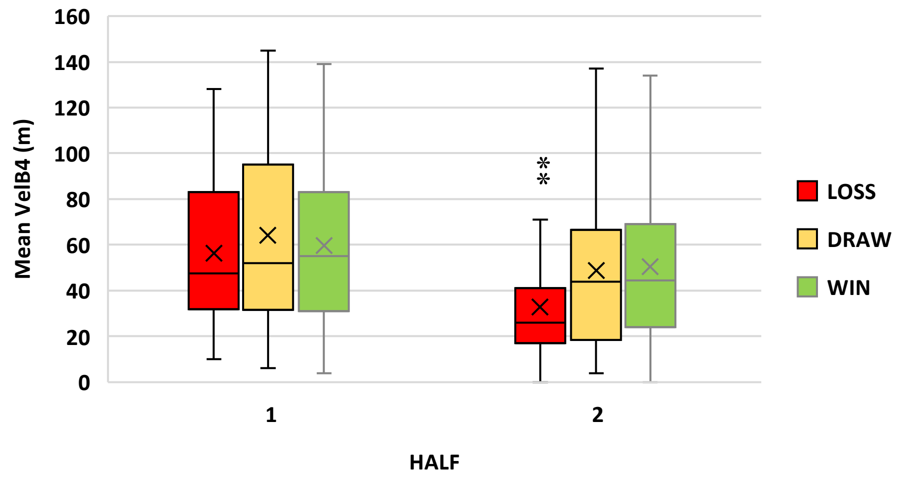
B)


300
250
200
150
100
50
0
Mean HSRD (m)
*
LOSS
DRAW
WIN
1
2
HALF

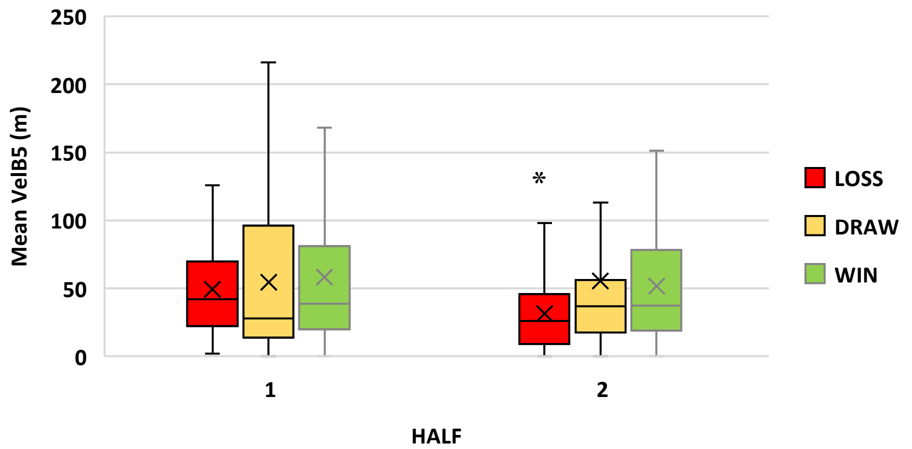
C)


80
70
60
50
40
30
20
10
0
Mean SD (m)
LOSS
DRAW
WIN
1
2
HALF

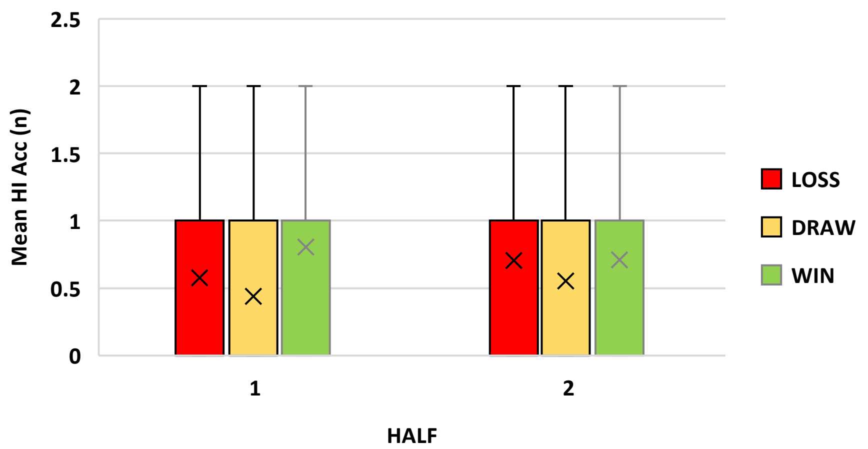
D)


160
140
120
100
80
60
40
20
0
Mean VelB4 (m)
**
LOSS
DRAW
WIN
1
2
HALF

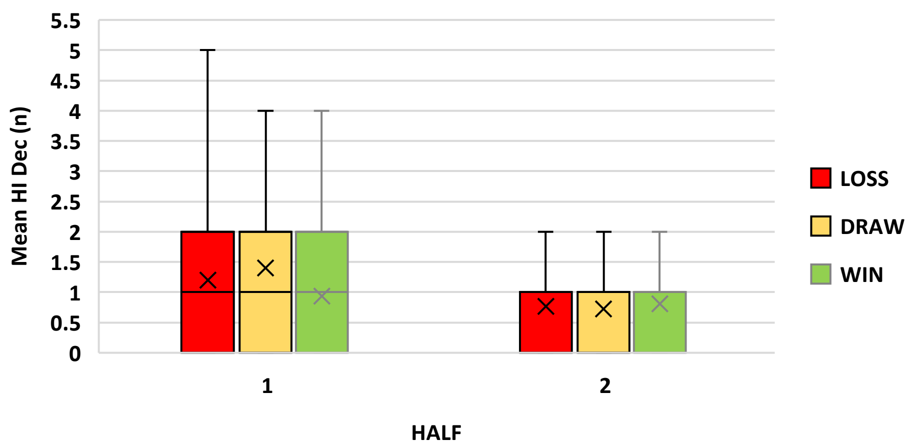
E)



F)



G)



H)

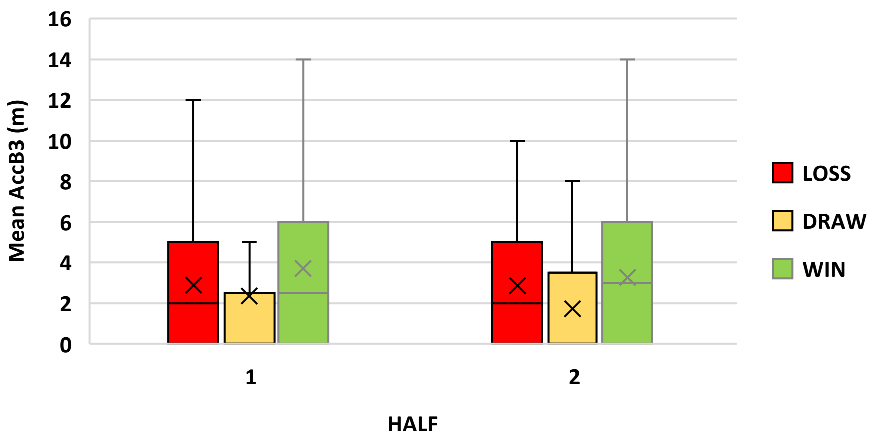


Figure 29. Comparisons between matches with loss, draw and win performance outcomes per match half (1 & 2) during transitions and high-pressure activities in a) mean total distance (TD), b) mean high-speed running distance (HSRD), c) mean sprint distance (SD), d) mean relative high-speed running distance (RelV4), e) mean relative sprint distance (RelV5), f) mean number of high-intensity accelerations (HI Acc), g) mean number of high-intensity decelerations (HI Dec), and h) mean high-intensity acceleration distance (AccB3).

Note: Different from WIN * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

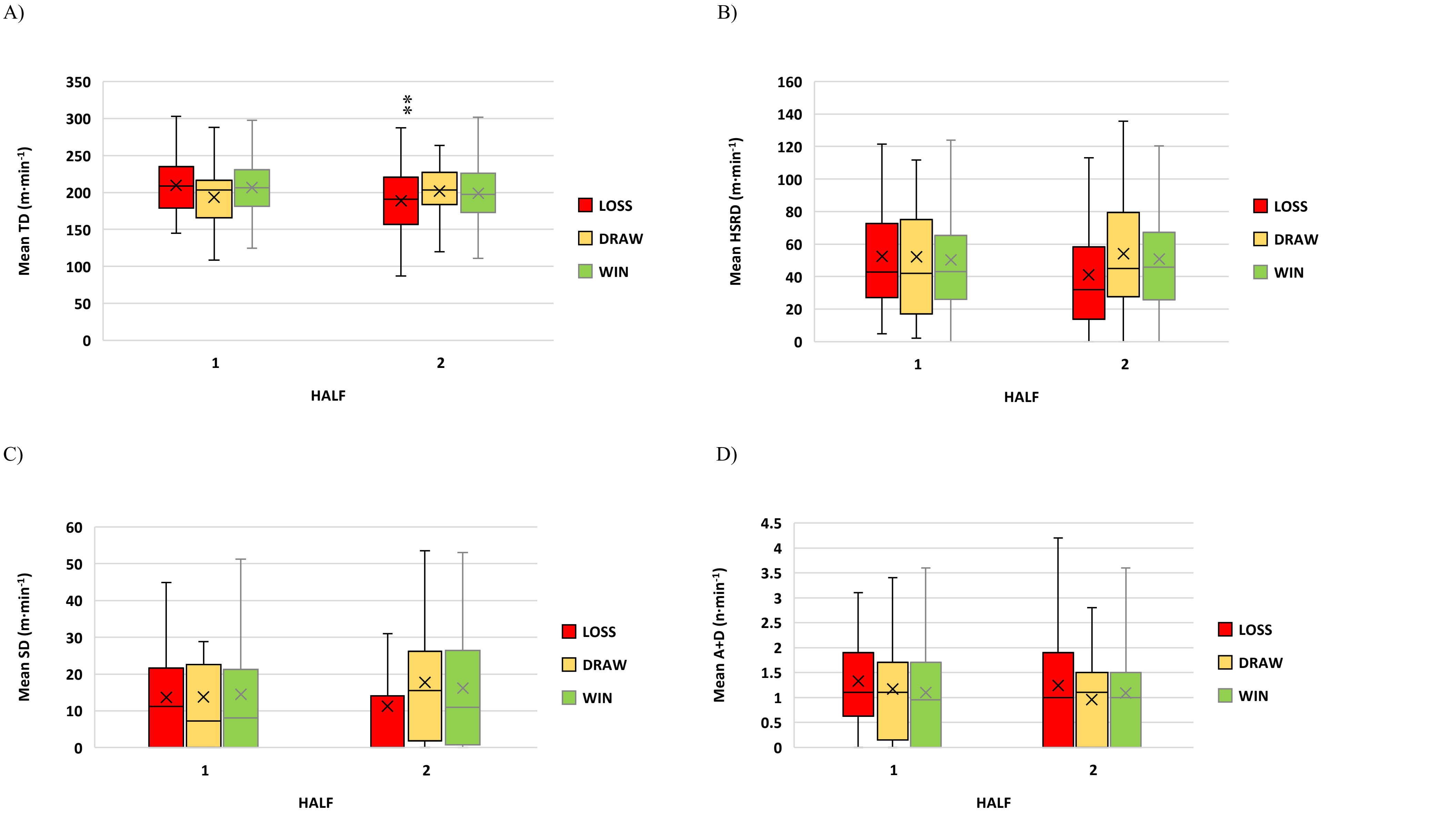


Figure 30. Comparisons between matches with loss, draw and win performance outcomes per match half (1 & 2) during transitions and high-pressure activities across 10 matches in a) mean TD ($m \cdot min^{-1}$), b) mean HSRD ($m \cdot min^{-1}$), c) mean SD ($m \cdot min^{-1}$), and d) mean A+D ($n \cdot min^{-1}$).
Note: Different from WIN * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

5.6 Discussion

The aims of Chapter 5 were to analyse the impact that different contextual variables (match half and match outcome) had on absolute and relative physical performance metrics during transitions and high-pressure activities in elite football. Global zones, which have been widely used in football match analysis, enable workload comparisons between players, but don't reflect their individual physical characteristics, capacities, and match context (Abbott et al., 2018b; Harper et al., 2019; Oliva-Lozano et al., 2021a; Rago et al., 2019a). This chapter provides additional knowledge regarding transitional activities and high-pressure actions by analysing relative speed zones. This approach could be more appropriate than global zones to assess running performance, determine positional differences (Chapter 4), and detect fatigue in elite football players (Carling et al., 2016; Silva et al., 2024). This is the first investigation introducing a novel concept of repeated TA's defined as clusters. Findings show that during a modern football game players are exposed to repeated short, intermittent high velocity actions together. Thus, emphasising the need to move away from training design guided by 90-minute averages (Chapter 3). The main findings also indicate significant effects of contextual factors on transitions. All volume-related (totals) physical metrics were lower in the second half, but differences between both halves were significant in TD (m), HSRD (m), VelB4 (m), and HI Dec (n). Interestingly, high-intensity decelerations noted a significant decrease in the second 45 minutes, emphasising the importance of these eccentric actions in the modern football. Match play demands high velocity activities, and imposes several sharp and explosive actions in smaller spaces (Rhodes et al., 2021). Accelerations and decelerations have been found more energetically stressful than velocity-based movements (Delaney et al., 2018a) and associated with success in contemporary football. Hence, training design, considering transitional game demands, should focus on exposing players to these important metrics. This will better prepare players for match demands, conditioning specifically for performance with the aim of reducing the effect of game specific fatigue (Chapter 3 & 4). The present work also revealed higher outputs in all physical variables in won games, except high-intensity accelerations and decelerations.

Importantly, volume-related locomotor variables were decreased during TA's in the second half in lost games reaching significance for TD, HSRD, VelB4, and VelB5. Moreover, TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$) and SD ($m \cdot min^{-1}$) were also lower in the second 45min in lost matches, but only TD ($m \cdot min^{-1}$) revealed a significant drop. That said, no effect of match outcome and match half on all metrics per minute was found. A possible explanation could be that these differences might not be detected in short duration high-intensity activities (transitions) (Chapter 3). These findings are consistent with previous work in elite football showing a decline in physical performance in the second 45min (Bradley et al., 2013) as well as exploring the impact of peak intensity periods on match result (Oliva-Lozano et al., 2020a). Fatigue and/or inadequate recovery could explain the phenomenon of declined physical outputs and an increased risk of injury (Alexander et al., 2022; Rhodes at al., 2021). Moreover, the ability to run at high-velocity as an important indicator of physical performance in contemporary football (Mohr et al., 2003) might not be optimally stressed in training (Vazquez et al., 2023), which could potentially lead to decreased outputs in the final moments of the game.

To our knowledge, this is the first body ow work in elite football investigating the impact of match outcome on the second half physical performance. Changing physical output, work-rate, and tactical strategy has been previously linked to motivational aspects and to the score-line (Ponce-Bordón et al., 2021). To note, this investigation failed to analyse the effect of score-line on transitions and future studies should address these concerns. Nevertheless, these findings show that both absolute/relative volume- and intensity-related metrics were lower in the second half in lost matches. Thus, posing a question if practitioners/coaches adequately perform transitional activities during a weekly microcycle to best prepare and condition the players for these maximum intensity periods. Each TA's should be performed at high intensity to surprise the opponent with speed and create goalscoring opportunities in the offensive part, and react quickly to squeeze space and/or make an effective recovery run defensively (Bortnik et al., 2022; Gonzalez-Rodenas et al., 2020). Coaches could overload different locomotor and mechanical demands using various tactical drills with/without the ball possession (defence-to-offense transitions, offense-to-defence transitions, and fast attacks) and/or transitional games (large-, medium-, and small-sided) during midweek sessions (MD-4 and/or MD-3) (Martín-García et al., 2018; Oliva-Lozano et al., 2021a; Vázquez et al., 2023). It would be crucial to add/create more space to reach near-maximum speed, and quickly arrive to the penalty area (Riboli et al., 2020).

Small-sided games impose high-pressure demands on players and have been shown to over-stimulate (150%) high-intensity accelerations/decelerations, while large-sided games have been reported to overload sprinting demands by 125% (Martín-García et al., 2019). Also, it has been suggested to supplement SSG's that include keepers played in a smaller area with additional positional drills and running-based exercises to replicate the match peak intensity periods for high-velocity activities (Riboli et al., 2022). It is noteworthy that counter-attacks and fast attacks (offensive transitions) expose players to maximum velocity activities and generate nearly half of the game sprint distance (Chapter 3). Players have been shown to achieve higher running speed in transitional games versus SSG's and LSG's (Asian-Clemente et al., 2022). Moreover, transitional games show lower variability for different physical metrics, which could indicate a better suitability if a similar external load and sprinting actions were the main session objectives (Asian-Clemente et al., 2022). Another alternative approach to lower external load variability and expose all players to a greater physical output in a similar manner during different small-sided games, would be to play without goalkeepers (Riboli et al., 2022).

Being consistent with the current definition of repeated high-velocity efforts and accelerations in football (Buchheit et al., 2010), this work introduces a novel concept of clusters defined as more than two transitional activities within a period of 1 min. Findings indicate that the mean total number of clusters present across ten games were 12.2, which were higher than the ones previously reported in professional football (Carling et al., 2012). Additionally, our results show that the mean number of activities in clusters was equal to 2.6, peak 4.5, and mean total number of all TA's as clusters reached nearly 33.7 efforts. Decisive and contextualised high-intensity offensive / defensive phases (Carling et al., 2012) happen within a short period of time (<1 min) over 90min (Chapter 3). Short rest periods between successive high-intensity bouts could deteriorate physical performance (Balsom et al., 1992). Modern physical conditioning programmes (team, individual, and/or end-stage rehabilitation sessions) should emphasize TA's to improve players' ability to repeat high-intensity efforts over 90min (Carling et al., 2012) to better prepare for competition demands (Martín-García et al., 2019; Wass et al., 2020; Vázquez et al., 2023), reduce injuries and prevent declines in physical performance in the last stages of match play (Malone et al., 2017c). It is imperative to acknowledge that individual physical profile, willingness to run, style of play, level of opponent, and other situational and contextual factors would impact these physical demands (Gregson et al., 2010).

The evolving nature of football and its unpredictability provides insight to the need to no longer look at the averages or totals over 90min periods, but to observe transitional play physical output to understand better how often these phases occur, what is their context, duration, and recovery period (Nassis et al., 2020). Knowledge regarding transitional physical requirements gives greater insight into condensed game demands. It provides coaches with greater information to ensure training exposure is optimal, decreasing chance of under/over exposure. Moreover, fatigue has been linked to decreased physical performance, and/or associated with a lower number of players involved during collective high-intensity actions in the final minutes of match play (Mohr et al., 2003). Hence, given that many goals are scored in the second half, it is crucial that all players including substitutions are well prepared and conditioned for these final periods in competition (Hills et al., 2018).

5.6.1 Limitations

The same matches were investigated in Chapter 4 and 5. Although only ten games and one team analysed, the results from Chapter 5 provide insights and ammunition for further research. Moreover, the findings emphasise the importance of relative data to further tailor training to individual physical capabilities, especially high-speed running, and sprinting. Future studies should investigate transitional play across a greater period, higher number of matches, and across many elite football teams. Moreover, future research should analyse transitions using individual acceleration and deceleration thresholds, determine duration and rest periods between clusters, identify positional differences, explore other contextual variables (match location, formation, score-line, style of play, tournament play, weather, surface, etc.) and analyse replication of transitional exposure in training in relation to game (Carling et al., 2012).

5.7 Conclusion

In conclusion, the present chapter examined the effect of different contextual variables on transitional activities and identify repeated TA's (clusters) in elite football. Understanding the meaning of contextualised blocks of maximum output activities occurring in modern match play is of high importance to practitioners and coaches. Players should be trained accordingly to be able to withstand the most demanding passages of contemporary game, effectively fulfil their tactical / positional requirements, and repeatedly perform high-intensity offensive and defensive activities. Absolute and relative locomotor metrics should be closely monitored, and high-intensity accelerations and decelerations regularly imposed on players. This might potentially reduce the negative effects of fatigue on match performance. Nevertheless, these findings should be applied with caution, since only one team was analysed across ten games and more research is required in the future.

5.8 Practical implications

- Transitional activities expose players to the maximum physical demands much greater than the 90min averages.
- To counteract declines in physical performance in the second half, coaches could prescribe appropriate conditioning and tactical drills, introduce offensive (in possession) and defensive (out of possession) exercises and transitional games manipulating the pitch size, number of players, and play with/without goalkeepers to best prepare athletes for the competition demands
- Repeated transitional activities integrating offensive and defensive actions with a rest period shorter than 1 min could be utilised in team, individual and return to play sessions; for instance, counter-attacks might be followed by a defensive transition and then by a fast attack once the ball has been recuperated
- High-velocity (high-speed running) and high-intensity (decelerations) activities should be closely monitored during a weekly microcycles in relation to different positional groups to best condition players for the modern demands of competition and reduce the risk of injury (underprepardness)

5.9 Chapter Summary & Link to Chapter 6

This chapter found a significant impact of match half and match outcome on physical metrics during transitions. This was the first investigation that introduced a novel concept of repeated transitional activities (clusters) defined as two or more transitions within 1 minute. Findings revealed more repeated high-intensity actions across 90min than previously reported in professional football. Emphasising the importance of highly contextualised transitional activities and their repeated nature for potentially successful football performance, fatigue tolerance, and reduced risk of injury. Chapter 5 raised another question however regarding the time-related contextual factors such as 15-minute blocks and their effect on the physical demands during these phases, which has not been explored previously. Furthermore, the novel concept of clusters led to additional questions about the frequency, type, duration, and recovery period between repeated transitional activities. This knowledge would be considered of high importance to practitioners. In fact, the ability to repeatedly generate high-intensity actions individually and collectively in matches have been found a crucial component of successful performance in contemporary football and coaches should be able to reflect the correct work-to-rest-ratios in in offensive/defensive phases to optimally prepare players for the most demanding passages in match play. The next Chapter 6 investigates the impact of 15-min blocks on physical metrics during transitions and further explores clusters trying to determine their number, type, duration, and recovery period.

Chapter 6: Utilisation of Transitional Clusters Exhibited within Football Game Play to Inform Training Design

This chapter comprises the following manuscript published in Scientific Journal of Sport and Performance:

Bortnik, L., Burger, J., Morgans, R., Rhodes, D. (2023b). Utilisation of Transitional Clusters Exhibited within Football Game Play to Inform Training Design: Are we meeting the required demands? *Scientific Journal of Sport Performance*, 2(4): 439-453. https://doi.org/10.55860/ZURN6735. A synthesis of this study is demonstrated in Table 21.

SCIENTIFIC JOURNAL OF SPORT AND PERFORMANCE

ORIGINAL ARTICLE

Utilisation of transitional clusters exhibited within soccer game play to inform training design: Are we meeting the required demands?

Lukasz Bortnik. Football Performance Hub. Institute of Coaching and Performance (ICaP). School of Sport and Health Sciences. University of Central Lancashire. Preston, United Kingdom.
Performance & Sport Science Department. Hapoel Beer Sheva FC. Israel.
Joost Burger. Vrije University, Amsterdam. Netherlands.
Ryland Morgans. Football Performance Hub. Institute of Coaching and Performance (ICaP). School of Sport and Health Sciences. University of Central Lancashire. Preston, United Kingdom.
David Rhodes . Football Performance Hub. Institute of Coaching and Performance (ICaP). School of Sport and Health Sciences. University of Central Lancashire. Preston, United Kingdom.
Human Performance Department. Burnley FC. United Kingdom.

ABSTRACT

The aims of this study were to investigate the effect of 15min blocks on physical metrics during transitions, analyse frequency, type, duration, and recovery period between clusters of transitional activities (CTA) in elite football. During ten official matches 23 elite footballers were tracked using GPS devices. Metrics per minute (m·min^{-1}) as well as absolute variables: total distance (TD), high-speed running distance (HSRD > 19.8 km·h^{-1}), sprint distance (SD > 25.2 km·h^{-1}), relative high-speed running distance (VelB4), relative sprint distance (VelB5), acceleration distance (AccB3 Dist, distance with variations in running speed > 3 m·s^{-2}), the number of high-intensity accelerations (HI Acc > 3 m·s^{-2}) and decelerations (HI Dec > 3 m·s^{-2}) were quantified. Significant effects of 15min blocks were found for TD (m) ($p < .001$; ES = .078), TD (m·min^{-1}) ($p = .047$; ES = .036), HSRD (m) ($p = .033$; ES = .039), VelB4 (m) ($p < .001$; ES = .132), and HI Dec (n·min^{-1}) ($p = .002$; ES = .059). Transitional activities recovery period was found to be 108.5 ± 26.2 s, CTA recovery period was 25.7 ± 3.6 s, while CTA peak duration reached 53.3 ± 18.2 s. This study indicates that physical metrics decrease in the last 15min blocks during transitions and high-pressure activities in games. In conclusion, repeated high intensity / high velocity activities frequently occur during contextualized peak intensity periods (transitions) in football, which should be reflected in modern training design.
Keywords: Performance analysis of sport, Soccer, Transitions, Counterattack, High pressure, Peak demands, Repeated activities.

Cite this article as:
Bortnik, L., Burger, J., Morgans, R., & Rhodes, D. (2023). Utilisation of transitional clusters exhibited within soccer game play to inform training design: Are we meeting the required demands?. *Scientific Journal of Sport and Performance*, 2(4), 439-453. https://doi.org/10.55860/ZURN6735

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6.1 Chapter Overview

Despite a high tactical value and significance of transitional play and high-pressure activities in a modern football strategic approach, there are no previous studies that attempt to provide physical and technical-tactical insights about these crucial periods, deliver detailed information about positional differences, determine the impact of different contextual factors nor explore density of transitional activities in modern match play (Nassis et a., 2020; Wass et al., 2020). Current literature describes the effect of different playing styles including counter-attacks on physical, technical, and success-related metrics, merely depicting 90-min totals and fails to contextualise these variables into transitions (Forcher et al., 2023). Moreover, there are no studies to the authors knowledge that identify frequency, type, density, pattern of occurrence, duration and recovery period of transitional activities and high-pressure actions. Therefore, the main objective of the present body of work and represented in Chapter 6 is to better understand the impact of different contextual factors (15-min blocks) on physical demands during transitions and further explore repeated transitional activities (clusters) in official games. It is hoped that measuring high-intensity actions during critical offensive and defensive activities commonly used by elite teams to win games, would significantly add to the existing body of knowledge, and most importantly, effectively transfer new evidence to practical applied settings (Aranda et al., 2019; Forcher et al., 2023). It is worth noting that these short and highly contextual periods could easily be applied and replicated in training, possibly giving practitioners powerful ammunition to holistically prepare footballers for the most demanding passages in modern match play (Martin-Garcia et al., 2018; Oliva-Lozano et al., 2021b; Rochael et al., 2023a). The following text has been taken directly from the manuscript published in Scientific Journal of Sport and Performance (Bortnik et al., 2023b).

6.2 Abstract

The aims of this chapter were to investigate the effect of 15-minute blocks on physical metrics during transitions, analyse frequency, type, duration, and recovery period between clusters of transitional activities (CTA) in elite football. During ten official matches 23 elite footballers were tracked using GPS devices. Metrics per minute ($m \cdot min^{-1}$) as well as absolute variables: total distance (TD), high-speed running distance (HSRD, > 19.8 $km \cdot h^{-1}$), sprint distance (SD, > 25.2 $km \cdot h^{-1}$), relative high-speed running distance (VelB4), relative sprint distance (VelB5), acceleration distance (AccB3 Dist, distance with variations in running speed > 3 $m \cdot s^{-2}$), the number of high-intensity accelerations (HI Acc, > 3 $m \cdot s^{-2}$) and decelerations (HI Dec, > 3 $m \cdot s^{-2}$) were quantified. Significant effects of 15min blocks were found for TD (m) (moderate ES*s*; $p < .001$;), TD ($m \cdot min^{-1}$) (small ES*s*; $p = .047$;), HSRD (m) (small ES*s*; $p = .033$), VelB4 (m) (moderate ES*s*; $p < .001$), and HI Dec ($n \cdot min^{-1}$) (moderate ES*s*; $p = .002$). Transitional activities recovery period was found to be 108.5 ± 26.2 s, CTA recovery period was 25.7 ± 3.6 s, while CTA peak duration reached 53.3 ± 18.2 s. This study indicates that physical metrics decrease in the last 15-minute blocks during transitions and high-pressure activities in games. In conclusion, repeated high intensity / high velocity activities frequently occur during contextualised peak intensity periods (transitions) in football, which should be reflected in modern training design.

6.3 Introduction

Modern football match play has been described as an intermittent sport where both aerobic and anaerobic energy systems are stimulated during intense activities (accelerations, decelerations, changes of direction and sprints), which are usually combined with football specific technical actions (tackles, passes, headings, and shots) (Oliva-Lozano et al., 2020c). It has been shown that both physical and technical demands have increased within contemporary football, thus emphasising the need to reflect these changes in training design and integrate physical conditioning with technical-tactical aspects to better prepare football players for the modern demands of match play (Barnes et al., 2014; Nassis et al., 2020). Previous work has shown the importance of the match physical output analysis to better inform coaches and performance staff and optimally prescribe training load for each playing position (Harper et al., 2019; Wass et al., 2020). For this very purpose, valid and reliable wearable technology has been extensively used in research and practice to measure and track different absolute and relative physical metrics in training and official competitions (Scott et al., 2016). Most of the available / current research has paid attention to total and average match physical metrics, which merely reflect the volume of activity, yet neglecting fluctuations in physical and technical-tactical intensity, which may underestimate the intensity of the most demanding passages of football match play (Bortnik et al., 2022; Martin-Garcia et al., 2018).

To overcome this issue in elite football, there has been an increased focus on peak match demands, also referred to as worst-case-scenarios (WCS) (Riboli et al., 2021b). Different WCS durations have been investigated, and shorter duration peak demands were shown to generate higher intensity in football, which posts a question whether modern training design best prepares athletes for these short and specific high-intensity periods (Bortnik et al., 2022; Martin-Garcia et al., 2018). Still there is more information needed regarding the football context behind these peak intensity blocks (Chapter 5) as well as their pattern of occurrence within a modern match play (Novak et al., 2021). This knowledge would enable coaches and practitioners to design, implement, and apply conditioning drills integrating football-specific and tactical aspects (small-sided games, tactical and positional drills, transition games, etc.) to better replicate true match demands for each playing position (Novak et al., 2021; Riboli et al., 2021a).

Recent work that analysed the physical demands during transitional activities (TA's) in elite football, found greater high velocity demands compared to the 90-minute averages (Chapter 3 and 4). Although, this body of work analysed phases in isolation. Offensive (defence-to-attack) and defensive (attack-to-defence) transitions have been identified as the key match phases when goals are conceived and many risks undertaken (Tenga et al., 2010; Wass et al., 2020). Accordingly, high-pressure activities were shown to be effective in scoring goals and creating goal-scoring opportunities as well as impose high mechanical (accel/decel) demands on offensive players (Chapter 3), emphasising the need to be physically fit (Tenga et al., 2010). In fact, transitional activities occur when a team is in possession of the ball during an offensive collective team activity and/or out of possession trying to collectively win the ball back (defensive activity) (Chapter 5). Thus, representing a high context within a modern football game. The increased body of knowledge on these specific match phases (clusters) might be crucial in modern physical preparation of football players potentially having a direct impact on their match performance as well as reducing the risk of injury.

Previous investigations have explored match average physical outputs taking into account different contextual factors (match half, match location, match outcome) (Oliva-Lozano et al., 2020b; Rhodes at al., 2021). Nevertheless, the effect of different contextual variables on the most demanding match passages, as shown in Chapter 5, has not been widely researched (Oliva-Lozano et al., 2021a; Riboli et al., 2021). To the author's best knowledge there is no study investigating the effect of 15-minute blocks (intervals) on physical metrics during transitions in elite football. From a practical standpoint, comparing and knowing physical outputs in the first and last minutes of the match, might significantly influence the training drill design, potentially reduce a detrimental impact of fatigue on match performance and minimise risk of injury. In addition, there are no studies to the author's knowledge, investigating frequency, type, duration, and recovery period between offensive/defensive repeated short high-intensity efforts (clusters) during transitional play in football (Aranda et al., 2019).

It is noteworthy that the ability to work intermittently and repeatedly produce high-intensity efforts collectively as a team over 90 minutes have been found a crucial aspect of successful performance in modern football (Carling et al., 2012; Ju et al., 2022b). This knowledge about the number of repeated efforts and the rest interval between them would enhance training drill design for team collective tactical training and potentially improve football performance during key match phases (Chapter 5). Therefore, the current Chapter 6 aimed to 1) analyse the effect of 15min blocks (B1: 1'-15'; B2: 15'-30'; B3: 30'-45'; B4: 45'-60'; B5: 60'-75'; B6: 75'-90') on different absolute and relative physical metrics during TA's; 2) investigate clusters of transitional activities (CTA) in elite football; 3) explore the recovery period between clusters.

6.4 Materials and Methods

6.4.1 Participants

Data were collected on all twenty-three elite outfield players (*n* = 23) during 2020-2021 1st Polish Division (Ekstraklasa) season. Players were categorised into the following playing positions: center backs (*n* = 4), full backs (*n* = 5), central defensive midfielders (*n* = 2), central attacking midfielders (*n* = 2), central midfielders (*n* = 2), wingers (*n* = 5), and attackers (*n* = 3). Only starting players who completed minimum 60 minutes were analysed. Substitution players were not included in this study because they might produce higher physical outputs than starters due to pacing strategies (Wass et al., 2020). All subjects provided written and verbal informed consent for the use of their GPS data, in accordance with the Helsinki Declaration (2013). To ensure player confidentiality, all data was anonymised. Ethical approval was provided by the University of Central Lancashire (HEALTH 0104) (Appendix 8).

6.*4.2 Procedures & Experimental Design*

One UEFA CL qualifier and nine Polish domestic league matches (Ekstraklasa) between August and November of 2020 were investigated giving a total of ten games analysed (6 wins, 1 draw, and 3 losses). Analysis included 1164 offensive transitions, 1269 defensive transitions, 1120 fast attacks, and 696 high pressure activities, giving a total number of 4249 individual observations. The following number of observations per position were recorded: center backs (*n* = 884), full backs (*n* = 972), central defensive midfielders (*n* = 236), central attacking midfielders (*n* = 270), central midfielders (*n* = 578), wingers (*n* = 778), and attackers (*n* = 531). During each match, all players wore portable MEMS (10 Hz; Vector S7, Catapult Sports, Melbourne, Australia) located between the scapulae in a custom-made vest underneath their playing shirt. All subjects were accustomed to the entire procedure since they used GPS devices daily as part of their routine monitoring strategy. All GPS units were turned on 15 mins before the start of the match to ensure satellite connection. The data was screened for satellite coverage and horizontal dilution of precision (HDOP) using an inclusion criterion of > 6 satellites and ≤ 1.0 respectively, to ensure acceptable GPS coverage as previously recommended (Malone et al., 2017a). Each subject used the same GPS device for the entire period of investigation to avoid inter-unit error (Appendix 9). The validity and reliability of these wearables have been shown previously (Johnston et al., 2014; Scott et al., 2016).

All analysed metrics were previously used in other studies (Riboli et al., 2021b; Wass et al., 2020). They represented absolute distances covered per minute ($m \cdot min^{-1}$) in the following categories: total distance (TD), high-speed running distance (HSRD, > 19.8 $km \cdot h^{-1}$), sprint distance (SD, > 25.2 $km \cdot h^{-1}$), as well as the number of high-intensity accelerations and decelerations (A+D, > 3 $m \cdot s^{-2}$; $n \cdot min^{-1}$). In addition, the metrics depicted absolute distanced covered in the following categories: total distance (TD), high-speed running distance (HSRD), sprint distance (SD), the number of high-intensity accelerations (HI Acc, > 3 $m \cdot s^{-2}$), the number of high-intensity decelerations (HI Dec, > 3 $m \cdot s^{-2}$), and acceleration distance (AccB3 Dist, distance with variations in running speed > 3 $m \cdot s^{-2}$). Moreover, these variables reflected total relative high-speed running distance (VelB4) and relative sprint distance (VelB5), which have been claimed to represent the functional limits of endurance and sprint locomotor capacities (Mendez-Villanueva et al., 2012). As previously recommended, relative high-speed running distance (VelB4) and relative sprint distance (VelB5) was set as 100% maximal aerobic speed (MAS) – 30% (anaerobic speed reserve) ASR, and above MAS + 30% ASR, respectively (Mendez-Villanueva et al., 2012).

An incremental running treadmill test was conducted by the club physiologist to measure VO_2max and MAS. The test was performed in the gym environment with a normal ambient temperature and took place on a mechanical treadmill (Technogym, Italy). It began with an initial speed of 10 km/h^{-1} and each stage was increases by 1.5 km/h^{-1}. Five stages were set., with each stage lasting4 minutes, separated by 1 minute passive break (Manzi et al., 2022). The inclination was set at 1.5%. Polar heart rate monitors (Polar, Norway) and Polar M400 are used to record HR data. Expired gases were analysed breath-by-breath using an online automated gas analysis system (MetaLyzer® 3b-R2; Cortex Biophysik Gmbh, Leipzig, Germany) and accompanying software (MetaSoft® 3). Maximum oxygen uptake (VO_2max) was defined as the highest 15-s average oxygen uptake. Velocity (km/h^{-1}) during the maximum oxygen uptake (VO_2max) was recorded and set as the MAS (study 3) (Chapter 5).

After each match, transitional activities (TA's) were manually selected and tagged by the club's analysis team in the Catapult Vision video analysis system (Catapult Sports Ltd, Melbourne, Australia). Analysts used the observational methodology REOFUT theoretical framework to identify these periods (Collins et al., 2006), which was part of the club's analysis protocols utilised daily by the analysis team. Good to high intra- and inter-observer reliability of the current analysis method was previously shown (Tenga et al., 2010; Aranda et al., 2019; González-Rodenas et at., 2020). Data from the Catapult vision software were then downloaded and integrated into the manufacturer's software package (*Openfield*, version 3.2.0) and finally exported into Microsoft Excel (Microsoft Corporation, USA) to make additional calculations for each transitional play, clusters, and recovery periods. Clusters (CTA) were defined as two or more transitional activities that occurred within a period shorter than 61 secs as explained in Chapter 5 and previously recommended (Buchheit et al., 2010; Carling et al., 2012). The transition mean count average for selected variables and clusters frequencies were calculated as the sum total of all TA's, divided by their number. To get the clusters' peak duration, the highest values in 10 games were found, and their average was calculated as the sum of all peak duration values during clusters, divided by their number. Transitions were categorised into the following activities: positive transition (PT), negative transition (NT), fast attack (FA), and high pressure (HP), which were previously investigated by other authors (González-Rodenas et at., 2020; Tenga et al., 2010) as shown in Table 2 and 3. In addition, the game was divided into six 15-minute blocks: B1 (1'-15'), B2 (15'-

30'), B3 (30'-45'), B4 (45'-60') B5 (60'-75') B6 (75'-90') to determine the effect of time on physical metrics during TA's.

6.4.3 Statistical Analysis

The study used a descriptive analysis, and the results are depicted as mean ± standard deviation (SD). Between-matches, between-halves, and between 15-min blocks coefficient of variation (CV) values were calculated for transitions for selected metrics per minute. Statistical analyses was performed using IBM Statistical Package for the Social Sciences (SPSS, Version 27.0, IBM Corporations, New York, USA) with the statistical significance accepted at the 0.05 level. A univariate analysis of variance (ANOVA) was conducted to quantify main effects for games, transition type, and time (15min blocks). Interaction effects were also quantified, and any significant main effects associated with games, transitions, and time were investigated using post hoc pairwise comparisons. The assumptions associated with the statistical model were assessed to ensure model adequacy. To assess residual normality for each dependent variable, q-q plots were generated using stacked standardised residuals. Scatterplots of the stacked unstandardized and standardised residuals were also utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. Partial eta squared (η^2) were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared was classified as small (0.01–0.059), moderate (0.06-0.137), and large (>0.138), as previously suggested (Cohen, 1988).

6.5 Results

TD (m) analysis showed significant effects for game ($F = 4.590$, $p < .001$, partial $\eta^2 = .071$) and a transition type ($F = 17.097$, $p < .001$, partial $\eta^2 = .109$). Also, analysis of HSRD (m), SD (m), VelB4 (m), and VelB5 (m) identified significant effects for a transition type (HSRD: $F = 15.298$, $p < .001$, partial $\eta^2 = .099$; SD: $F = 9.916$, $p < .001$, partial $\eta^2 = .066$; VelB4: $F = 15.471$, $p < .001$, partial $\eta^2 = .100$; VelB5: $F = 12.614$, $p < .001$, partial $\eta^2 = .083$). In addition, TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$), SD ($m \cdot min^{-1}$), and A+D ($n \cdot min^{-1}$) analysis revealed significant effects for a transition type (TD: $F = 29.754$, $p < .001$, partial $\eta^2 = .176$; HSRD: $F = 14.441$, $p < .001$, partial $\eta^2 = .094$; SD: $F = 6.248$, $p < .001$, partial $\eta^2 = .043$; A+D: $F = 4.453$, $p = .004$, partial $\eta^2 = .031$). Moreover, a game x time interaction for HI Acc (n) ($F = 3.511$, $p = .001$, partial $\eta^2 = .055$) and A+D ($n \cdot min^{-1}$) ($F = 2.178$, $p = .035$, partial $\eta^2 = .035$) was discovered. Interactions of game, transition type, and time were nor found for TD (m), TD ($m \cdot min^{-1}$), HSRD (m), HSRD ($m \cdot min^{-1}$), SD (m), SD ($m \cdot min^{-1}$), VelB4 (m), VelB5 (m), HI Dec (n), and AccB3 distance (m) ($p > .05$)

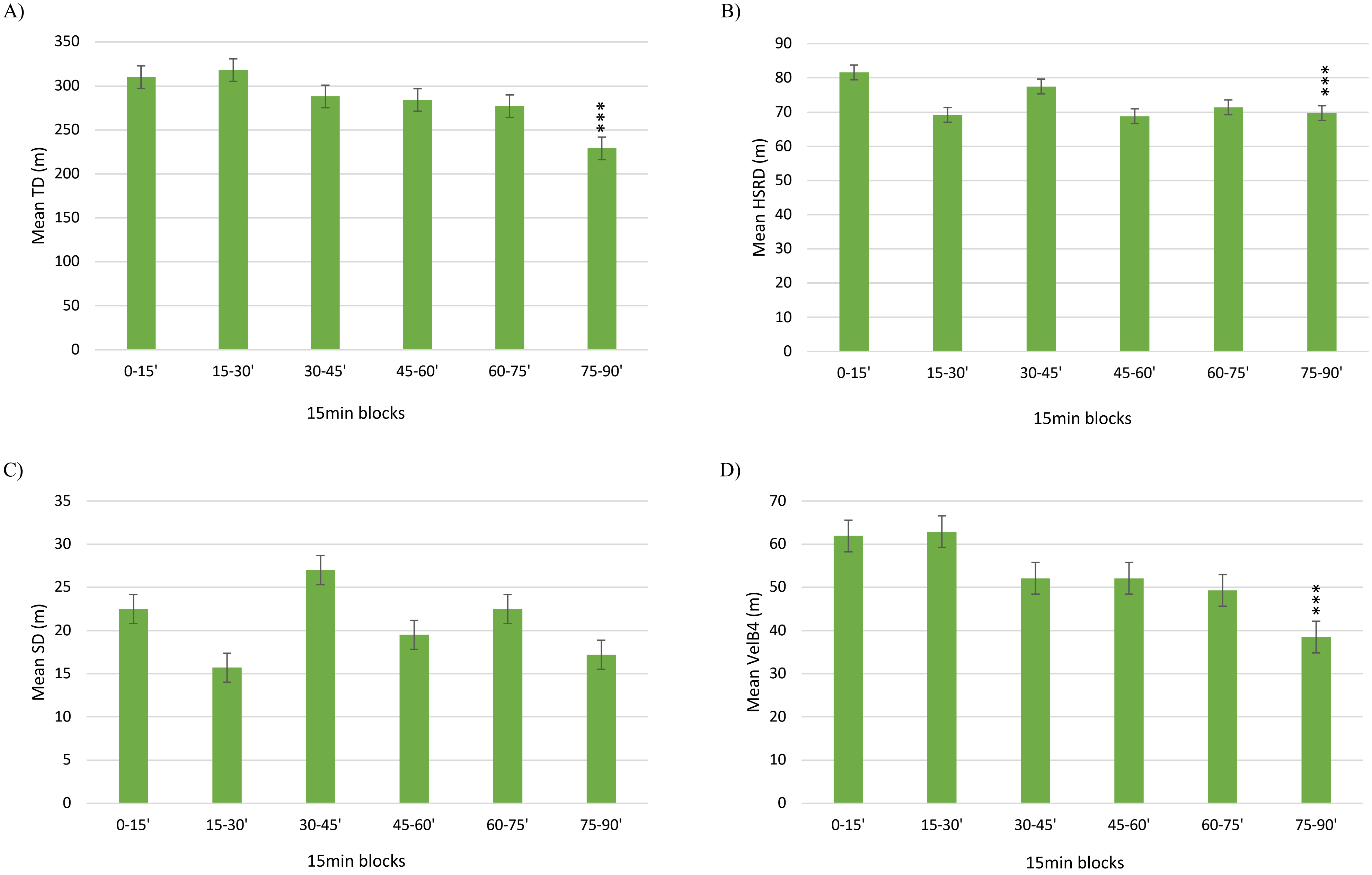
6.5.1 15-minute blocks

Analysis of TD (m), HSRD (m), SD (m), VelB4 (m), Vel B5 (m), HI accel (n), HI Dec (n) identified significant effects of game (TD: $F = 3.865$, $p < .001$, partial $\eta^2 = .081$; VelB5: $F = 2.079$, $p = .046$, partial $\eta^2 = .046$) and a transition type (TD: $F = 16.361$, $p < .001$, partial $\eta^2 = .139$; HSRD: $F = 15.437$, $p < .001$, partial $\eta^2 = .132$; SD: $F = 7.766$, $p < .001$, partial $\eta^2 = .071$; VelB4: $F = 19.383$, $p < .001$, partial $\eta^2 = .160$; VelB5: $F = 12.041$, $p < .001$, partial $\eta^2 = .106$; HI Accel: $F = 3.009$, $p = .031$, partial $\eta^2 = .029$; HI Dec: $F = 2.998$, $p = .031$, partial $\eta^2 = .029$). There was a game x time interaction ($F = 1.536$, $p = .031$, partial $\eta^2 = .150$) and a game x transition type x time interaction ($F = 1.493$, $p = .018$, partial $\eta^2 = .218$) for VelB4 (m). Also, a game x time interaction was found for HI Acc (n) ($F = 2.580$, $p < .001$, partial $\eta^2 = .228$) as well as a game x transition type x time interaction for HI Dec (n) ($F = 1.493$, $p = .018$, partial $\eta^2 = .218$). No interactions of game, transition type, and time were discovered for TD (m), HSRD (m), SD (m), VelB5 (m), AccB3 distance (m) ($p > .05$).

Additional analysis identified statistically significant effects of time (15min blocks) for TD (m), HSRD (m), Relative high-speed running distance (VelB4) (m), and high-intensity decelerations HI Dec ($n \cdot min^{-1}$) (TD: $F(5,305) = 5.195$, $p < .001$, partial $\eta^2 = .078$; HSRD: $F(5,305) = 2.263$, $p = .033$, partial $\eta^2 = .039$; VelB4: $F(5,305) = 9.303$, $p < .001$, partial $\eta^2 = .132$; HI Dec: $F(5,305) = 2.407$, $p = .002$, partial $\eta^2 = .0590$). Further analysis of metrics per minute revealed only significant effects for TD ($m \cdot min^{-1}$) (TD: $F(5,305) = 2.277$, $p = .047$, partial $\eta^2 = .036$).

Post Hoc tests showed significant difference between the first and last 15min blocks for TD (m) and TD ($m \cdot min^{-1}$), HSRD (m), relative high-speed running distance (VelB4) (m), relative sprint distance (VelB5) (m) ($p < .001$) as well as number of HI Dec ($p = .006$). Other metrics did not reveal any significant differences between 15min blocks ($p > .05$).

Figure 31 highlights the effects of time (15min blocks) on absolute physical metrics that occur during transitions, accompanied with significant difference between 0-15’ and 75-90’. The effect of time (15min blocks) on metrics per minute in all transitions across the games analysed, accompanied with the p-value for 0-15’ and 75-90’ is displayed in Figure 32. Figure 33 displays the match-to-match variability for transitions in 1st and 2nd half, transitions in 15min blocks, and all transitions.


A)
Mean TD (m)
350
300
250
200
150
100
50
0
***
0-15'
15-30'
30-45'
45-60'
60-75'
75-90'
15min blocks
B)
Mean HSRD (m)
90
80
70
60
50
40
30
20
10
0
***
0-15'
15-30'
30-45'
45-60'
60-75'
75-90'
15min blocks
C)
Mean SD (m)
35
30
25
20
15
10
5
0
0-15'
15-30'
30-45'
45-60'
60-75'
75-90'
15min blocks
D)
Mean VelB4 (m)
70
60
50
40
30
20
10
0
***
0-15'
15-30'
30-45'
45-60'
60-75'
75-90'
15min blocks

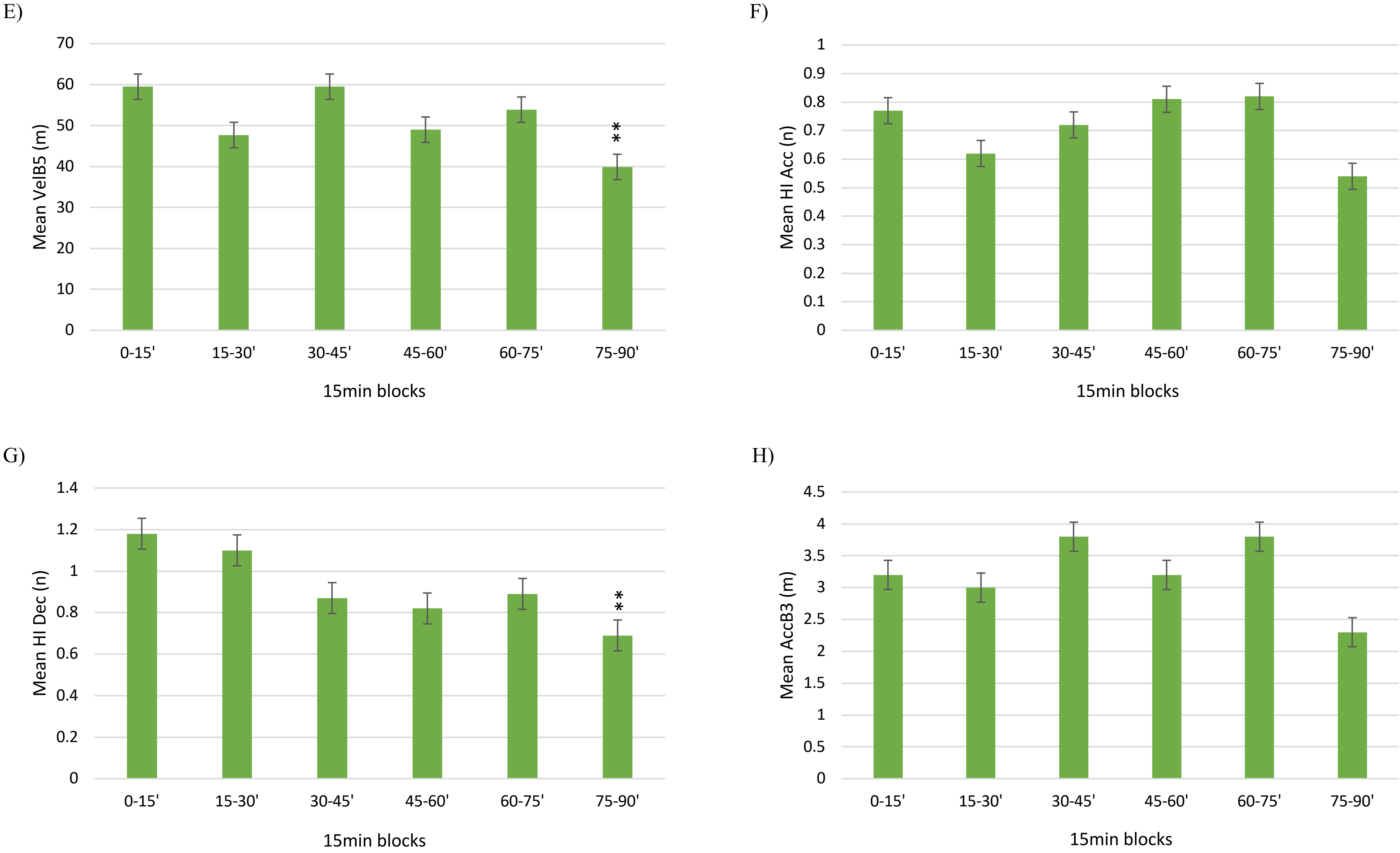


Figure 31. Effects of time (0-15', 15-30', 30-45', 45-60', 60-75' and 75-90') on a) mean total distance (TD), b) mean high-speed running distance (HSRD), c) mean sprint distance (SD), d) mean relative high-speed running distance (RelV4), e) mean relative sprint distance (RelV5), f) mean number of high-intensity accelerations (HI Acc), g) mean number of high-intensity decelerations (HI Dec), and h) mean high-intensity acceleration distance (AccB3) during transitions and high pressure activities.

Note: Different from 0-15' * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

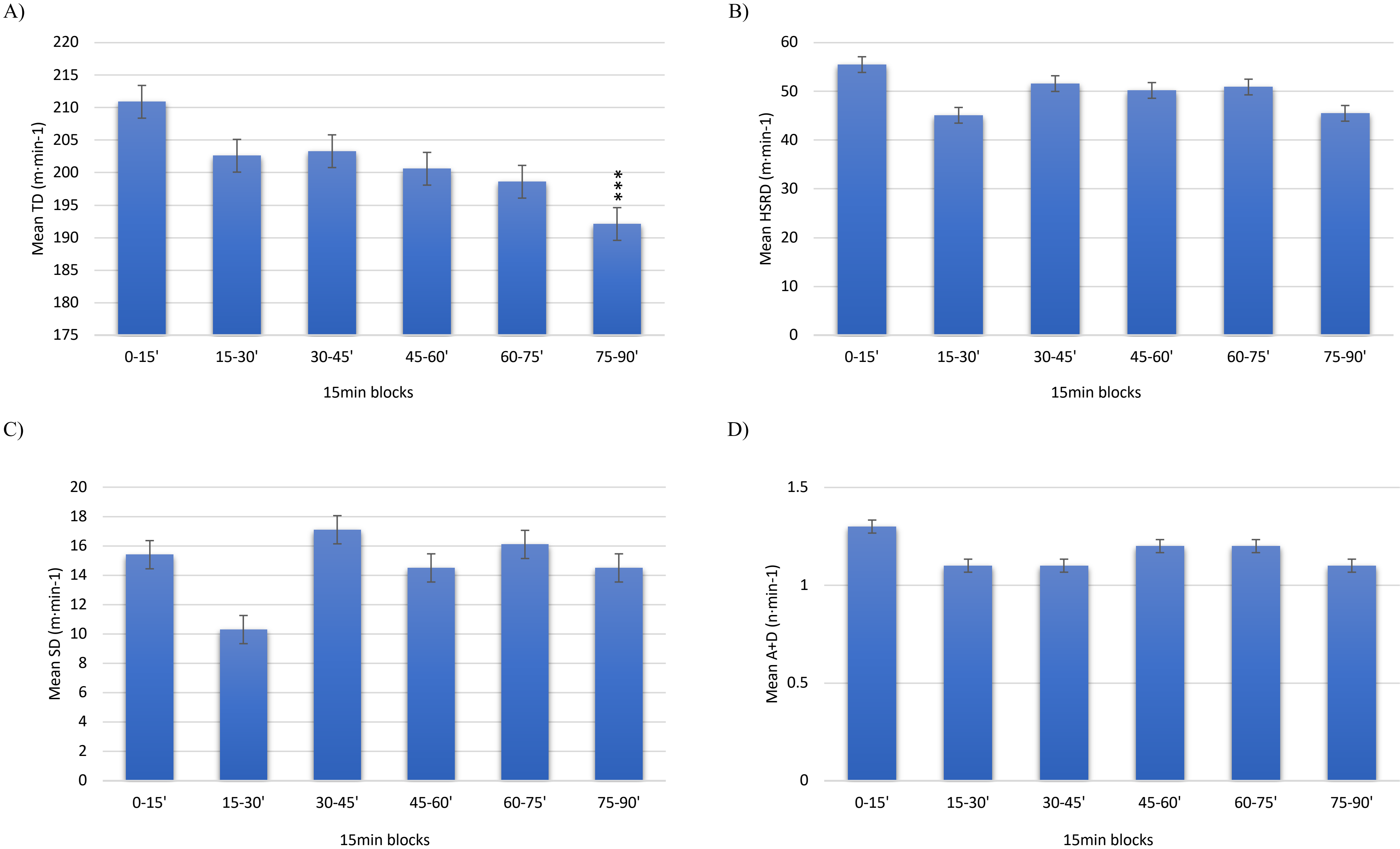


Figure 32. Effects of time (0-15', 15-30', 30-45', 45-60', 60-75' and 75-90') on a) mean TD (m·min^{-1}), b) mean HSRD (m·min^{-1}), c) mean SD (m·min^{-1}), and d) mean A+D (n·min^{-1}) during transitions and high-pressure activities across 10 matches.

Note: Different from 0-15' * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

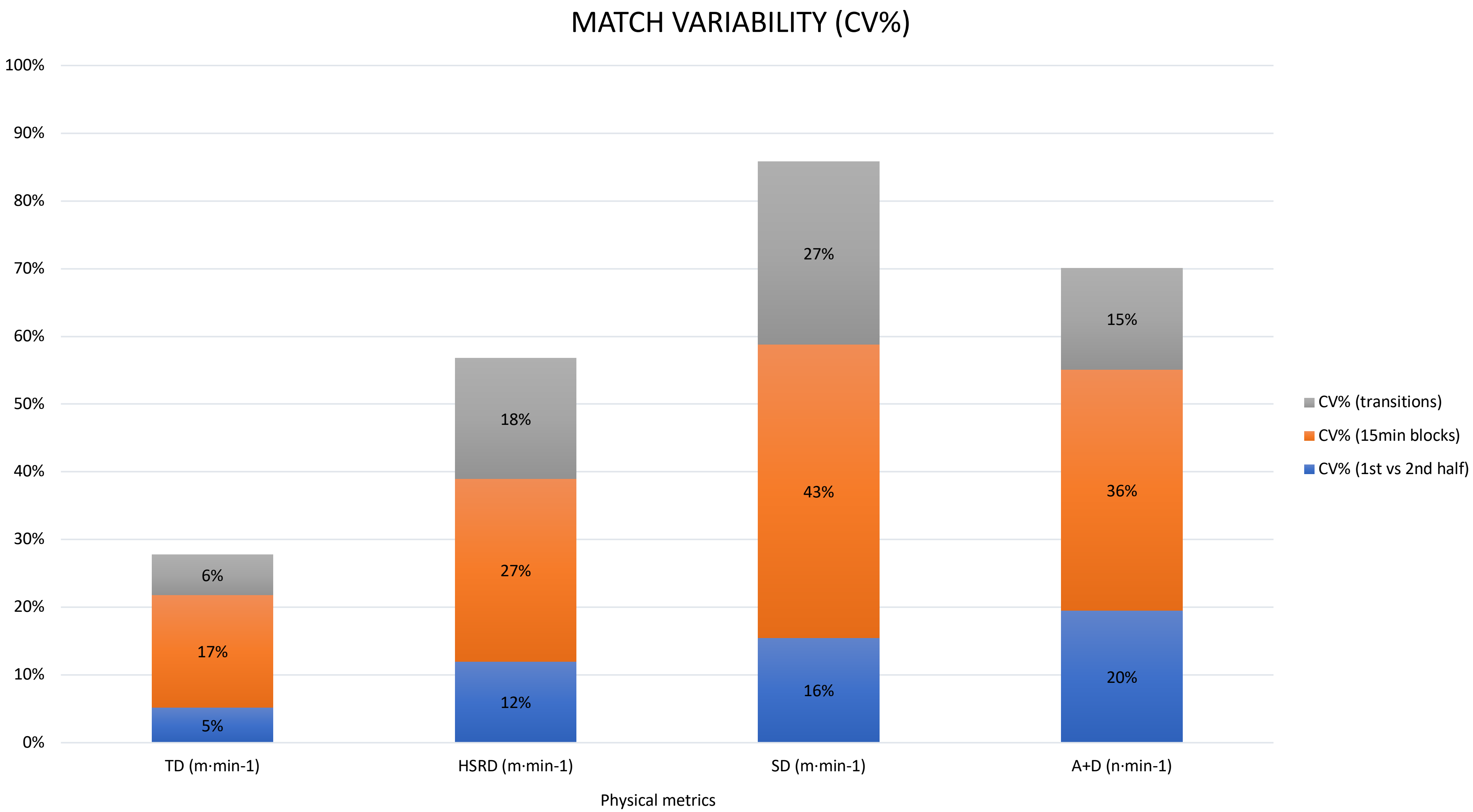


Figure 33. The match-to-match variability depicted as CV (%) for transitions in 1st vs. 2nd half (white), transitions in 15min blocks (granite), and all transitions (white marble) across 10 matches are shown for total distance: TD (m·min^{-1}), high-speed running distance: HSRD (m·min^{-1}), sprint distance: SD (m·min^{-1}), and number of accelerations/decelerations: A+D (n·min^{-1}).

Table 12 depicts duration-related metrics including recovery periods for transitional activities (TA's) and clusters, accompanied by the mean, standard deviations, confidence interval (CI), min and max. Frequency of clusters' transitional activities shown as the mean, standard deviations, percent, min, and max are detailed in Table 13. Table 14 highlights the frequencies of transitional activities in clusters and matches expressed as the mean, standard deviations, confidence interval (CI), and percent.

Table 12. Mean ± SD, 95% confidence intervals and minimum/maximum duration-related metrics including recovery periods for transitional activities (TA's) and clusters across 10 official matches.

DURATION (s)	*Mean ± SD*	*95%CI*	*Minimum*	*Maximum*
TAs recovery period	108.5 ± 26.2	89.8 – 127.2	72.0	164.0
Cluster TAs duration	9.9 ± 1.0	9.2 – 10.6	9.0	12.0
Cluster total duration	28.0 ± 5.8	23.9 – 32.1	23.0	42.0
Cluster TA recovery period	25.7 ± 3.6	23.1 – 28.3	21.0	32.0
Cluster peak duration	53.3 ± 18.2	40.0 – 66.3	29.0	94.0

Table 13. Frequency of clusters' transitional activities.

TRANSITION	*Mean count ± SD (cluster)*	*Percent (%)*	*Minimum count*	*Maximum count*
NT	10.1 ± 3.7	31	4	17
PT	8.3 ± 3.6	25	5	17
FA	7.9 ± 4.0	24	3	15
HP	6.4 ± 5.1	20	1	15
TOTAL	**32.7 ± 11.5**	**100**	**16**	**52**

Table 14. Comparisons between clusters' transitional activities and match TA's frequencies.

TRANSITION	*Mean count ± SD (cluster)*	*Mean count ± SD (match)*	*Percent (%)*
NT	10.1 ± 3.7	15.2 ± 4.6	66%
PT	8.3 ± 3.6	13.7 ± 4.2	61%
FA	7.9 ± 4.0	13.0 ± 3.6	61%
HP	6.4 ± 5.1	7.7 ± 6.5	83%
TOTAL	**32.7 ± 11.5**	**50.0 ± 11.1**	**66%**

Note: PT = Positive transition; NT = Negative transition; FA = Fast attack; HP = High pressure depicted as a count and percent of transitions in clusters expressed as a mean ± SD and percent across 10 official matches.

6.6 Discussion

The aims of the present Chapter 6 were to investigate the effect of 15min blocks on physical metrics during transitions, analyse clusters of transitional activities (CTA), and explore the recovery period between clusters in elite football. This is the first research investigating frequency, type, duration, and recovery period between repeated TA's defined as clusters. Main findings revealed that out of 50 transitions that occurred on average across ten games (Chapter 3), 33 were repeated activities (CTA), with a range of 16 to 52. In fact, on average 66% of all transitional activities were clusters, which in practical terms means that more than 2 TA's occurred within 1 min as explained in Chapter 5 (Buchheit et al., 2010). Repeated high-intensity / high-velocity efforts during short and contextualised blocks of activity might be more frequent in modern football match play than previously reported (Carling et al., 2012). Thus, posing a question whether coaches and practitioners adequately prepare players for modern match play demands. Further work is required to determine this by comparing transitional work completed in training to game output. Negative transitions (NT) reached highest number (31%), followed by positive transitions (PT), and fast attacks (25%, and 24% respectively). High-pressure activities (HP) were least frequent (20%). However, 83% of all HP activities were repeated revealing the importance and an integrative meaning of these defensive actions in modern match play (Appendix 11).

The current body of work found that mean cluster transitional activity (CTA) duration was no different from other transitional activities (Chapter 3) and lasted around 10 secs (Gonzalez-Rodenas et al., 2020). CTA mean total duration was nearly three times longer (28 secs), with CTA peak duration found to be 53 secs. In addition, the study showed that the mean rest interval between all transitional activities was over four times longer than mean CTA recovery period (108.5 sec vs. 25.7 sec). An important consideration in relation to work:rest ratios, when specifically conditioning players.
This work revealed a novel concept of clusters described as > 2 transitional activities occurring within 1 minute (Chapter 5). Football is an intermittent sport, and the ability to perform repeated actions has been found an important component of success in elite football (Carling et al., 2012). Short recovery between phases of high-intensity efforts might have a detrimental effect on physical performance (Balsom et al., 1992) and hence, gaining knowledge surrounding repeated high-intensity efforts (CTA) within match play in relation to the frequency, tactical context, and recovery periods informs training design, thus potentially influencing match performance, and injury risk (Carling et al., 2012; Nassis et al., 2020). Future research should consider the positional differences during these intensified blocks of activity.

Interestingly, absolute and relative physical metrics during transitions decreased as the game progressed in time. Recently, it has been reported that players generated the highest number of high-intensity actions in the first 15min blocks of each half (Oliva-Lozano et al., 2023a). Fatigue and/or insufficient rest might be the main reason of a declined physical performance and potentially a higher risk of injury (Rhodes et al., 2021). These findings are consistent with previous studies exploring fatigue effects in elite football revealing physical performance differences existing between both halves and separate 15-minute periods in male and female footballers (Barrera et al., 2021; Bortnik et al., 2023a; Datson et al., 2017). This could be due to non-specific approach to physical performance analysis. Demands of the games are influenced by individual team approach, individual capacity, level of opponent, and playing philosophy (Rampinini et al., 2007). Consideration of cluster analysis would provide vital information for practitioners to inform the physical demands required for each player and the prescribed work:rest ratios needed within training design. It is acknowledged that these demands were quantified over 10 games and further work is needed over a greater number of games across different leagues and clubs in a season.

Findings within the present chapter revealed a significant reduction in absolute metrics of TD (m), HSRD (m), VelB4 (m), and the number of HI Dec during TA's, when comparing the first and last 15min blocks. The detrimental impact of fatigue on muscle function due to repeated high velocity actions has been well documented (Harper et al., 2019; Rhodes et al., 2019). Suggesting that the repeated actions experienced in the clusters presented in the current body of work, result in a decrease in physical performance of these metrics over time. This reduction in high velocity running has been associated with inadequate training or preparation (Vasquez et al., 2023). It is proposed that this is a result of decreased insight into the current demands of transitional play (Chapter 5), and the present study provides a deeper analysis of the true physical demands of contemporary football. Recently, there has been an increased focus on acceleration and deceleration performance due to their high neuromuscular demand and impact on match outcome (Djaoui et al., 2022; Rhodes et al., 2021). It is important to note that despite low running speed in game play these high intensity actions are repeatedly required (Gaudino et al., 2013). Increasing knowledge of the peak demands of these actions, will inform training design, potentially reducing the resultant fatigue effects demonstrated in this body of work. It is noteworthy to state that we explored absolute and relative locomotor metrics, and future work should also use individual acceleration / deceleration thresholds to better reflect players' individual physical performance capacities (Carling et al., 2012).

Interestingly, the current chapter demonstrated that 83% of HP activities were performed in conjunction with other transitional actions. Evidence identifies that HP activities are an aggressive approach to winning the ball back and creating goalscoring chances (Vogelbain et al., 2014). Resulting in higher mechanical loads (Chapter 3 and 4). Incorporation of defensive tasks aiming at rapidly closing down space and pressing opponents with other offensive activities in possession to either keep the ball and/or initiate a fast attack and/or counter-attack, would provide specificity in preparing players for game play. This would potentially increase fatigue tolerance of repeated high velocity actions that can occur at any time within a game (Oliva-Lozano et al., 2021b). Cluster analysis related to transitional activity provides practitioners with greater detail with regards the intensity and frequency of the blocks of activity and it is essential that training design incorporates this notion (Chapter 5). This would maximise physical performance and specifically condition players, potentially reducing injury risk.

Previous studies reported that the mean transition performance ($m \cdot min^{-1}$) between official football games had around 16% match-to-match-variability (Rampinini et al., 2007; Riboli et al., 2021b). Our findings showed lower variability between the first and second 45-min (13%), and higher between 15min blocks (31%). Hence, shorter high-intensity specific blocks of activity were revealing highest unpredictability within each game. Surprisingly, sprinting activities (SD; $m \cdot min^{-1}$) were found to be much more consistent between halves (16% variability) in contrast to the match transitions sprinting demands (27% variability) and 15min blocks that had the highest variance (43%). Data demonstrated that not high-velocity activities (Gregson et al., 2010; Rampinini et al., 2007), but A+D ($n \cdot min^{-1}$) represented the greatest unpredictability between both halves (20%). However, SD ($m \cdot min^{-1}$) had the highest overall variability across all metrics, which is consistent with previous studies (Bortnik et al., 2022; Riboli et al., 2021b). These results show high dynamics and unpredictability of the contemporary game and hence, inform how challenging it is to design training for elite footballers in practical settings (Gregson et al., 2010). Nevertheless, the physical and tactical workload players are exposed to during peak intensity blocks in contemporary match play is not only dependent on opponent / teammate's activities (Bradley et al., 2020), but also on many different contextual factors such as match location, match half, match outcome (Chapter 5), score-line, playing formation, etc., and other (Gregson et al., 2010). These important match-related contextual variables were not included in our analysis and future studies should investigate the impact of these factors on the physical demands during transitions in football.

Based on the main findings, transitional activities and transitional games in/out of possession (defence-to-offense transitions, offense-to-defence transitions, and fast attacks) could be considered a crucial component of a weekly training plan in modern training design (Ju et al., 2022a). Offensive transitions (counter-attacks) should be executed at maximum effort to surprise opponents and create chances to score a goal (Gonzalez-Rodenas, et al., 2020). From a practical standpoint, it would be important to add more space to reach near-maximum velocity (Chapter 3) while over/underlapping, running with ball, exploiting space, and breaking into penalty box (Riboli et al., 2020) since successful elite football teams were found to generate higher intensity during these activities (Ju et al., 2023a). Offensive transitions have recently been found to significantly overload 90min sprinting demands and accumulate nearly half match sprint distance (Chapter 3). These phases are full of technical-tactical context and a powerful ammunition to expose players to maximum velocity actions in training (Chapter 4). Defensively, on the other hand, players should be able to react quickly, squeeze space, apply high pressure, cover, and perform a recovery run to stop the opposition attack (Gonzalez-Rodenas et al., 2020; Ju et al., 2022a). Midweek sessions (MD-4 / MD-3) might offer an optimal timeframe to overload different locomotor and mechanical metrics and reflect the repeated high-intensity activity profile of modern match play (Martín-García et al., 2018; Martín-García et al., 2019; Oliva-Lozano et al., 2021a; Vázquez et al., 2023).

Despite quite long mean recovery period between TA’s found in this chapter (108 sec), the mean total duration of clusters and mean recovery periods between repeated transitional activities (CTA) indicated that speed endurance production mode could be effectively used with elite footballers integrating both physical and tactical aspects to improve performance during blocks of maximum intensity as previously reported in football (Bradley et al., 2018a; Mohr et al., 2016; 2017). Repeated sprint training consisting of actions below 10 seconds and sprint interval training using all-out efforts lasting around 20-30 secs might also be utilized to prepare players for CTA in competition (Hostrup et al., 2019). More research is needed to compare training to match transitional activities and determine if speed endurance training / sprint intervals positively impacts players physical performance during CTA.

6.6.1 Limitations

Clusters of transitional activities were quantified over 10 games and further work is needed over a greater number of games across different leagues and clubs in a season. This body of work only explored absolute and relative locomotor metrics, and future studies should also use individual acceleration / deceleration thresholds to better represent players' individual physical performance capacities (Carling et al., 2012). Many important contextual factors such as match location, match half, match outcome, score-line, playing formation, etc., (Gregson et al., 2010) were not included in our analysis and future investigations should determine the impact of these factors on the physical demands during transitions in football. Also, research should consider and explore the positional differences during clusters of transitional activities. Previous Chapters 3 to 6 merely analysed physical performance in matches and further work is required to compare transitional work completed in training to game output.

6.7 Conclusions

It is highly important to understand the meaning of contextualised blocks of maximum intensity activities (transitions) within contemporary football match play. Modern football training design should move away from 90min averages and consider conditioning players for short blocks of repeated high intensity / high velocity activities that frequently occur together during transitional play in elite football. Such approach might counteract a detrimental impact of fatigue on team and individual physical / tactical performance in last stages of match play and potentially reduce the risk of injuries. This knowledge might prevent the mismatch between true match physical demands and training content during an overload weekly phase. Findings of this research could serve a high practical significance for coaches, practitioners, and physical therapists. It is important to note that any analysis of game demand and resultant training design is individually defined by the football philosophy of the club and coaching team.

6.8 Practical implications

Transitional activities in games expose players to repeated and intermittent high intensity / high velocity actions together. To reduce decline in physical output during contextualised blocks of maximum intensity at the end of match play, coaches and practitioners could apply different transitional games in and out of ball possession, tactical drills (offensive and defensive), and various sided games (pitch size, number of players, with/without goalkeepers) to adequately condition players for the modern physical demands of competition and potentially lower injury risk. During transitional games and tactical drills coaches might consider performing pressing high up in the opponent's half in conjunction with other transitional activities. For instance, pressing should be followed by a counter-attack and/or fast attack within a short period of time. Additionally, speed endurance production, repeated sprints, and sprint intervals with appropriate work:rest ratios that integrate position-specific technical / tactical aspects might be considered during team/individual/return-to-play sessions to replicate the demands of clusters in training and optimally prepare players for the most physically demanding passages in games. It would be important in these sessions to create additional space to perform attacking actions and break into penalty box at high velocity. Finally, high-speed activities and high-intensity decelerations should be monitored closely during a weekly microcycle taking into a consideration position-specific needs in football to avoid over/underloading.

6.9 Chapter Summary & Link to Chapter 7

The four Chapters above (3 to 6) provided more insights about short specific and highly contextualised maximum-intensity periods defined as transitions and high-pressures in modern football match play. It has been widely accepted that by monitoring match performance coaches could gain additional knowledge necessary to optimise training design in practical settings by selecting appropriate and effective exercise modes to maximise players development and improve physical performance, increase readiness to play and potentially reduce injury risk. These chapters analysed only match performance and the gap between training and competition should be further explored regarding these maximum-intensity periods. Therefore, the findings raised another important question whether the physical outputs ($m \cdot min^{-1}$) during the maximum-intensity blocks (WCS) in training would reflect the match play peak intensity periods (30-second WCS) in different contextual scenarios (playing status, playing position, congested periods). Rationale for selecting 30-sec periods was based on findings in Chapter 6 that revealed repeated transitional activities (clusters) occurring frequently in match play and lasting on average around 30 seconds. This knowledge of potential training vs. match play mismatch for various physical metrics relative to positional demands would be considered important for coaches in elite football settings. Practitioners should be able to select optimal drills, games and exercise modes to effectively mimic/overload the high-velocity/intensity demands of competition, adequately stress starters and substitutes as well as gain more insight about the short WCS during the intensified match phases (congested period). Therefore, the next Chapters 7 will try to better understand 30-second WCS within training and game play in professional football.

Chapter 7: Worst Case Scenarios in Football Training and Competition: Analysis of Playing Position, Congested Periods and Substitutes

This chapter comprises the following manuscript published in Research Quarterly for Exercise and Sport:

Bortnik, L., Nir, O., Forbes, N., Alexander, J., Harper, D., Bruce-Low, S., Carling, C., & Rhodes, D. (2023c). Worst Case Scenarios in Soccer Training and Competition: Analysis of Playing Position, Congested Periods, and Substitutes. *Research Quarterly for Exercise and Sport*, 1–13. Advanced online publication. https://doi.org/10.1080/02701367.2023.2290265. A synthesis of this study is demonstrated in Table 22.

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Worst Case Scenarios in Soccer Training and Competition: Analysis of Playing Position, Congested Periods, and Substitutes

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ABSTRACT

Aim: To understand mean (WCS_{mean}) and peak (WCS_{peak}) worst case scenarios within training and game play in male professional soccer. **Methods**: Thirty-one ($n = 31$) first team players were monitored across 37 matches and 14 MD-3 sessions. Playing status was distinguished, football drills analyzed, and performance explored in long-period: >6 days, moderate-period: 5–6 days, and congested-period: ≤4 days. Relative total distance (TD), high-speed running distance (HSRD, >19.8 km·h^{-1}), sprint distance (SD, >25.2 km·h^{-1}), accelerations/decelerations (A+D, >3 m·s^{-2}), accelerations (Acc, >3 m·s^{-2}), and decelerations (Dec, >–3 m·s^{-2}) were measured as well as Maximum acceleration (Max Acc; m·s^{-2}) and deceleration (Max Dec; m·s^{-2}). **Results**: Analysis of variance found differences between matches and training in WCS_{mean} for TD, HSRD, SD, and Max Dec in all positions ($p < .001$; partial $\eta^2 > .275$). Fullbacks displayed differences between match and training in Max Acc (moderate ESs; $p < .001$), while center backs and central midfielders in Max Dec (large ESs; $p > .05$). Main effects of playing status were discovered for all metrics except Max Dec ($p < .001$; partial $\eta^2 > .124$). Analysis showed differences between long- and congested-period for A+D and Dec (large ESs; $p \leq .05$). **Conclusions**: Findings provide more insights into short peak intensity demands of soccer showing that the maximum high velocity action of acceleration and deceleration is not being replicated in training. Nonstarters lack maximum intensity exposure in matches (WCS_{peak}) increasing the gap between training and competition even higher during congested fixture periods.

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7.1 Chapter Overview

Despite a high tactical value and significance of transitional play in a modern football strategic approach, there are no previous studies that attempt to provide physical and technical-tactical insights about these crucial periods, deliver detailed information about positional differences, determine the impact of different contextual factors nor explore short 30-sec worst-case-scenarios (WCS) in modern match play (Nassis et a., 2020; Wass et al., 2020). Current literature describes the effect of different playing styles including counter-attacks on physical, technical, and success-related metrics, merely depicting 90-min totals and fails to contextualise these variables into short and specific maximum-intensity periods (Forcher et al., 2023). Therefore, the main objective of the present body of work and represented in Chapter 7 is to compare training to official matches and analyse the effect of various contextual factors (playing position, playing status, congested periods) on physical performance during these maximum-intensity blocks (WCS_{mean} and WCS_{peak}) in elite football. It is hoped that measuring high-intensity actions during critical offensive and defensive activities would significantly add to the existing body of knowledge, and most importantly, effectively transfer new evidence to practical applied settings (Aranda et al., 2019; Forcher et al., 2023). It is worth noting that these short and highly contextual periods could easily be applied and replicated in training, possibly giving practitioners powerful ammunition to holistically prepare footballers for the most demanding passages in modern match play (Martin-Garcia et al., 2018; Oliva-Lozano et al., 2021b; Rochael et al., 2023a). The following text has been taken directly from the manuscript published in Research Quarterly for Exercise and Sport (Bortnik et al., 2023c).

7.2 Abstract

To understand mean (WCS_{mean}) and peak (WCS_{peak}) worst case scenarios within training and game play in male professional football. Thirty one (n = 31) first team players were monitored across 37 matches and 14 MD-3 sessions. Playing status was distinguished, football drills analysed, and performance explored in long-period: > 6 days, moderate-period: 5-6 days and congested-period: ≤ 4 days. Relative total distance (TD), high-speed running distance (HSRD, > 19.8 $km \cdot h^{-1}$), sprint distance (SD, > 25.2 $km \cdot h^{-1}$), accelerations/decelerations (A+D, > 3 $m \cdot s^{-2}$), accelerations (Acc, > 3 $m \cdot s^{-2}$), decelerations (Dec, > -3 $m \cdot s^{-2}$) were measured as well as Maximum acceleration (Max Acc; $m \cdot s^{-2}$) and deceleration (Max Dec; $m \cdot s^{-2}$). Analysis of variance found differences between matches and training in WCS_{mean} for TD, HSRD, SD, Max Dec in all positions (large ES*s*; $p < .001$). Fullbacks displayed differences between match and training in Max Acc (moderate ES*s*; $p < .001$), while center backs and central midfielders in Max Dec (large ES*s*; $p > .05$). Main effects of playing status were discovered for all metrics except Max Dec (moderate ES*s*; $p < 0.001$). Analysis showed differences between long- and congested-period for A+D and Dec (large ES*s*; $p \leq .05$). Findings provide more insights into short peak intensity demands of football showing that the maximum high velocity action of acceleration and deceleration is not being replicated in training. Non-starters lack maximum intensity exposure in matches (WCS_{peak}) increasing the gap between training and competition even higher during congested fixture periods.

7.3 Introduction

Wearable technology has been accepted as a valid and reliable tool to track absolute and relative distances in different speed zones, average speed, and changes in speed (accelerations and decelerations) in various team sports including football (Scott et al., 2016). Technical-tactical, and physical analysis of modern match play informs the training process by making a comparison between competition and training prescription in all aspects (Harper et al., 2019; Wass et al., 2020). Thus, coaches can better understand the required intensity of certain football specific drills and comprehend each player's activity profile to a higher extent (Carling et al, 2008; Delaney et al., 2018b). The main goal of comparing competition physical demands to training, is to ensure players receive optimal physical stimulus relative to competition and positional demands to maximise their physical performance and reduce injury risk (Novak et al., 2021; Riboli et al., 2021a).

It is crucial to understand how match physical metrics are presented, to not only describe the volume of activity over the full, half and/or quarter of the game, but truly reflect intensity over shorter duration windows (Delaney et al. 2018b; Novak et al., 2021). To depict intensity during different moments of the game and assess worst-case-scenarios (WCS), data can be analysed during attacking / defending phases, in ball possession (ball-in-play), using shorter periods of predetermined durations, and applying a rolling average during different time windows (e.g. 1 to 15 min) (Novak et al., 2021; Weaving et al., 2022). Football is very unpredictable; events and actions happen randomly and don't usually occur during predetermined phases (Delaney et al., 2018b). Hence, using fixed durations to assess WCS lacks sensitivity and might underestimate true running demands up to ~ 25% (Fereday et al., 2020). Rolling averages compared to fixed time epochs across different durations could be more accurate and appropriate to calculate locomotor load during peak match demands in professional football (Fereday et al., 2020; Martin-Garcia et al., 2018; Riboli et al., 2021a; Riboli et al., 2021b). The moving average approach considers the intermittent nature of football and the natural variability within the game (Whitehead et al., 2018). These WCS are often characterised by high intensity actions, occurring at intermittent moments, often impacted by contextual and situational factors (Oliva-Lozano et al., 2020b). Varying durations of WCS have been analysed in football, and shorter periods have been shown to produce the highest physical outputs (Martin-Garcia et al., 2018).

The multifactorial WCS concept has recently been questioned due to its instability and difficulty to be applied in practical settings (Novak et al., 2021). Despite new findings about match peak demands distribution (Riboli et al., 2021a), there is no knowledge about what happens during these peak intensity passages with regards to technical-tactical activities as well as physiological adaptations (internal response) (Novak et al., 2021). This knowledge could enable coaches and practitioners to integrate physical and tactical aspects in training design to best prepare athletes for the position specific high-intensity periods within a modern game (Chapter 3). Regrettably, current literature focuses on how to design and deliver WCS training merely based on one physical metric (i.e. total distance per minute), which has been considered a limitation since high physical stress players are exposed to during these peak phases would not be fully reflected (Martin-Garcia et al., 2018). Importantly, WCS although maximal in matches, might not truly represent players' maximal aerobic capacity nor speed, and therefore should never be used by practitioners as a substitute of running drills based on physiological markers (e.g. VO_{2max} and lactate threshold), commonly used as intensity indicators in physical preparation training in football (Weaving et al., 2022).

It has been reported that different WCS time epochs appear far greater than the football match mean values, especially for high-velocity activities and sprinting actions (Riboli et al., 2021b). Logically, mean values include periods of inactivity and all stoppages, which severely underestimates the locomotor and mechanical intensity of competition (Martin-Garcia et al., 2019). Recent study found that most distances covered at various speed zones, and acceleration/deceleration efforts were performed at intensity above the average 90-min demands (Riboli et al., 2022). This shows how important it is to apply high-intensity work in training, use regular mechanical exposure to high speed and specific conditioning drills to reduce injury risk and prepare players physically for specific demands (Novak et al., 2021; Riboli et al., 2021a). Differences across various playing positions during the most physically demanding passages in football have also been reported, and thus positions should always be considered in the WCS concept (Martín-García et al., 2018; Riboli et al., 2021b). It is noteworthy that physical outputs change in relation to many different contextual and situational factors such as willingness to compete, coaching style and philosophy, level of opposition, etc. (Gregson et al., 2010; Bradley et al., 2011; Carling et al., 2011). Moreover, future studies should provide better understanding of these factors including players status differences (starting vs substitute players) as well as analyse differences between congested and non-congested periods during peak intensity moments in football (Jiménez et al., 2022; Novak et al., 2021). This information would be considered important for coaches and practitioners for optimal top-up session design as well as adequate workload application and recovery strategy during the weekly microcycle (Novak et al., 2021; Riboli et al., 2021b).

It has been shown in football that central sessions of the microcycle such as match day minus three (MD-3) have been the most demanding days of the week (Morgans et al., 2023). We will refer to it as the football conditioning day. Coaches seek to replicate and/or overload different physical metrics (distances in various speed zones, sprint, accelerations, and decelerations) on that day by using small-sided (SSG), medium-sided, and large-sided games (LSG), possession, and transitional games, and pressing activities, which all reflect high specificity (Oliva-Lozano et al., 2021b). Recently, the WCS between training and match play in elite football was compared and discovered significant differences in all physical metrics (total distance, high-speed running, and sprint distance) across all days of the week including MD-3 (Oliva-Lozano et al., 2021b). Different game formats have also been compared to match day peak intensity blocks across different time epochs. In fact, SSG exposed players to lower locomotor load compared to competition, while overloading the mechanical load (accelerations and decelerations) (Lacome et al., 2018). This suggests that players might not be conditioned appropriately to meet the demands placed on them during match play and in particular the physical stresses imposed during WCS.

Given the limited number of papers on the peak intensity periods in elite football, more work is required for both training and game scenarios to answer many questions and better inform training prescription regarding the WCS concept. Specifically, research has mainly studied time epochs from 1 to 10 min durations (Weaving at al., 2022) and knowing that elite football teams perform high tempo attacking actions below 20 sec, and peak duration of crucial attacking/defending activities (transitions) last between 20-30 sec (Chapter 3 and 6), more focus should be paid to shorter duration epochs (e.g., 30 sec). These short periods could offer more football specific ways to expose players to maximum physical outputs they achieve in competition (Chapter 4). Also, short running-based exercises (short high-intensity intervals and repeated sprints) have been commonplace in football training and associated with better sprinting performance (Nobari et al., 2023). Thus, it could be reasonable to suggest that regular mechanical exposure to high-velocity activities in training might offer many benefits linked to improved football performance, increased readiness to play and potentially lower risk of injury (Chapter 3 and 6). Moreover, coaches and practitioners are limited today to basic and commonly used physical variables (locomotor and mechanical) to reflect match demands in training during short maximum intensity periods (Riboli et al., 2021b). Additional metrics comparing match play and training intensity should be explored. This research is unique and novel since it includes additional physical data (Max Acc and Max Dec) and for the first time, analyses physical match and training performance during 30-sec maximum intensity periods in different situational and contextual scenarios, which could potentially add more practical value to football training design. Therefore, the current Chapter 7 aims to 1) compare 90-min demands to mean and peak 30-sec WCS in different metrics per minute; 2) investigate physical outputs in WCS during selected football specific drills and assess positional differences between MD-3 and competition; 3) explore differences between starters and non-starters during WCS; and 4) measure the impact of different recovery periods between games (long vs moderate vs congested period) on match day WCS.

7.4 Materials and Methods

7.4.1 Participants

Thirty one (*n* = 31) Israel Premier League male outfield players from a top three team in the country were monitored in thirty-seven (*n* = 37) competitive matches across two consecutive seasons: 2021-2022 and 2022-2023 from February to October. Players were classified according to playing positions: center backs (*n* = 4), full backs (*n* = 5), central midfielders (*n* = 10), wingers (*n* = 6), and attackers (*n* = 6). Both starters (n = 3063 individual observations) and non-starters (*n* = 846 individual observations) were included in the study and their outputs compared. Starters completed minimum 60 min, while non-starters (subs) entered the game in the 2nd half and played minimum 5 min (i.e. including stoppage time) and maximum 45 min (Hills et al., 2022). Players needed to participate in MD-3, MD-2, and MD-1 sessions and match play to be included in the study. Only comparisons between match and training performance were made with players who participated in an official match; other players were excluded from analysis. The study was approved by the Ethics Committee of the University of Central Lancashire (HEALTH 0104) (Appendix 8). All participants provided written and verbal informed consent for the use of their GPS data in accordance with the Declaration of Helsinki (1975).

7.4.2 Procedures & Experimental Design

A total of thirty seven (*n* = 37) competitive games were analysed. Both match day (MD) and match day minus three (MD-3) physical data were collected during this period. A total of *n* = 3,909 individual observations were extracted from all matches. To compare match to training performance, thirteen MD (n = 13) played in the late evening (between 19:00 to 21:00) and fourteen MD-3 (n = 14) sessions conducted in the morning (between 9:00 to 10:00) were investigated, giving a total of *n* = 1,533 match observations and *n* = 1,860 training observations. The comparisons were averaged across all training sessions and matches for each playing position. Training sessions are commonly categorised according to days prior a match (MD minus (-)) and post-match (MD plus (+)) (Morgans et al., 2023). This investigation analysed only a conditioning day in the coaches' weekly schedule (MD-3). This day integrated technical, tactical, and physical components and aimed to overload different physical outputs in relation to individual match physical demands. Small-sided (SSG) and large-sided games (LSG) were used to reflect the football specific match demands (Riboli et al., 2020). Detailed description of all drills performed on MD-3 are reported in Table 16. Different formats of LSG and SSG were undertaken as well as running drills performed. Area per player (ApP) was calculated excluding goalkeepers. All exercises were done under a supervision of several coaches to maintain a high work ratio. In games, a ball was immediately made available by replacement when it went out of play. Corners were replaced by a ball in game by the keeper who had additional balls positioned near the goal to facilitate the restart of the game. Coach feedback was present during each drill (Riboli et al., 2020). High pressure was demanded after the ball was lost and high-intensity ("as fast as possible") required during offensive transitional attacks (10v10 Transitions) (Rochael 2023b). Players were instructed to follow intensity (timed activity) guided by a coach during running-based drills (Extra and Submax). A standardised warm up preceded each game under a guidance of the club's strength and conditioning coach. In addition, tagging 30-sec periods for each participant (explained below) was very labour extensive, hence only MD-3 was included in the current study. The following number of observations per positions were recorded: center backs (*n* = 701), full backs (*n* = 421), central midfielders (*n* = 1223), wingers (*n* = 525), and attackers (*n* = 325). Matches were categorised according to number of recovery days between matches: a) long-period: > 6 days (*n* = 12), b) moderate-period: 5-6 days (*n* = 10), and c) congested-period: ≤ 4 days (*n* = 15) (Djaoui et al., 2022).

Physical performance data was captured using portable MEMS (10 Hz; Vector X7, Catapult Sports, Melbourne, Australia) which were worn between players' scapulae under a playing/training jersey in a custom designed vest. This reflected routine monitoring strategies in the club and all players were familiar with it. Each subject wore the same device throughout the study to avoid inter-unit variation. The MEMS units were turned on at least 15-min prior to the start of session warm-ups to ensure acceptable satellite coverage. As previously suggested, the data was checked for satellite coverage and horizontal dilution of precision (HDOP) using an inclusion criterion of > 6 satellites and ≤ 1.0, respectively (Malone et al., 2017a). The validity and reliability of this system have been reported previously, indicating excellent intra-unit reliability (Scott et al., 2016). ICC values varied between 0.77 (95% CI: 0.62-0.89) (very large) to 1.0 (95% CI: 0.99-1.0) (nearly perfect) for the measurement of physical outputs such as distances at different velocity bands (Nicolella et al., 2018). For mechanical load, these devices have shown acceptable reliability for accelerations (CV = 1.4 ± 1.5% to 4.2 ± 1.5%), and acceptable to poor reliability for decelerations (CV = 2.5 ± 1.5% to 10.9 ± 1.5%) (Thornton et al., 2019).

Variables studied were previously used by others (Riboli et al., 2021b; Wass et al., 2020) and represented the following metrics covered per minute ($m \cdot min^{-1}$): total distance (TD), high-speed running distance (HSRD, > 19.8 $km \cdot h^{-1}$), sprint distance (SD, > 25.2 $km \cdot h^{-1}$). In addition, number of the following actions were quantified: accelerations and decelerations (A+D, > 3 $m \cdot s^{-2}$; $n \cdot min^{-1}$), accelerations (Acc, > 3 $m \cdot s^{-2}$; $n \cdot min^{-1}$), and decelerations (Dec, < -3 $m \cdot s^{-2}$; $n \cdot min^{-1}$). Also, the value of maximum acceleration (Max Acc; $m \cdot s^{-2}$), and deceleration (Max Dec; $m \cdot s^{-2}$) was analysed.

Once the session (training and game) had concluded, the data was transferred to the manufacturer's software package (*Openfield*, version 3.7.3) to extract training and 90-min match data. Extra time was excluded from analysis. The software used rolling moving average to calculate the most demanding 30-sec period (WCS: worst case scenario) of each participant for total distance (TD; $m \cdot min^{-1}$). To include all above metrics for analysis, 30-sec periods / tags were manually created on top of these individual peak intensity passages by the club's analysis department. In contrast to generally adopted technique to analyse different metrics in isolation during WCS, this technique enables observing locomotor demands in conjunction with accelerations and decelerations during the maximum intensity intervals in football match play (Novak et al., 2021; Sydney et al., 2023). For match day minus three (MD-3), 30-sec WCS were named after a drill they occurred in and were used to analyse and compare peak intensity periods between different exercises utilised in training. Finally, data were exported into Microsoft Excel (Microsoft Corporation, USA) to make additional calculations for all peak intensity periods. The mean 30-sec period (WCS_{mean}) for selected variables was calculated as the sum total of all observations, divided by their number. To compute the peak 30-sec period (WCS_{peak}), the highest values for all metrics in each game were found, and their average was calculated as the sum of all peak values, divided by their number.

7.4.3 Statistical Analysis

The study used descriptive analysis, and the results are depicted as mean ± standard deviation (SD). Between-matches coefficient of variation (CV) values was calculated for 30-sec blocks during different recovery periods for all metrics. Inferential statistical analyses were performed using IBM Statistical Package for the Social Sciences (SPSS, Version 27.0, IBM Corporations, New York, USA) with the statistical significance accepted at the 0.05 level. A univariate analysis of variance (ANOVA) was conducted to quantify main effects for 30-sec period, position, players' status (starters and non-starters), and recovery period (long-, moderate-, and congested-period). Interaction effects were also quantified, and any significant main effects associated with periods, positions, status, and recovery period were investigated using Bonferroni post hoc pairwise comparisons. The assumptions associated with the statistical model were assessed to ensure model adequacy. To assess residual normality for each dependent variable, q-q plots were generated using stacked standardised residuals. Scatterplots of the stacked unstandardized and standardised residuals were also utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. Partial eta squared (η^2) were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared was classified as small (0.01–0.059), moderate (0.06-0.137), and large (>0.138), as previously suggested (Cohen, 1988).

7.5 Results

Displayed in Table 15 is the mean, standard deviations, and 95% confidence intervals (CI) for TD ($m \cdot min^{-1}$), HSRD ($m \cdot min^{-1}$), SD ($m \cdot min^{-1}$), A+D ($n \cdot min^{-1}$), Acc ($n \cdot min^{-1}$), Dec ($m \cdot min^{-1}$), Max Acc ($m \cdot s^{-2}$), and Max Dec ($m \cdot s^{-2}$) for WCS_{mean} and WCS_{peak}, respectively and 90-minute averages for each of the listed metrics. Table 16 highlights drills performed on match day minus three (MD-3), their level of specificity, area size, and characteristics. Table 17 depicts all analysed physical metrics for match day WCS_{mean} in long-period (>6days), moderate-period (5-6 days), and congested-period (≤ 4days), accompanied by the mean, standard deviations, confidence interval (CI), and match-to-match variability of the listed physical variables.

Table 15. Team mean ± SD and 95% confidence intervals for total distance: TD ($m{\cdot}min^{-1}$), high speed running distance: HSRD ($m{\cdot}min^{-1}$), sprint distance: SD ($m{\cdot}min^{-1}$), number of accelerations and decelerations: A+D ($m{\cdot}min^{-1}$), number of accelerations: Acc ($m{\cdot}min^{-1}$), number of decelerations: Dec ($m{\cdot}min^{-1}$), maximum acceleration: Max Acc ($m{\cdot}s^{-2}$), maximum deceleration: Max Dec ($m{\cdot}s^{-2}$), and differences (%) between whole-match (90-min), mean and peak 30sec WCS across 37 official matches.

	90-min		WCS_{mean}		WCS_{peak}		Percentage (%)	
	Mean ± SD	95%CI	Mean ± SD	95%CI	Mean ± SD	95%CI	90-min vs WCS_{mean}	90-min vs WCS_{peak}
TD (m)	101.4 ± 4.3	100.0 to 102.8	174.3 ± 8.0	171.3 to 177.0	203.8 ± 12.0	199.8 to 207.8	58.2	49.8
HSRD (m)	5.7 ± 1.1	5.3 to 6.1	29.7 ± 6.4	27.6 to 31.8	54.6 ± 8.9	51.6 to 57.6	19.2	10.4
SD (m)	1.1 ± 0.3	1.0 to 1.2	7.7 ± 2.9	6.7 to 8.7	21.4 ± 7.2	19.0 to 23.8	14.3	5.1
A+D (n)	2.4 ± 0.3	2.3 to 2.5	4.1 ± 0.4	4.0 to 3.9	6.3 ± 1.2	5.9 to 6.7	58.5	38.1
Acc (n)	1.2 ± 0.1	1.16 to 1.24	2.0 ± 0.2	1.9 to 2.1	3.3 ± 0.6	3.1 to 3.5	60.0	36.4
Dec (n)	1.2 ± 0.1	1.15 to 1.25	2.0 ± 0.2	1.9 to 2.1	3.3 ± 0.6	3.1 to 3.5	60.0	36.4
Max Acc	5.1 ± 0.6	4.9 to 5.3	3.8 ± 0.2	3.7 to 3.9	4.7 ± 0.4	4.6 to 4.8	134.2	108.5
Max Dec	-6.5 ± 0.6	-6.7 to -6.3	-4.5 ± 0.3	-4.6 to -4.4	-6.0 ± 0.6	-6.2 to -5.8	144.4	108.3

Table 16. Selected drills performed on MD-3 (match day minus three), their technical-tactical level of specificity, area size (ApP: area per player; m²), content and characteristics.

Drills	Exercise mode	Level of technical-tactical specificity (Chena et al.,2022)	Area size	Content and characteristics of each drill	Duration range	Bouts range
10v10 Medium	Large-sided game	High specificity	ApP: 170 - 200 m^2 (medium space)	10v10 training games continuously played on a medium space with two keepers. Players keep their positions and normal game rules apply.	8-20 min	2 to 3
10v10 Transitions	Large-sided tactical game		ApP: 200 - 250 m^2 (medium - large space)	10v10 training intermittent games played on a large space with two keepers. Players keep a ball possession in a small-medium space and attempt to exploit a free space behind the defence line to quickly get into the opposition box. Five players attack and three players defend.	3-6 min	4 to 6
5v5	Small-sided game	Moderate - high specificity	ApP: 128 - 160 m^2 (small - medium space)	5v5 games continuously played on a small-medium space with two keepers. Players aren't assigned to playing positions. All balls are distributed by keepers.	3-5 min	3 to 4
4v4			ApP: 120 - 160 m^2 (small - medium space)	4v4 games continuously played on a small-medium space with two keepers. Players aren't assigned to playing positions. All balls are distributed by keepers.	3-4 min	4 to 5
Extra	Top-ups - high velocity running with changes of direction	Minimum specificity	box to box: 75 meters	Box-to-box (around 75m) runs alternated with box-to-half pitch-to-box (around 38m) runs. Each effort lasts between 12-15 seconds and its interspersed with 24 to 30-second recovery period (1:2 work to rest ratio)	12-15 sec	8 to 12
Submax runs	High velocity shuttles		50 meters	50-meter straight-line shuttles lasting 7-8 seconds (22 - 25 km/h) interspersed with 22-second recovery period (1:3 work to rest ratio)	7-8 sec	8 to 10

Table 17. Team mean ± SD, 95% confidence intervals, and coefficient of variation: CV (%) in periods of long-period (>6days), moderate-period (5-6days), and congested-period (≤4days recovery) during mean 30sec WCS for total distance: TD ($m\cdot min^{-1}$), high speed running distance: HSRD ($m\cdot min^{-1}$), sprint distance: SD ($m\cdot min^{-1}$), number of accelerations and decelerations: A+D ($n\cdot min^{-1}$), number of accelerations: Acc ($n\cdot min^{-1}$), number of decelerations: Dec ($n\cdot min^{-1}$), maximum acceleration: Max Acc ($m\cdot s^{-2}$), maximum deceleration: Max Dec ($m\cdot s^{-2}$) across 37 official matches.

	WCS_{mean}								
	LONG-PERIOD (>6days) (n=12)			MODERATE-PERIOD (5-6days) (n=10)			CONGESTED-PERIOD (≤4days) (n=15)		
	Mean ± SD	95%CI	CV (%)	Mean ± SD	95%CI	CV (%)	Mean ± SD	95%CI	CV (%)
TD (m)	174.6 ± 10.6	170.1 to 179.1	6.1	176.0 ± 14.1	169.4 to 182.6	8.0	181.8 ± 16.8	175.6 to 188.1	9.2
HSRD (m)	30.0 ± 7.2	33.0 to 36.0	24.1	32.2 ± 10.7	27.2 to 37.2	33.2	36.6 ± 15.6	30.8 to 42.5	42.6
SD (m)	7.9 ± 3.3	6.5 to 9.3	41.3	7.9 ± 4.4	5.8 to 9.9	55.4	10.2 ± 6.7	7.7 to 12.7	65.8
A+D (n)	4.6 ± 1.2 #	4.2 to 5.0	25.8	4.2 ± 0.7	3.7 to 4.6	15.9	4.1 ± 0.9	3.8 to 4.4	20.8
Acc (n)	2.4 ± 0.6	2.1 to 2.6	26.7	2.1 ± 0.4	1.9 to 2.4	19.8	2.0 ± 0.5	1.9 to 2.3	26.3
Dec (n)	2.3 ± 0.6 #	2.1 to 2.5	27.2	2.0 ± 0.3	1.8 to 2.3	13.9	2.0 ± 0.4	1.8 to 2.2	22.0
Max Acc	2.5 ± 0.2	2.4 to 2.6	8.2	2.5 ± 0.2	2.4 to 2.6	9.0	2.4 ± 0.2	2.3 to 2.5	9.8
Max Dec	-2.7 ± 0.3	-2.8 to -2.6	9.7	-2.7 ± 0.2	-2.8 to -2.6	8.6	-2.6 ± 0.3	-2.7 to -2.5	9.9
Overall			22.8			20.5			25.8

Note: Significant differences from congested periods # ($p \leq 0.05$). Number of games are displayed as n.

Comparisons between WCS_{peak} in training and competition for TD ($m{\cdot}min^{-1}$), HSRD ($m{\cdot}min^{-1}$), SD ($m{\cdot}min^{-1}$), A+D ($n{\cdot}min^{-1}$), Acc ($n{\cdot}min^{-1}$), Dec ($n{\cdot}min^{-1}$), Max Acc ($m{\cdot}s^{-2}$), and Max Dec ($m{\cdot}s^{-2}$) for different playing positions can be seen in Figure 34. Figure 35 shows differences between WCS_{mean} in drills, match day as well as 90-minute averages for selected physical metrics. Comparison between starters and non-starters in match day WCS_{mean} and WCS_{peak} for TD ($m{\cdot}min^{-1}$), HSRD ($m{\cdot}min^{-1}$), SD ($m{\cdot}min^{-1}$), Acc ($n{\cdot}min^{-1}$), and Dec ($m{\cdot}min^{-1}$) is displayed in Figure 36.

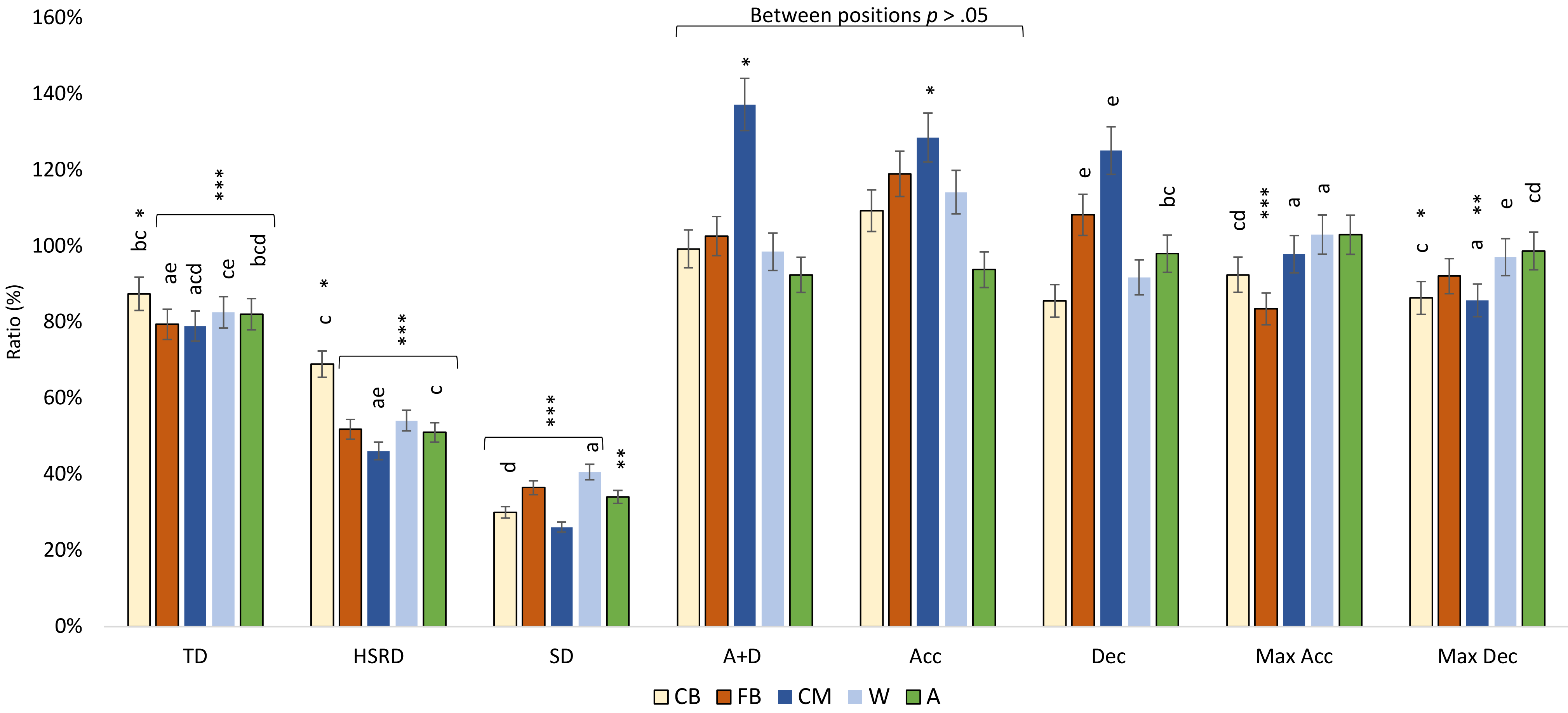
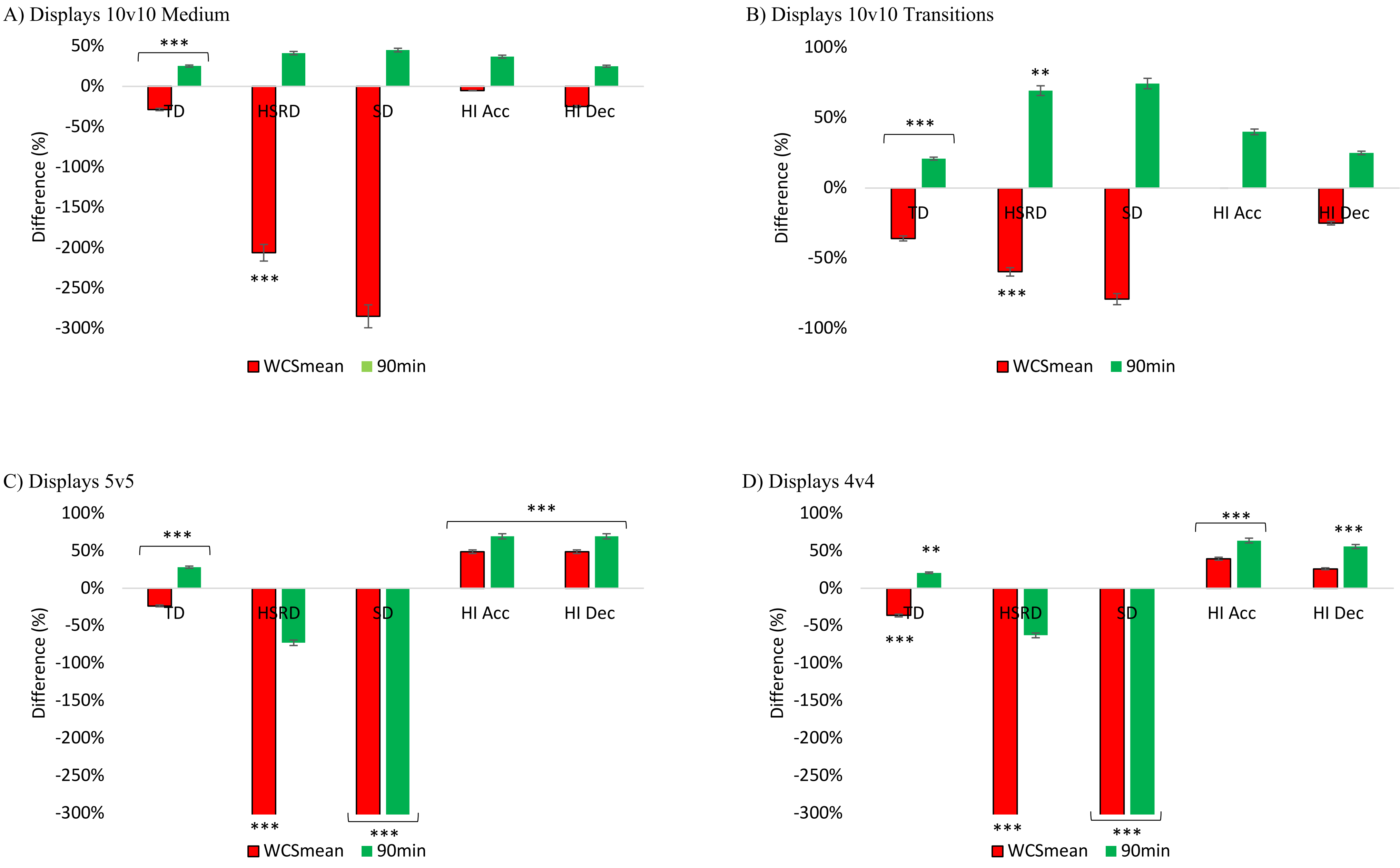


Figure 34. The ratio (%) of training (MD-3 WCS_{peak}) and competition (MD WCS_{peak}) for CB (Center Back), FB (Full Back), CM (Central Midfielder), W (Winger), and A (Attacker) in total distance: TD ($m \cdot min^{-1}$), high-speed running distance: HSRD ($m \cdot min^{-1}$), sprint distance: SD ($m \cdot min^{-1}$), number of accelerations/decelerations A+D ($n \cdot min^{-1}$), number of accelerations: Acc ($m \cdot min^{-1}$), number of decelerations: Dec ($m \cdot min^{-1}$), maximum acceleration: Max Acc ($m \cdot s^{-2}$), and maximum deceleration: Max Dec ($m \cdot s^{-2}$).

Note: Significant differences [a] CB, [b] FB, [c] CM, [d] W, and [e] A ($p < 0.05$). Different from MD * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.
MD-3 is match day minus three; MD is match day; WCS_{peak} is peak 30-second period (worst case scenario).


A) Displays 10v10 Medium
50%
0%
-50%
-100%
-150%
-200%
-250%
-300%
Difference (%)
TD
HSRD
SD
HI Acc
HI Dec
***
***
WCSmean
90min
B) Displays 10v10 Transitions
100%
50%
0%
-50%
-100%
Difference (%)
TD
HSRD
SD
HI Acc
HI Dec
***
**
***
WCSmean
90min
C) Displays 5v5
100%
50%
0%
-50%
-100%
-150%
-200%
-250%
-300%
Difference (%)
TD
HSRD
SD
HI Acc
HI Dec
***
***
***
***
WCSmean
90min
D) Displays 4v4
100%
50%
0%
-50%
-100%
-150%
-200%
-250%
-300%
Difference (%)
TD
HSRD
SD
HI Acc
HI Dec
**
***
***
***
***
***
WCSmean
90min

E) Displays Extra

F) Displays Submax runs

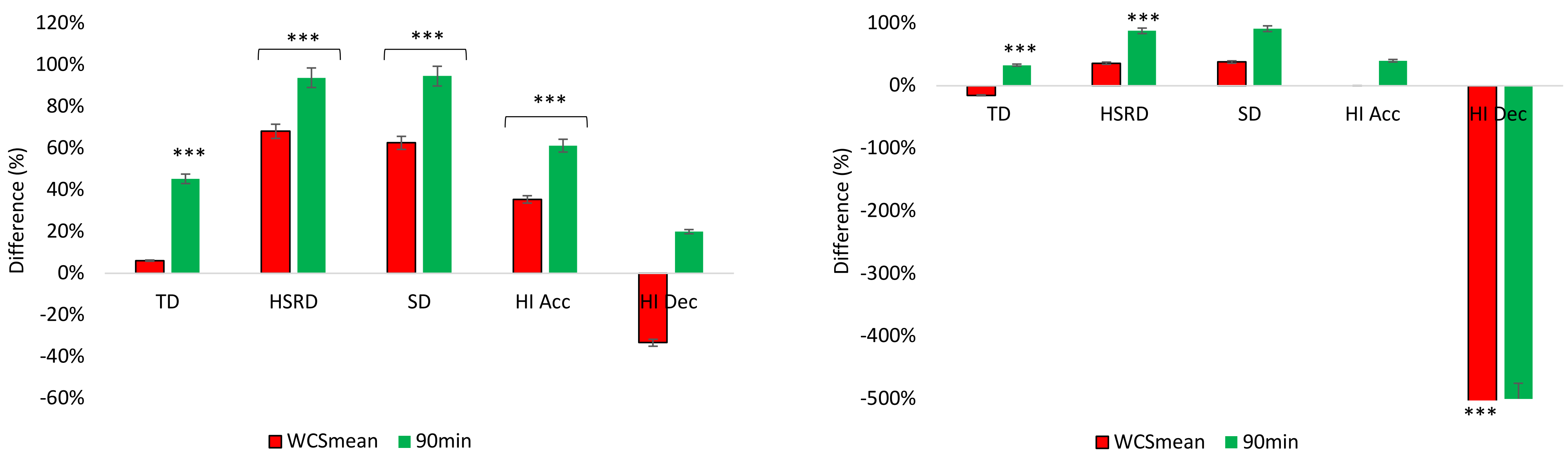
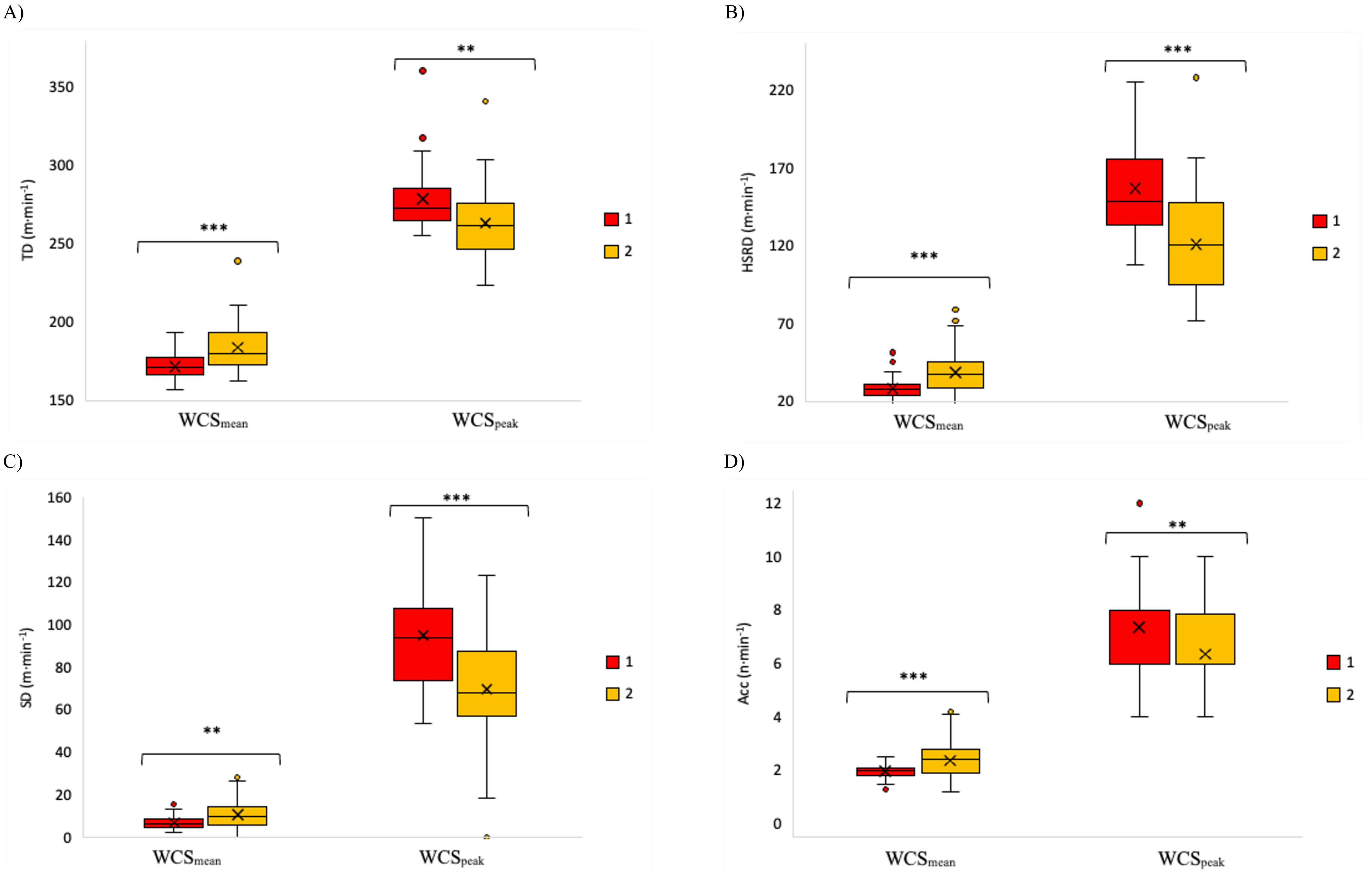
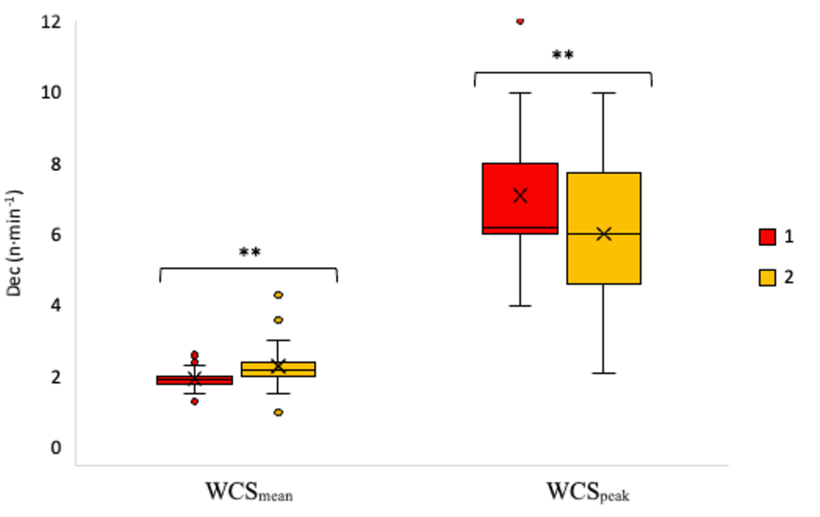


Figure 35. Differences (%) between drill WCS$_{mean}$ vs match day WCS$_{mean}$ (white bar) and drill WCSmean vs 90-min average demands (horizontal stripes bar) in total distance: TD (m·min^{-1}), high-speed running distance: HSRD (m·min^{-1}), sprint distance: SD (m·min^{-1}), number of accelerations: Acc (m·min^{-1}), and number of decelerations: Dec (m·min^{-1}).

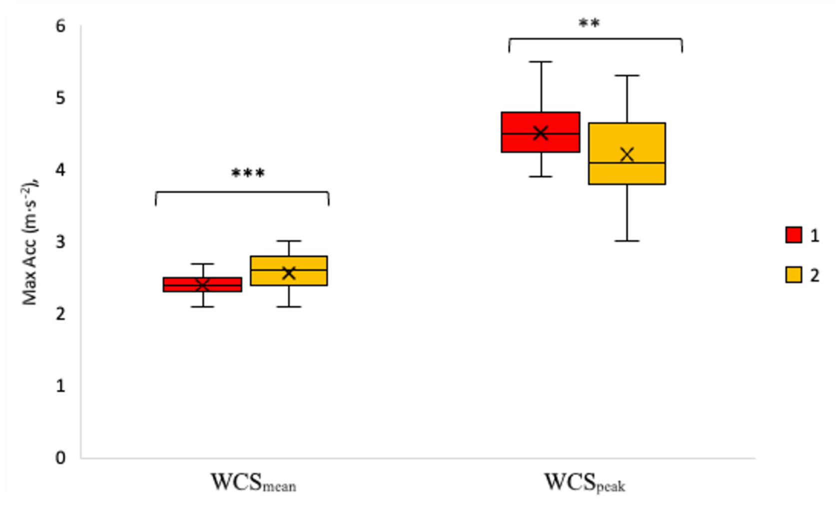
Note: Significant differences from drill WCS$_{mean}$ * p < 0.05; ** p < 0.01; *** p < 0.001
Drills were performed on match day minus three (MD-3).


A)
TD (m·min-1)
350
300
250
200
150
***
**
WCSmean
WCSpeak
1
2
B)
HSRD (m·min-1)
220
170
120
70
20
***
***
WCSmean
WCSpeak
1
2
C)
SD (m·min-1)
160
140
120
100
80
60
40
20
0
**
***
WCSmean
WCSpeak
1
2
D)
Acc (n·min-1)
12
10
8
6
4
2
0
***
**
WCSmean
WCSpeak
1
2

E)



F)



G)

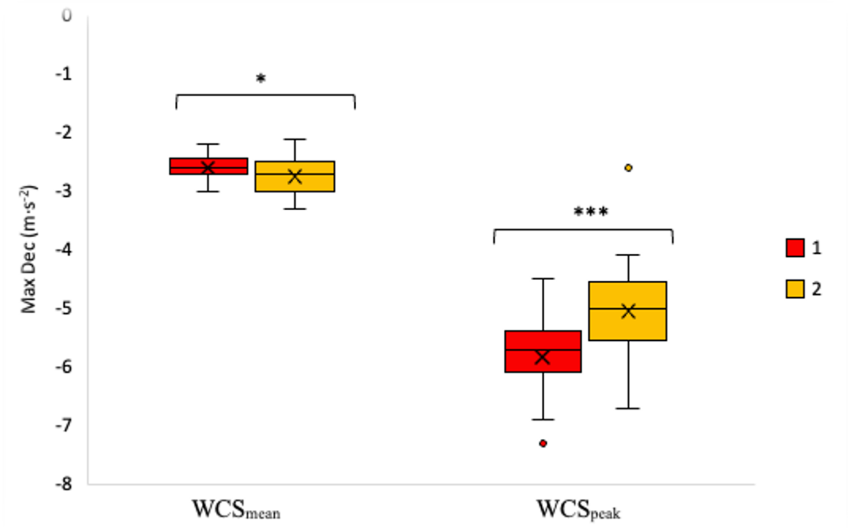


Figure 36. Clustered boxplots with mean and outliers comparing Starters (1 - white) and Non-Starters (2 - granite) during MD WCS_{mean} and MD WCS_{peak} in a) total distance:TD ($m \cdot min^{-1}$), b) high-speed running distance: HSRD ($m \cdot min^{-1}$), c) sprint distance: SD ($m \cdot min^{-1}$), d) number of accelerations: Acc ($m \cdot min^{-1}$), and e) number of decelerations: Dec ($m \cdot min^{-1}$), f) maximum acceleration: Max Acc ($m \cdot s^{-2}$), and g) maximum deceleration: Max Dec ($m \cdot s^{-2}$) across 37 games.
Note: Significant difference * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.
MD is match day; WCS_{mean} is mean 30-second period; WCS_{peak} is peak 30-second period.

7.5.1 90-min vs WCS_{mean} vs WCS_{peak}

Significant effects of period (WCS_{mean}, WCS_{peak}, 90-min) were found for all analysed metrics: TD (m·min^{-1}), HSRD (m·min^{-1}), SD (m·min^{-1}), A+D (n·min^{-1}), Acc (n·min^{-1}), Dec (m·min^{-1}), Max Acc (m·s^{-2}), and Max Dec (m·s^{-2}) (large ESs; $p \leq 0.001$).

7.5.2 Positional Differences in WCS_{peak} Between Training and Competition (MD-3 vs MD)

Main effects of position were found on TD (m·min^{-1}), HSRD (m·min^{-1}), SD (m·min^{-1}), A+D (n·min^{-1}), Acc (n·min^{-1}), Dec (m·min^{-1}), Max Acc (m·s^{-2}), and Max Dec (m·s^{-2}) (TD: $F(4,124) = 13.663$, $p < .001$, partial $\eta^2 = .306$; HSRD: $F(4,124) = 4.834$, $p = .001$, partial $\eta^2 = .135$; SD: $F(4,124) = 3.724$, $p = .007$, partial $\eta^2 = .107$; Dec: $F(4,124) = 4.149$, $p = .003$, partial $\eta^2 = .118$; Max Acc: $F(4,124) = 3.986$, $p = .004$, partial $\eta^2 = .114$; Max Dec: $F(4,124) = 6.768$, $p < .001$, partial $\eta^2 = .179$). No main effects were found for A+D (n·min^{-1}) and Acc (n·min^{-1}) ($p > .05$). There was a game x time interaction for Max Acc (m·s^{-2}) $F = 4{,}124$, $p = .013$, partial $\eta^2 = .096$). No interactions of position x session were discovered for TD (m·min^{-1}), HSRD (m·min^{-1}), SD (m·min^{-1}), A+D (n·min^{-1}), Acc (n·min^{-1}), Dec (n·min^{-1}), and Max Dec (m·s^{-2}) ($p > .05$). Further analysis for all individual positions revealed significant differences between training and competition for TD (m·min^{-1}), HSRD (m·min^{-1}), and SD (m·min^{-1}) ($p < .05$). No differences were detected in A+D (n·min^{-1}), Acc (n·min^{-1}), Dec (m·min^{-1}) for all positions ($p > .05$) except CM. Difference in Max Acc (m·s^{-2}) between MD and MD-3 was only present for FB ($p < .001$), whereas CB and CM revealed significance in Max Dec (m·s^{-2}) ($p > .05$).

7.5.3 Starters vs Non-starters (WCS_{mean} and WCS_{peak})

Significant effects of player status (starters or non-starters) were found in WCS_{mean} for TD (m·min^{-1}), HSRD (m·min^{-1}), SD (m·min^{-1}), A+D (n·min^{-1}), Acc (n·min^{-1}), Dec (m·min^{-1}), Max Acc (m·s^{-2}) (large ESs; $p < 0.001$). Only Max Dec (m·s^{-2}) revealed moderate ESs; $p = .013$. In addition, significant effects of player status were found in WCS_{peak} for all analysed metrics (moderate to large ESs; $p \leq 0.005$).

7.5.4 WCS_{mean} in Long-period vs Moderate-period vs Congested-period

No main effects of recovery period between games were found on any metrics ($p > .05$). Post Hoc tests showed significant difference between the long-period (>6days) and congested-period (≤4days recovery) for A+D ($n \cdot min^{-1}$) and Dec ($m \cdot min^{-1}$) ($p \leq .05$). Other metrics did not show any significant differences between recovery period ($p > .05$).

7.6 Discussion

The main purpose of the present study was to analyse and explore 30-sec WCS_{mean} and WCS_{peak} in an elite football team. Rationale for selecting 30-sec periods for analysis was based on findings in Chapter 5, which revealed that transitions frequently occurred repeatedly as clusters (on average 2.6 activities within 1 min) lasting nearly 30 seconds (Chapter 6). To the authors' knowledge this is the first research to investigate and compare 30-sec peak training to match demands in football and introduce new metrics for analysis such as Max Acc and Max Dec ($m \cdot s^{-2}$). Main findings discovered that during these short time windows, football specific drills used by coaches in conditioning sessions, failed to replicate high-velocity and maximum deceleration actions relative to match peak demands across all playing positions. However, acceleration and deceleration demands were adequately imposed in training. Significantly higher metrics were discovered only in central midfielders for A+D, Acc, and Dec (137%, 129%, and 125% respectively) between MD and MD-3. Findings highlight the importance of prescribing running based drills for starting and non-starting players in team conditioning, individual top-up and return to play sessions. This exercise was found to be the only mode to overload high-speed running and sprinting metrics, which might better mechanically prepare players to sprint and cover distances at higher velocity in matches, potentially improving football performance and lowering the risk of injury (Ekstrand et al., 2023). The current research showed that during congested fixture periods, accelerations and decelerations should be closely monitored in training and games, since these mechanical metrics were significantly lowered in peak intensity blocks in competition. Emphasising detrimental effect of fatigue on eccentric muscle abilities, effective breaking and quality movement in tight spaces during congested periods in football (Djaoui et al., 2022; Rhodes et al., 2021).

7.6.1 Peak Demands in Relation to 90-minute Averages

Findings revealed that all periods (WCS_{mean} vs WCS_{peak} vs 90-min) significantly differed in all physical metrics. The greatest discrepancies for WCS_{peak} were present for HSRD ($m \cdot min^{-1}$) and SD ($m \cdot min^{-1}$), which constituted 10.4% and 5.1%, respectively of the average match demands. TD ($m \cdot min^{-1}$) was around 50%, while A+D ($n \cdot min^{-1}$) was just below 40% of the whole-match mean. Interestingly, competition averages generated higher than WCS_{mean} Max Acc and Dec by 34.2% and 44.4% respectively, which could indicate that highest values of acceleration and deceleration occurred at other phases of the game. These findings are lower than the 1-min peak periods data reported by Riboli et al. (2021b) across different positions, but consistent with others who determined similar differences between 90-minute average demands and the 1-minute peak values for TD, HSRD, and SPD (~50%, ~10%, and ~5%, respectively) for all playing positions (Oliva-Lozano et al., 2023d). Hence, how we analyse physical metrics, guides whether players are meeting demands of the game (Martin-Garcia et al., 2019; Riboli et al., 2022).

Indeed, Chapter 3 revealed that during transitional activities players covered greater distances per minute than reported for WCS_{peak} in our study: ~ 290 m vs 204 m (with ~ 165 m vs 55 m considered to be high-speed running, and ~ 84 m vs 21 m to be sprinting) and performed an equal number of accelerations and decelerations per min (~ 5). In this regard, more studies answering 'WHY' and not only 'WHAT' should be conducted by investigating contextualised blocks of high-intensity activities to better inform/guide coaches and practitioners and integrate physical with technical-tactical aspects in contemporary training design (Ju et al., 2023b).

7.6.2 Training in Relation to Competition

All locomotor variables (TD, HSRD, SD) during training were insufficiently imposed on all playing positions, which is consistent with previous studies (Oliva-Lozano et al., 2021b). Large discrepancies were identified for SD ($m\cdot min^{-1}$) across all positions in WCS_{peak}. Central midfielders received only 26%, center backs 30%, attackers 34%, full backs 37%, and wingers 41% of the competition sprint distance. A novel finding of the current investigation was that Max Dec ($m\cdot s^{-2}$) value was also lower for all positions in training WCS_{mean} / WCS_{peak}, especially for center backs and central midfielders, reaching 86% of competition WCS_{peak}. Deficit between match play and training might potentially fatigue players to a greater extent and place these positional groups at higher risk of injury in matches if muscles are not adequately stressed and adapted to specific demands of competition in training (Ekstrand et al., 2023; Rhodes et al., 2021). Hence, it could be suggested to use collective high intensity efforts in activities aiming to provide support to offensive players and then rapidly switch to recovery runs during defensive transitions (Ju et al., 2023b). Special attention might be paid to center backs and central midfielders to expose them to maximum efforts during these transitions.

Maximum Acc ($m\cdot s^{-2}$) on MD-3 was very similar to the MD WCS_{peak}, with only full backs falling below to 84%. Again, showing that training failed to provide adequate amount of maximum acceleration actions in this positional group, which could possibly under-prepare them for specific demands of competition and increase risk of injury (Bengtsson et al., 2017). Full backs have a unique tactical role to provide support by over/underlapping movements in possession, while performing recovery runs out of possession, both occurring at high velocity (Ju et al., 2023b). Therefore, these two tactical phases could be initiated by maximum acceleration movements to ensure this positional group receives adequate accel stimuli in training. In general, more attention could be paid for covering greater distances (TD, HSRD, SD; $m\cdot min^{-1}$) and including maximum deceleration actions in training across all positions. Regular mechanical exposure to high-velocity and high-intensity activities could better replicate match peak intensity and condition players for these demanding periods (Nobari et al., 2023). More work is required in this area.

7.6.3 Drills in Relation to Competition

Coaches integrate technical-tactical and physical aspects in training usually by selecting football-specific modes of exercise (Barrett et al., 2020; Moniz et al., 2020; Oliva-Lozano et al., 2021b), which could compromise and lower the physical outputs (Weaving et al., 2022) as it can be seen in this chapter. Results reported that all high-intensity locomotor demands during all games were far lower than the match WCS_{mean}. Only large-sided transitional game (10v10 Transitions) overloaded the whole-match average HSRD ($m \cdot min^{-1}$) by nearly 70%. Small-sided games (5v5 and 4v4) produced 30 to 50% higher Acc and Dec ($m \cdot min^{-1}$) relative to match WCS_{mean}, which is in accordance with others (Lacome et al., 2018; Riboli et al., 2023a). It has been recommended in previous chapters to use larger areas in different game formats, utilise transition games with large spaces, and complement football specific drills with additional positional exercises and running based activities to truly reflect HSRD, and SD relative to the match play demands (Riboli et al., 2023a). In fact, the current chapter revealed "Extra" (top-up high-velocity action with changes of direction) and "Submax runs" being the only exercise modes that overloaded MD WCS_{mean} high-velocity metrics (HSRD, SD) by ~60% and ~36%, respectively. Also, "Extra" elicited 35% and 61% higher than WCS_{mean} and 90-min acceleration demands, respectively. Hence, it might be effectively used to increase mechanical stress on players when SSG could not be performed. For instance, this mode could be utilised for subs and bench players right after competition to compensate match demands and overload locomotor and mechanical demands. Indeed, high-velocity actions and frequent exposure to higher speed have been linked to reduced likelihood of non-contact injuries and determined a key action leading to goal-scoring opportunities in football (Beato et al., 2021; Faude et al., 2012). This body of work found positional differences during various football specific drills performed on MD-3 and hence, an individualised approach would be best to replicate/overload individual WCS (Lacome et al., 2018). More work should be done in this area by investigating other exercise modes and comparing them to shorter WCS time epochs found in official matches.

7.6.4 Starting and Substitute Players

A large number of studies in football compared 90-min external/internal load differences between starting and non-starting players (Bradley et al., 2013; Liu et al., 2020; Los Arcos et al., 2017). Research analysing playing status during WCS in football is scarce (Sydney et al., 2023; Fereday et al., 2020). The current chapter showed non-starters (subs) generating higher physical output in all metrics analysed during WCS_{mean} compared to starting players. Findings consistent with others that reported greater TD ($m \cdot min^{-1}$) covered by non-starters over shorter peak periods (1-, 2-min), and higher HSRD ($m \cdot min^{-1}$) in all time epochs (Delaney et al., 2018b; Fereday et al., 2020). A feasible explanation for lower outputs detected in starters, would be self-pacing strategy (conscious or sub-conscious) adopted to minimise the physical effort and preserve energy over the course of match play (Bradley et al., 2013). In turn, subs have been shown to display more aggressive pacing behaviour compared to starters due to their knowledge regarding exercise/match duration in which they have to make an impact on team performance by achieving a higher physical effort (Ferraz et al., 2018). Since substitutes are expected to bring about higher effort comparing to starters, the importance of high-intensity warm up preceding the match entry should be highlighted and emphasised. Previous investigations reported insufficient preparation and/or decrease of body temperature post warm up impacting physical performance of substitute players (Hills et al., 2021). Substitutes should be provided with optimal physical and tactical preparation pre entry to make the best impact on the team performance (Hills et al., 2021).

Further and novel findings of Chapter 7 revealed non-starters covering lower distances (TD, HSRD, SD: $m \cdot min^{-1}$), performing less high-intensity accelerations and decelerations (Acc and Dec: $n \cdot min^{-1}$), and generating lower values of Max Acc and Dec ($m \cdot s^{-2}$) compared to starting players in WCS_{peak}. These results are consistent with Sydney et al. (2023) who also showed lower peak physical demands experiences in non-starters. In fact, subs might not be subjected to the most demanding passages of match play, and hence may have less opportunities to reach maximum intensity (running outputs), which was reported in the opening ~10 to 15 min post kick off (Bradley et al., 2013; Hills et al., 2022). Therefore, knowing maximum intensity periods of all players could help practitioners to design more accurate training programme (top-up conditioning sessions) and provide adequate recovery, ensure optimal preparation/readiness for competition demands, less discrepancies in total weekly load, and reduced risk of injury (Ekstrand et al., 2023; Hills et al., 2022). Both starting and substitute players should be frequently exposed to maximum intensity in training (speed, max accelerations, and decelerations) to be able to maintain a higher physical output (non-starters) and withstand peak match demands (starters). Thus, it would be reasonable to suggest repeated sprint training: < 10 sec all-out short sprint sequences for starters and short high-intensity-interval training: < 45 sec sub-maximal efforts for non-starters (Buchheit et al., 2013; Nobari et al., 2023). Future work should determine and distinguish best exercise modes for these groups.

7.6.5 Congested Fixture Period

Short recovery time between subsequent matches, has been associated with high physical stress resulting in fatigue, decreased tactical behaviour, and higher risk of muscle injury, hence coaches should individualise load prescription and recovery, and use rotation strategy during congested periods (Ekstrand et al., 2023; Julian et al., 2021). Despite unchanged locomotor metrics across 90-min (Carling et al., 2011), it has been shown that number, distance of accelerations and decelerations, and time spent accelerating / decelerating were significantly lowered during congested fixture period in youth and elite football players (Djaoui et al., 2022; Rhodes et al., 2021). Research investigating peak match demands during congested periods in elite football is very limited (Jiménez et al., 2022), so this work is paramount to add to the body of literature. Previous studies did not reveal significant differences in physical outputs during WCS between non- and congested periods, which might indicate that players pace their physical effort during 90-min to preserve their energy for peak intensity passages (Bradley et al., 2013).

These findings showed that only accelerations/decelerations (A+D; $n \cdot min^{-1}$) and Dec ($n \cdot min^{-1}$) significantly decreased in WCS_{mean} during congested period, which is contradictory to previous WCS studies highlighted before, but consistent with literature analysing the whole match performance (Djaoui et al., 2022; Rhodes et al., 2021). Indeed, accelerations and decelerations alongside high-speed running and sprint distance has been recently perceived as important indicators of high-intensity demands of football training and competition (Ju et al., 2023b). It is worth noting that quick changes of direction, which produces high eccentric muscle actions, have been found more physically stressful than high-velocity activities (Delaney et al., 2018b) and recommended as a reliable tool to assess match physical performance and fatigue in football (Djaoui et al., 2022; Mohr et al., 2016). Decelerations have also been shown to occur more frequently than accelerations in football competition regardless match result (Harper et al., 2019; Rhodes et al. 2021). Since contemporary football imposes high-velocity actions and rapid changes of direction in small and tight areas, it is of paramount importance to monitor A+D performance and apply high-intensity decelerations in training. This might better prepare football players for competition demands and potentially reduce detrimental effect of fatigue on their abilities to fulfil their positional tasks and tactical responsibilities across the whole match duration and peak intensity passages (Harper et al., 2019; Rhodes et al. 2021).

7.6.6 Match-to-match-variability

Further novel findings of this chapter showed that match-to-match variability of locomotor variables (e.g., SD) during the congested-period was highest compared to long-, and moderate-periods (65.8% vs 41.3% vs 55.4%, respectively). The results are greater compared to previous studies reporting variability of physical performance during peak intensity periods in football for high-intensity metrics such as SD and A+D, but similar for TD and HSRD (Riboli et al., 2021b; Thoseby et al., 2022). This might be accounted for due to shorter duration WCS in this investigation, which could provide higher unpredictability in match play compared to longer time epochs and display the real challenge of modern football training design in practice (Gregson et al., 2010).

7.6.7 Limitations

Only one team was analysed in Chapter 7, no technical-tactical data was presented, nor team formation reported. Future studies should include additional contextual factors such as playing style, system of play, game status (win, draw, loss), score-line, match location (home, away), match half, and substitution timing, players' rotations, and recovery strategies. Deeper knowledge about contextual factors not included in this investigation, would allow more holistic approach to verify physical performance during peak intensity periods in football. Other situational factors such as opponents' level/ranking could also be included. Moreover, internal load (RPE, HR) during peak match demands should be considered (Sydney et al., 2023). Furthermore, only absolute metrics were explored, and future studies should analyse relative locomotor and mechanical variables to describe individual physical capabilities more accurately, which might provide greater insight into injury incidence. Finally, this body of work analysed only MD-3 sessions and other days of the week should also be investigated in the future.

7.7 Conclusions

In conclusion, it is of high importance that football coaches use 90-min averages in conjunction with peak intensity periods to guide their training prescription, top-up conditioning and return-to-play sessions. The findings of Chapter 7 are unique as they contribute to the existing body of knowledge in football about physical performance during WCS of shorter duration (30-sec), analysing positional differences and assessing impact of different drills on physical performance during these phases. However, the current chapter also proposes additional metrics such as maximum acceleration and deceleration for more accurate training design. High discrepancies were identified between match and training overload phase, highlighting a slightly different approach needed to take place to truly reflect and better prepare all positions for the high intensity/velocity demands of competition, and minimise the risk of injury. This chapter found starters being exposed to maximum intensity (WCS_{peak}), whereas non-starters generating higher effort during the entire bout of activity (WCS_{mean}). This could suggest that the gap between training and match play for maximum intensity actions was even greater in substitute players. Finally, significant differences between long-period and congested-period were determined for A+D and Dec. The findings might serve high value to coaches, practitioners, and physical therapists in ensuring training demands better match playing demands, especially in periods of WCS.

7.8 Practical implications

In football conditioning sessions, practitioners could pay more attention to total distances covered and high-velocity actions (HSRD, SD) regardless of playing position. Include more activities generating maximum decelerations for center backs and central midfielders and expose fullbacks to maximum accelerations to truly reflect match play demands during short peak intensity blocks. This could be achieved by using rapid changes from offensive to defensive activities (transitions) in team/individual training prescription. Regarding the drill selection, in addition to football-specific exercises (SSG) that adequately reflect/overload mechanical metrics during WCS, running based drills could be utilised as an effective strategy to minimise discrepancies between training and match play peak demands, especially in terms of high-speed and sprinting exposure. Repeated sprint training: < 10 sec all-out short sprint sequences might be used for starters to reach peak intensity and short high-intensity-interval training: < 45 sec sub-maximal efforts for non-starters to maintain high physical effort over short duration activities. Furthermore, the running-based drills with change of direction might be applied post-match during a compensatory session for bench and substitute players. On MD-3, LSG could be utilised to overload 90-min total distance, whereas transitional LSG to overcome the whole-match HSRD and SD demands. Accelerations and decelerations should be monitored during a weekly microcycle, especially during a period of congested fixture to assess potential fatigue, inability to recover between matches and higher risk of muscle injury.

Chapter 8: Synthesis of Findings, Future Research Directions and Practical Applications

8.0 Synthesis

This chapter will demonstrate the relationship between the present findings and the original aims and objectives of the overarching research thesis. A construct of solid foundations, strong arguments throughout a general discussion as well as critique and conclusion will be provided. Also, the limitations of the current body of work will be presented and future research directions suggested. Finally, and most importantly, practical recommendations to coaches, practitioners and physical therapists will be delivered based on the key findings.

8.1 Synopsis Overview

This body of research aimed to investigate the physical demands of short and specific maximum intensity periods defined as transitional play and high-pressure activities, which have been identified as crucial phases of modern match play (Appendix 1). The main objective was to better inform coaches and transfer knowledge to practical settings by measuring physical output during transitions in games, analysing physical and technical-tactical aspects of training to make comparisons and determine whether training met competition demands and prepared footballers for frequent maximum-intensity exposure in crucial tactical match phases. This approach offers more context to the data from a practical perspective. Initially in Chapter 3 depicted in Table 18, the research explored and analysed physical performance of Polish elite football players (*n = 23*) during the following transitions in competition: offensive transition (OT = counter-attack), defensive transition (DT = opposition's counter-attack), fast attack (FA), and high-pressure (HP). Mean and peak physical efforts during transitional activity were established, concluding it was something imperative to consider when training players for the demands of the game. In Chapter 4 presented in Table 19, players were categorised to the following positions: center backs (CB), full backs (FB), central defensive midfielders (CDM), central midfielders (CM), central attacking midfielders (CAM), wingers (W), and attackers (A) (Ju et al., 2023b) and positional differences during transitions were established. In Chapter 5 shown in Table 20, the effect of each transition type had on match outcome was analysed to highlight the importance to consider and include WCS concept in modern match analysis and training design. Chapter 6 depicted in Table 21, analysed how frequently transitional activities occurred in a given time frame (cluster), thus informing what should be done in training to meet the match physical demands.

Secondly, in Chapter 7 presented in Table 22, the focus of the research changed to investigate 30-second-worst-case-scenarios due to findings in earlier chapters. It aimed at comparing match play (MD) to training demands (MD-3) during different contextual scenarios such as training mode (football drills), playing status (starters vs non-starters), and a microcycle length (long-period vs moderate-period vs congested-period). In this body of work, Israel Premier League male elite football players were monitored across thirty seven matches (*n* = 37) and fourteen sessions (*n* = 14). These aims and objectives were completed and achieved across Chapters 3 to 7, which are summarised in Tables 18 to 22, respectively.

Table 18. A synthesis of the Chapter 3 completed as part of the present research programme analysing the physical demands during transitional play and high-pressure activities in elite football.

	Objective 1	**To identify and analyse short high-intensity passages (transitional play and high-pressure activities) in an elite football team using an integrated approach by combining running metrics and tactical aspects.**
	Method	Elite footballers from the Polish premier league were included in the study. Data was collected during ten official competitive matches in season 2020-2021. Different absolute and relative physical metrics were recorded during the following transitional activities: positive transition (PT), negative transition (NT), fast attack (FA), and high-pressure (HP).
	Main findings	The investigation revealed elevated physical metrics during transitional play and high-pressure activities. Offensive activities (counter-attacks and fast attacks) exposed players to maximum velocity activities (sprint distance), while high-pressure actions increased mechanical load (accelerations and decelerations).
	Conclusion	Highly contextualised transitions frequently expose players to maximum intensity during matches (n = 50 ± 11.1) . The study revealed that high-velocity actions were 7-9 times greater when compared to the 90-min averages. Informing practitioners of the physical demands footballers will face within given time frames during offensive and defensive activities.
	Practical impact	The chapter guides coaches how to best condition and prepare a team collectively for specific high-intensity offensive and defensive phases in match play. Practitioners could quantify short critical tactical phases in competition to better understand their impact on different physical metrics and thus, optimally design training not only based on 90-min averages but in conjunction with highly contextual maximum-intensity periods.
	Evaluation	Objective 1 (page 78) was achieved within Chapter 3. ✅

Table 19. A synthesis of the Chapter 4 completed as part of the present research programme analysing the physical demands during transitional play and high-pressure activities across different playing positions.

Objective 2	**To investigate physical match demands across different playing positions during specific short duration actions such as offensive transitions, defensive transitions, fast attack, and high-pressure activities.**
Method	Male elite football players representing a Polish top-level team participated in the study. Data was collected in the 2020-2021 season. The following number of observations per position were recorded: center backs (*n* = 884), full backs (*n* = 972), central defensive midfielders (*n* = 236), central attacking midfielders (*n* = 270), central midfielders (*n* = 578), wingers (*n* = 778), and attackers (*n* = 531).
Main Findings	Center backs experienced the lowest physical demands but achieved the highest accelerations and decelerations during defensive transitions (out-of-possession). Full backs covered the highest sprint distance in all transitions, central attacking midfielders ran higher high-speed running distance and wingers accumulated the greatest number of accelerations and decelerations during offensive transitions. Attackers reached highest physical metrics in high-pressure activities.
Conclusion	Physical performance during transitions varies between different playing positions.
Practical Impact	This chapter guides practitioners how to best tailor position specific offensive/defensive tasks to optimally load each player in training, reflecting specificity of high-intensity periods of competition. Additionally, it enables coaches to better periodise a weekly plan and optimally select offensive/defensive drills for each playing position to improve readiness and minimise fatigue prior competition.
Evaluation	Objective 2 (page 104) was achieved withing Chapter 4. ✓

Table 20. A synthesis of the Chapter 5 completed as part of the present research programme analysing the impact of match half and match outcome on the physical demands during transitions and introducing the novel concept of repeated transitional activities in football.

Objective 3	**To explore the effect of match half (1^{st} vs 2^{nd} half) and match outcome (win vs draw vs loss) on different physical metrics during transitions in football match play. To analyse the effect of match outcome on the second half physical metrics and investigate repeated transitional activities defined as clusters.**
Method	GPS and accelerometery data were captured from elite football players during official matches in the 2020-2021 season in the Polish premier league. A total of 4249 individual observations were recorded including 1164 positive transitions (defence-to-attack), 1269 negative transitions (attack-to-defence), 1120 fast attacks, and 696 high pressure activities. Clusters were defined as two or more transitional activities that occurred withing a period shorter than 61 secs.
Main Findings	The main findings indicate significant effects of contextual factors on transitions. All volume-related physical metrics were lower in the 2^{nd} half, while won games displayed higher outputs in all variables, except high-intensity accelerations and decelerations. Physical metrics were found to be lower in the 2^{nd} half in lost matches. Findings also indicate that the mean number of clusters across ten games was 12.2 (± 3.2).
Conclusion	During a modern football game, players are exposed to repeated short, intermittent high intensity/velocity actions together and coaches should move away from training design guided by 90-min averages.
Practical Impact	Coaches and practitioners should adequately condition footballers and mimic high density of repeated transitional activities (clusters) in training to improve match performance and reduce injury risk. To counteract declines in physical performance in the 2^{nd} half, practitioners could prescribe appropriate transition drills in- and out-of-possession (offensive and defensive) as well as play transition games on larger areas. Both high-velocity actions and high-intensity decelerations should be closely monitored during a weekly microcycle in relation do different positional groups.
Evaluation	Objective 3 (page 127) was achieved withing Chapter 5. ✓

Table 21. A synthesis of the Chapter 6 completed as part of the present research programme analysing the impact of 15-minute blocks on the physical demands during transitions and determining frequency, type, duration and recovery period between clusters.

Objective 4	**To investigate the effect of 15min blocks on physical metrics during transitions. To analyse frequency, type, duration, and recovery period between clusters of transitional activities.**
Method	Data were collected on elite outfield football players during 2020-2021 1st Polish Division (Ekstraklasa) season. Analysis included 1164 offensive transitions (defence-to-attack), 1269 defensive transitions (attack-to-defence), 1120 fast attacks, and 696 high pressure activities giving a total number of 4249 individual observations. Clusters included two or more transitional activities within a period shorter than 61 secs.
Main Findings	The main findings revealed significant effect of 15min blocks on different locomotor and mechanical variables. On average, 66% of transitions were clusters, while 83% of all high-pressure activities occurred in conjunction with other actions. Recovery period between clusters were 4 times lower compared to single transitional activities (25.7 ± 3.6 vs 105.6 ± 26.2 s, respectively). Clusters total duration was 28 ± 5.8 s, while peak duration reached 53.3 ± 18.2 s.
Conclusion	Physical metrics decrease in the last 15min blocks during transitions and high-pressure actions in games possibly indicating a detrimental impact of fatigue on physical and tactical performance. Transitions expose players to repeated and intermittent high-intensity actions together.
Practical Impact	This chapter provides a powerful ammunition for coaches to deliver specific short high-intensity exercises with accurate work-to-rest-ratios in contemporary training design relative to true match demands. Coaches could use tactical drills that fall into a category of speed endurance, repeated sprints, and sprint intervals to optimally prepare footballers for the most physically demanding passages in match play.
Evaluation	Objective 4 (page 152) was achieved withing Chapter 6. ✓

Table 22. A synthesis of the Chapter 7 completed as part of the present research programme analysing the 30-second worst-case-scenarios and exploring the effect of various contextual scenarios on the physical output during these periods in elite football matches and training.

Objective 5	**To understand 30-sec WCS_{mean} and WCS_{peak} (worst-case-scenarios) within training and game play in professional football.**
Method	Elite footballers were monitored across 37 matches and 14 MD-3 (match-day minus three) sessions. The following number of observations per positions were recorded: center backs (*n* = 701), full backs (*n* = 421), central midfielders (*n* = 1223), wingers (*n* = 525), and attackers (*n* = 325). Starters and non-starters were included in the study and their outputs compared. Football drills were analysed, and performance explored in long-period: > 6 days, moderate-period: 5-6 days and congested-period: ≤ 4 days.
Main Findings	The main findings indicated differences between matches and training in WCS for various physical variables, especially high-velocity metrics and maximum deceleration across all positions. Starters revealed high physical output compared to non-starters in WCS_{peak} but lower in WCS_{mean}. Significant differences between long-period and congested-period were determined for accelerations and decelerations. Transitional large-sided game exceeded the 90min average high-speed running by nearly 70%. Running based drills were the only exercise that overloaded match WCS_{mean} high-velocity metrics by > 36%.
Conclusion	Coaches should value the effectiveness of transition games and running based drills to reflect high-intensity/velocity metrics and generate maximum deceleration experienced during short WCS in matches. More activities producing maximum decelerations should be included in training for all playing positions and differences between substitutes and starters considered in a weekly training plan. Mechanical load should be closely monitored during a period of congested fixtures and rotational strategy used to minimise the effect of fatigue on match performance and reduce the risk of injury.
Practical Impact	Isolated running based drills and transitional games are best to replicate / overload the high-velocity demands of competition. Repeated sprint training might be used for starters to reach peak intensity and short high-intensity-interval training for non-starters to maintain high physical effort over short duration activities. Practitioners should avoid small-sided games and high-pressure actions in training during congested periods to minimise mechanical load experienced by footballers.
Evaluation	Objective 5 (page 175) was achieved withing Chapter 7. ✓

8.2 Putting All The Pieces Together

8.2.1 Physical Demands in Transitions and High-pressure Activities

Physical outputs were largely elevated when contextualised into transitional activities (TA's), representing the maximum exposure footballers experience in competition. During peak TA's players covered greater distances per minute ($m{\cdot}min^{-1}$) than reported for the whole match demands: ~ 290 m vs 110 m (with ~ 165 m vs 7.7 m considered to be high-speed running: HSRD, and ~ 84 m vs 1.6 m to be sprinting: SD) and performed higher number of high-intensity accelerations and decelerations ($n{\cdot}min^{-1}$): A+D (~ 4.7 vs ~ 0.8). Therefore, the main findings reveal that transitional activities could be treated as the most demanding passages in modern match play.

Offensive / Defensive Transitions and Fast Attacks

On average transitions in matches occurred 50 ± 11.1 times, with a range of 32 to 68. Offensive transitions (OT = counter-attacks) and defensive transitions (DT = opposition's counter-attacks) were most frequent (28% and 31%, respectively) followed by fast attacks (FA) (26%). Peak duration of all transitions lasted between 22-27 seconds, mean duration was around 10 secs, while OT lasted significantly longer (around 11 seconds) compared to DT and FA (9.3 ± 3.9 and 10.0 ± 3.1 seconds, respectively). Transitions surpassed the whole match demands in all metrics, especially in high-speed running (HSRD; $m{\cdot}min^{-1}$) and sprint distance (SD; $m{\cdot}min^{-1}$), which were 7–9-fold greater than the 90-min demands, respectively. DT accumulated higher total distance (TD; $m{\cdot}min^{-1}$), HSRD ($m{\cdot}min^{-1}$) and number of accelerations and decelerations (A+D; $n{\cdot}min^{-1}$), while OT (counter-attacks) generated highest SD ($m{\cdot}min^{-1}$). Nearly half of match total high-velocity distance (SD and HSRD; m) came from transitional play (51% and 38%, respectively), whereas 41% of that distance was generated during OT (counter-attacks) and 28% from FA. Therefore, offensive actions (OT and FA) expose footballers to maximum velocity during a rapid entrance to the attacking third, with the main objective to quickly surprise an opponent, exploit space behind a defensive line and take advantage of the opponents' imbalanced tactical shape. These findings acknowledge the demands of football matches, thus guiding practitioners how to better replicate these demands in training. By understanding the physical output required during short and specific tactical periods (duration, type, and frequency), coaches can design more accurate training sessions that may mimic physiological and biomechanical demands during these short bouts of activity. This could positively change the way practitioners analyse physical-tactical demands in matches and training, shifting their focus from whole match averages to shorter blocks of maximum intensity to fully comprehend modern game demands.

High-pressure Activities

High-pressure activities (HP) were less frequent (16%) and less physically demanding compared to other TA's merely in terms of distances covered. Mean duration was ~ 10 ± 3.7 seconds, which was similar to other activities, although peak duration was highest and lasted 27 seconds. Mean total distance covered per minute (TD; $m \cdot min^{-1}$) was only ~ 159 m, while other phases generated distances well above 200 $m \cdot min^{-1}$. These differences were even more significant in high-velocity zones where HP mean sprint distance per minute SD ($m \cdot min^{-1}$) was ~ 4 times lower compared to counter-attacks (~ 5 m vs 20 m, respectively). Nevertheless, these crucial defensive phases imposed a high mechanical load reflected in high number of accelerations and decelerations per min (A+D: ~ 1.2 $n \cdot min^{-1}$). Additionally, during HP footballers were covering around 20% more acceleration distance (AccelB3 dist; m) compared to other phases. Given that 83% of all HP occurred as repeated actions in conjunction with other tactical activities, these periods could possibly generate high metabolic stress on offensive players such as attackers, wingers, and central attacking midfielders. Coaches may use this knowledge when designing position specific conditioning drills that expose footballers to a high mechanical load in tactical constraints, and for planning tactical drills over MD-1 and MD-2 respectively, before competition. Excessive exposure to high-pressure actions during a weekly taper phase might lead to neuromuscular fatigue, poor performance and potentially higher risk of muscle injury in matches (Boden et al., 2009; Brophy et al., 2015; Ekstrand et al., 2023).

Analysis of Playing Position

Center backs (CB) experienced the lowest physical metrics in all TA's but achieved the highest number of A+D ($n \cdot min^{-1}$) in defensive transitions (DT). Full backs (FB) covered the greatest sprint distance: SD ($m \cdot min^{-1}$), which was most evident in defensive transitions (DT) and fast attacks (FA). Central attacking midfielders (CAM) ran higher total distance: TD ($m \cdot min^{-1}$), high-speed running distance: HSRD ($m \cdot min^{-1}$) from other positions during offensive actions (counter-attacks and fast attacks). Wingers (W) had the highest number of A+D ($n \cdot min^{-1}$), especially during offensive actions (counter-attacks and fast attacks). Attackers (A) experienced lower physical demands in defensive transitions (DT), while reaching higher physical outputs in high-pressure activities (HP). Findings provide additional tools for practitioners to design accurate drills that reflect true positional demands during peak intensity periods in matches.

Total distance: TD ($m \cdot min^{-1}$)

The midfield positional group including CAM, CDM, and CM achieved highest mean TD ($m \cdot min^{-1}$): 234 m, 215 m, and 212 m, respectively. For CAM this was the most apparent during offensive actions such as OT and FA when a mean distance of ~ 255 $m \cdot min^{-1}$ was recorded. In contrast, CDM and CM had to cover higher grounds during defensive phases (DT) of ~ 250 $m \cdot min^{-1}$. Interestingly, FB ran more in DT: ~ 243 $m \cdot min^{-1}$ and W in OT: ~ 255 $m \cdot min^{-1}$. Considering a special tactical role of attackers (A) as being first defenders on opponents' half, this group covered the highest distance during HP: ~ 233 $m \cdot min^{-1}$. CB accumulated the lowest distances ($m \cdot min^{-1}$) but ran ~ 233 $m \cdot min^{-1}$ in defensive phases (DT) which was significantly higher ($p < 0.05$) compared to offensive players.

High-speed running distance: HSRD ($m \cdot min^{-1}$)

CAM as well as wide positions including W and FB covered the highest mean HSRD ($m \cdot min^{-1}$) (67 m vs 63 m vs 61 m, respectively), followed by A (~ 53 m). CM and CDM accumulated lowest physical output of around 45 m. Offensive phases of play (OT and FA) had the greatest high-speed impact on W and CAM (> 100 $m \cdot min^{-1}$ vs > 80 $m \cdot min^{-1}$, respectively). Defensive phases (DT) displayed higher distances ($m \cdot min^{-1}$) for CM, FB and CDM (~ 86 m vs 84 m vs 80 m, respectively). Again, A accumulated the highest outputs during high-pressure HP: ~ 80 $m \cdot min^{-1}$, while CB reached high-velocity zones mainly during defensive phases DT: ~ 66 $m \cdot min^{-1}$.

Sprint distance: SD ($m \cdot min^{-1}$)

Wide positions such as FB and W ran the greatest mean SD ($m \cdot min^{-1}$) (24 m vs 20 m, respectively), whereas central defensive positions including CDM and CM had the lowest distances equal to only ~ 5 m. FB reached maximum velocity zones in all TA's but HP. This group was specifically active in both offensive and defensive transitions running ~ 30 $m \cdot min^{-1}$. Other positions such as CAM, CM, and A accumulated ~ 50% lower values compared to wide players (~ 14 m vs ~ 13 m vs ~ 11 m, respectively). OT generated the highest outputs ($m \cdot min^{-1}$) for W (~ 44 $m \cdot min^{-1}$), HP had the strongest effect on A (~ 17 $m \cdot min^{-1}$), while CM ran the most during defensive periods – DT: ~ 23 $m \cdot min^{-1}$.

Accelerations and decelerations: A+D ($n \cdot min^{-1}$)

Offensive players including W and A achieved the highest mean number of A+D ($n \cdot min^{-1}$) compared to other positional groups (1.7 and 1.3, respectively). Wingers were most active during FA: ~ 2.5 $n \cdot min^{-1}$ and full backs in HP: ~ 2.4 $n \cdot min^{-1}$. In contrast, central defensive players such as CB and CDM accumulated the lowest number (0.7 and 0.9 , respectively) but reached greatest outputs in DT (~ 1.9 $n \cdot min^{-1}$).

Absolute vs Relative sprint distance: SD (m) vs Rel B5 (m)

FB and W accumulated the highest absolute sprint distance: SD (m) during all TA's, followed by CAM, CM, A, CDM and CB. Revealing a high match-to-match variability expressed as nearly 54%. Contrary to absolute metrics, relative sprint distance – Rel B5 (m) had only 33% variability showing that differences across playing positions were minimised by adopting relative metrics into analysis, especially for CDM and CM. Rel B5 (m) was greatest for W, CAM, and FB. Consequently, these findings emphasise that absolute data alone is not enough to fully analyse a football players' physical performance. Instead, relative data based on individual capabilities should also be considered to better reflect players' true physiological status, physical potential and limitations (Piñero et al., 2023). This is particularly important for central position players, as our findings have demonstrated.

8.2.2 Repeated Transitional Activities – Clusters

Frequency & type

Clusters (CTA) occurred on average 12.2 ± 3.2 times across ten official matches, with a range between 8 to 18. Mean number of transitional activities (TA's) in CTA was ~ 3, whereas peak number increased to ~ 5, with a range of 2 to 7 repeated actions. Total number of transitions categorised into repeated actions was 32.7 ± 11.5. Considering that in match play on average a team was exposed to ~ 50 TA's, around 33 actions out of these 50 occurred within 1 min, giving a high 66% of all TA's being repeated transitional activities. Defensive transitions (DT) were most frequent, followed by offensive transitions (OT), fast attacks (FA) and high-pressure actions (HP) (31% vs 25% vs 24% vs 20%, respectively). The latter, 83% of the time, occurred in conjunction with other actions within 1 min.

Duration & recovery period

Mean duration of a single transitional activity within a cluster was ~ 10 seconds, which turned out to be very similar to TA's duration. Nevertheless, cluster total duration was almost 3 times longer (~ 28 seconds), while its peak duration was ~ 53 seconds, with a minimum value equal to 29 and maximum to 94 seconds. Moreover, mean recovery period between a single TA's was close to 2 min (~ 109 seconds), whereas it decreased to around 26 seconds in CTA. Revealing over 4 times shorter recovery duration between repeated transitional activities.

8.2.3 Contextual Factors and Transitional Activities

Effect of time (match half and 15minute blocks)

Differences between both halves reached significance ($p < 0.05$) in volume-related metrics such as total distance: TD (~ 306 m vs ~ 258 m), high-speed running distance: HSRD (~ 78 m vs ~ 52 m), relative high-speed distance: RelB4 (~ 60 m vs ~ 46 m), and number (n) of high-intensity decelerations: HI Dec (1.1 vs ~ 0.8). Also, absolute sprint distance: SD (~ 22 m vs 20m) and relative sprint distance: VelB5 (~ 59 m vs ~ 47 m) were lower in the 2nd half, however it was not statistically significant. The number of high-intensity accelerations: HI Acc (n) and acceleration distance: AccelB3 distance (m) remained unchanged between halves. None of the physical variables per minute ($m \cdot min^{-1}$) showed differences between 1st and 2nd half. Our findings revealed significant ($p < 0.05$) decrease in TD (~ 310 m vs ~ 229 m), HSRD (~ 82 m vs ~ 70 m), VelB4 (~ 62 m vs ~ 39 m), VelB5 (~ 60 m vs ~ 40 m) and the number of high-intensity decelerations: HI Dec (~ 1.2 vs ~ 0.7) between the first and last 15min blocks, respectively. Sprint distance: SD (~ 23 m vs ~ 17 m), the number of accelerations: HI Acc (~ 0.8 vs ~ 0.5), and AccelB3 distance (3.2 m vs 2.3 m) was lower in the last 15min, but differences were not significant. When analysing intensity-related metrics per minute ($m \cdot min^{-1}$) in 15-minute blocks, only in TD (~ 211 m vs ~ 192 m) was reduced in match play. Other variables per minute ($m \cdot min^{-1}$) such as HSRD, SD, and the number of accelerations and decelerations: A+D showed no differences between 0-15' and 75-90' periods. Reduced volume-related metrics in the last stages of match play could indicate that fewer players took part during transitions possibly to due fatigue and/or tactical reasons to maintain correct tactical balance and shape at the end of match play (Ju et al., 2023b). Despite this, unchanged intensity (metrics per minute) highlights the need for high velocity and high tempo actions during transitional activities, regardless of the match stage. This emphasises the importance of preparing footballers in practical settings for these crucial game phases, revealing its WCS identity.

Effect of match outcome (win vs draw vs loss)

Differences ($p < 0.05$) in physical metrics were present between matches won and lost in TD (~ 297 m vs ~ 247 m), HSRD (~ 74 m vs ~ 55 m), SD (~ 23 m vs ~ 14 m), VelB4 (~ 55 m vs ~ 44 m), VelB5 (~ 55 m vs ~ 40 m), and AccelB3 distance (~ 3.5 m vs ~ 2.8 m). The number of high-intensity accelerations: HI Acc (n) and decelerations: HI Dec (n) remained similar between wins, draws and losses. Likewise, all metrics per minute ($m \cdot min^{-1}$) did not reveal any significant changes. Moreover, volume-related physical performance was reduced in the 2nd half in lost matches in TD (~ 285 m vs ~ 213 m), HSRD (~ 69 m vs ~ 43 m), VelB4 (~ 56 m vs ~ 32 m), and VelB5 (~ 50 m vs ~ 31 m). Additionally, TD ($m \cdot min^{-1}$) was the only intensity-related variable that was decreased in the 2nd half in lost games (~ 210 m vs ~ 188 m).

8.2.4 Maximum-intensity Periods (30-sec WCS)

Physical metrics per minute ($m \cdot min^{-1}$) during mean and peak maximum intensity periods (WCS_{mean} and WCS_{peak}, respectively) were significantly elevated when compared to the 90-min averages. For WCS_{peak}, the greatest differences were present for HSRD and SD, which constituted 10.4% and 5.1%, respectively of the average match demands. TD ($m \cdot min^{-1}$) was around 50%, while A+D ($n \cdot min^{-1}$) was ~ 40% of the whole-match mean. In contrast, competition averages generated higher values than WCS_{mean} for maximum acceleration: Max Acc ($m \cdot s^{-2}$) and maximum deceleration" Max Dec ($m \cdot s^{-2}$) by ~ 34% and ~ 44%, respectively.

Football-specific Drills

All locomotor demands, especially high-velocity metrics (HSRD, SD) in maximum-intensity periods (WCS_{mean}) during various game formats analysed in this body of work were far lower than the match WCS_{mean}. Only 10v10 Medium surpassed match averages by around 25-45%, reaching significance merely for TD ($m \cdot min^{-1}$). 10v10 Transitions were the only large-sided game that significantly overloaded HSRD ($m \cdot min^{-1}$) by ~ 70% relative to the 90-min averages. In contrast, small-sided games (5v5 and 4v4) overloaded running demands (TD; $m \cdot min^{-1}$) compared to the whole match data and exceeded match WCS_{mean} in the number of high-intensity accelerations: Acc and decelerations; Dec ($n \cdot min^{-1}$) by 30 to 50%. Nevertheless, running-based drills that included high-velocity actions with changes of direction (Extra) as well as submaximal running efforts (Submax runs) were the only exercise modes which overloaded HSRD ($m \cdot min^{-1}$) and SD ($m \cdot min^{-1}$) by 60% and ~ 36%, respectively. In addition, Extra exceeded match WCS_{mean} and the whole match demands in Acc ($n \cdot min^{-1}$) by ~ 40% and 60%, respectively.

Playing Position (Training vs Match Demands)

During training 30-second WCS, all locomotor metrics such as (TD, HSRD, SD) were insufficiently imposed on all playing positions relative to the match demands. Large differences were discovered particularly for high-velocity variables such as HSRD ($m \cdot min^{-1}$) and SD ($m \cdot min^{-1}$). Training to match ratio for HSRD ($m \cdot min^{-1}$) oscillated between ~ 45% to 54% in all positions but center backs (CB), who achieved ~ 70%. SD ($m \cdot min^{-1}$) in central midfielders (CM) and center backs (CB) was below 30% of the competition sprint distance. In comparison, attackers received ~ 34%, full backs ~ 37%, and wingers ~ 41%. Also, Max Dec ($m \cdot s^{-2}$) was lower for all positions during training WCS, specifically for CB and CM, reaching only ~ 86% of competition WCS_{peak}. In addition, full backs (FB) displayed discrepancies between match play and training WCS in Max Acc ($m \cdot s^{-2}$) reaching a ratio equal to ~ 84%. Given that locomotor metrics were not adequately imposed on all playing positions during football specific drills relative to the match WCS, our findings showed that acceleration and deceleration demands were sufficiently generated in training. Higher mechanical load was discovered especially in CM for A+D, Acc, and Dec (137%, 129%, and 125% respectively).

Playing Status

During WCS_{mean}, non-starters (subs) displayed higher distances per minute ($m \cdot min^{-1}$) compared to starters in TD (~ 184 m vs ~ 172 m), HSRD (~ 39 m vs ~ 27 m), and SD (~ 11 m vs ~ 7 m). Also, a greater number of high-intensity actions ($n \cdot min^{-1}$) was found in non-starters for Acc (~ 2.4 vs ~ 1.9) and Dec (~ 2.3 vs ~ 1.9). In addition, non-starting players showed higher efforts in Max Acc ($m \cdot s^{-2}$) (~ 2.6 vs ~ 2.3) and Max Dec ($m \cdot s^{-2}$) (- 2.7 vs - 2.6). Contrary to the mean maximum-intensity passages, starters during WCS_{peak} were exposed to higher running demands ($m \cdot min^{-1}$) in TD (~ 279 m vs ~ 263 m), HSRD (~ 157 m vs ~ 121 m), and SD (~ 95 m vs ~ 70 m). They also did more high-intensity actions ($n \cdot min^{-1}$) measured as Acc (~ 7.4 vs ~ 6.4) and Dec (~ 7.1 vs ~ 6). Moreover, starting players reached higher outputs in Max Acc ($m \cdot s^{-2}$) (~ 4.5 vs ~ 4.2) and Max Dec ($m \cdot s^{-2}$) (-5.8 vs -5.1).

Congested Fixture Period

When comparing physical outputs per minute between long-period (>6days), moderate-period (5-6days) and congested-period (≤4days), none of locomotor metrics ($m \cdot min^{-1}$) were significantly different. Nevertheless, findings revealed reduced accelerations/decelerations (A+D; $n \cdot min^{-1}$) (~ 4.6 vs ~ 4.1) and Dec ($n \cdot min^{-1}$) (~ 2.3 vs ~ 2) in WCS_{mean} during a congested-period. Moreover, match-to-match variability amid these recovery periods was highest for high-velocity variables ($m \cdot min^{-1}$) such as HSRD and SD (~ 43% vs ~ 66%, respectively). Other metrics' coefficient of variation: CV (%) was between 9 to 26%.

8.3 General Discussion

Training design based on whole game averages underestimates the physical and technical-tactical demands of high-intensity periods experienced by players misinforming practitioners on the physiological and mechanical demands required in competition (Delaney et al., 2015; Lacome et al., 2016). Indeed, changes in running performance and fluctuations of intensity during match play have previously been observed and highlighted in elite football matches (Novak et al., 2021). Although, we might ask ourselves whether designing training based on 90-minute data best prepares our athletes for the highest demands experienced during game play. Despite the most intense periods often referred to as the "worst case scenarios" (WCS), maximum-intensity periods and/or peak match demands, are widely investigated (Novak et al., 2021; Pollard et al., 2018; Whitehead et al., 2018) and analysed in regard to different contextual and situational factors within professional football (Casamichana et al., 2019; Fereday et al., 2020; Martin-Garcia et al., 2018; Martin-Garcia et al., 2019; Oliva-Lozano et al., 2020a; Oliva-Lozano et al., 2023a; Riboli et al., 2021a; Riboli et al., 2021b; Riboli et al., 2023a). That said, many questions remain unanswered (Bradley et al., 2018a; Carling et al., 2019; Ju et al., 2023b; Novak et al., 2021; Riboli et al., 2020). A clearer understanding of this concept through contextualisation of the data, might allow coaches to prepare players more precisely for maximum-intensity exposures in competition (McCall et al., 2020; Novak et al., 2021; Wass et al., 2020).

It is imperative in football performance analysis to quantify physical, technical, and tactical components together during peak intensity periods, adding context and trying to understand "what" happens physically, 'why" and "how" it takes place tactically, alongside the "when", "how many", "how often" and "how long" these moments occur (Figure 2) (Ju et al., 2023b; Sarmento et al., 2014). Moreover, previous research has mainly studied time epochs from 1-10 minute durations and found shorter windows exposing footballers to greater physical demands (Delaney et al., 2018b; Doncaster et al., 2020; Lacome et al., 2018; Martin-Garcia et al., 2018; Weaving at al., 2022). Knowing that elite football teams perform crucial high tempo actions below 20 seconds (Gonzalez-Rodenas et al., 2020; Oliva-Lozano et al., 2023c), more focus and attention should be paid to shorter than 1-minute duration epochs (e.g., 10-; 20-; 30-sec). These short periods could reflect true contemporary match demands that players are continuously exposed to during offensive and defensive actions across 90 minutes.

Therefore, the initial aim and objective of the present body of work was to capture physical performance during crucial moments of modern football game, whereupon coaches and practitioners could gain more insights about decisive transitional phases, high-pressure activities, and short maximum-intensity periods (Lago-Penas et al., 2018; Maneiro et al., 2019; Wass et al., 2020) (Figure 51). It was hoped that quantifying high-intensity actions during critical offensive and defensive activities commonly used by elite teams to win games, would significantly add to the existing body of knowledge, and most importantly, effectively transfer new evidence to practical settings (Aranda et al., 2019; Forcher et al., 2023; Pollard et al., 2018). Through this body of work, it was identified that these periods include offensive (counter-attacks and fast attacks) and defensive phases (offense-to-defence transition and high-pressure) that could easily be replicated in training, providing practitioners with powerful ammunition to holistically prepare footballers for the most demanding passages in modern match play (Martin-Garcia et al., 2018; Oliva-Lozano et al., 2021b). Elite clubs and the most successful coaches in the modern game have their own philosophy, tactical patterns, and playing style, which inevitably affects the physical, technical, and tactical demands and ultimately determines the physical profile footballers should possess to perfectly fit a given playing strategy and fulfill all the criteria successfully (Fernandez-Navaro et al., 2018; Forcher et al., 2022; Zhou et al., 2020). Yet the findings from body of work presented in this thesis offers a contemporary approach to the analysis of physical demands during contextualised periods of intensity (*transitional play, high-pressure activities and 30-second worst case scenarios*) in the elite football environment.

To the author's knowledge at the beginning of the DProf journey/research, there were no previous studies quantifying physical metrics during these crucial periods despite their high tactical value, meaning, and undoubted importance in football strategic approach, which is always to be one step ahead of the competition (Fernandez-Navaro et al., 2018; Nassis et al., 2020; Wass et al., 2020; Wright et al., 2011). Current literature however describes the effect of different playing styles including counter-attacks on various physical, technical performance and success-related factors, although these data are not contextualised into phases of match play, merely reflecting 90-minute totals (Forcher et al., 2023). Additionally, no previous work had investigated or distinguished physical output differences between offensive and defensive transitional actions nor identified their frequency, pattern of occurrence, duration, recovery period and positional differences. Joining technical-tactical and physical dots together and providing practitioners with a better understanding of how each of these TA's impact physical performance (locomotor and mechanical load) in matches and training (Chapter 3), how they affect playing position and playing status (Chapter 4; Chapter 7), and what is their likelihood during congested fixture periods (Chapter 7) are provided throughout the collective chapters of this thesis (Chapters 3-7). Furthermore, findings collectively offer the delivery of better tools to precisely select optimal football specific and running based drills for each playing position in team/individual training with proper work-to-rest ratios (Chapter 3-7). In addition, these findings may enable coaches to more effectively develop a weekly plan that includes well-chosen fluctuations of volume and intensity to reach desired physical/physiological and tactical outcomes and fulfill all important weekly objectives prior to match play (Clemente et al., 2019a; Nassis et al., 2020). Particularly on training days with the main objective being physical conditioning that integrates technical-tactical components and replicates match demands. Nonetheless, knowledge that comes from this research project should equip coaches with better instruments to treat starting and non-starting players accordingly by tailoring technical-tactical and conditioning training to their specific needs, especially during periods of intensified match load in competitive season (Chapter 7).

Alternatively, it is hoped that Chapter 4 and 5, regarding the physical demands during short and specific maximum intensity periods respectively would help coaches to maximise drills and tactical phases selection in training to better prepare various playing positions for matches, and optimise decisions, adequate high-velocity exposures, use effective weekly tapering strategies and avoid unwanted training load during congested fixture periods (Brink et al., 2014; Buchheit et al., 2023; Dupont et al., 2010). This approach could ensure footballers come fresh without residual weekly fatigue and unnecessary physical stress during tactical drills two- and one-day prior competition (MD-2 and MD-1, respectively) (Morgans et al., 2023). That said, coaches usually focus on detailed tactical preparation including collective offensive (counter-attacks) and defensive (high-pressures) phases during these two days (Morgans et al., 2023; Oliva-Lozano et al., 2021b). For instance, wide players (full backs and wingers) might achieve unwanted high-velocity stress when performing offensive transitions (counter-attacks), defensive players (center backs, central defensive midfielders, and full backs) could generate high-intensity actions during defensive transitions, whereas offensive players (attackers, wingers, and attacking central midfielders) could be exposed to excessive high-intensity accelerations and decelerations (Chapter 4). Consequently, this may lead to fatigue and result in suboptimal physical preparation for the upcoming match if there is lack of control and knowledge about the specific physical impact of these phases on each playing position (Harper et al., 2019; Jaspers et al., 2017; Rhodes et al. 2021).

This is the first research programme that has clearly defined repeated transitions as clusters, associated high-pressure activities with a significant mechanical stress, and found that high pressure should mainly be used in conjunction with other tactical actions giving coaches better instruments to precisely reflect the demands of competition in training (Chapter 5-6). Indeed, counter-pressing also referred to as "Gegen pressing" as an aggressive attempt to regain ball possession within 5 seconds, has recently become very popular tactical strategy used by top football teams (Barreira et al., 2014; Bauer et al., 2021; Maneiro et al., 2019; Nassis et al., 2020). Hence, it is imperative that coaches understand this concept more clearly and adopt these findings within the applied settings to optimise training process and enhance their training design. Thereupon, findings of this research project are unique and provide novel evidence to coaches, practitioners, and physical therapists about short, specific, and highly contextualised maximum intensity phases experienced by footballers in matches.

To the author's knowledge studies that describe the WCS magnitude and depict number of these moments across 90 minutes as well as indicate their pattern of occurrence in football matches are scarce (Delaney et al., 2018b; Novak et al., 2021; Oliva-Lozano et al., 2023b; Weaving et al., 2022). In fact, the maximum-intensity period concept states that intensified blocks of activity occur only once or a few times during the game (Riboli et al., 2024; Varley et al., 2012). One compares the physical demands between the first three most demanding passages in professional football across all positions and durations (1-, 3-, 5-, and 10-minute) and highlighted the importance of considering all maximum-intensity periods experienced by footballers in competition (Oliva-Lozano et al., 2021b). Another investigated the distribution of the time spent at varied percentages of 1-min_{peak} for different physical metrics and showed that most of match actions were performed at intensity above the average 90-minute demands, especially for the high-intensity activities such as sprints and accelerations (Riboli et al., 2022). The present research thesis therefore contributes to the existing body of knowledge regarding the frequency, tactical type, duration, and recovery period of high-intensity passages in contemporary football. For the first time it has been revealed that footballers were on multiple occasions (around 50 times) exposed to high-intensity phases in matches performing on average 15.2 defensive transitions, 13.7 offensive transitions (counter-attacks), 13 fast attacks and 7.7 high-pressure activities collectively (Chapter 3-4). TA's could be treated as the most demanding passages of modern football games, because mean and peak physical metrics during these actions were highly elevated in relation to the 90-minute averages (Chapters 3-4).

This novel evidence might further question and undermine the meaning of the multifactorial WCS concept, which brings attention only to one block of intensified physical stress neglecting other demanding phases across the whole match duration (Novak et al., 2021; Ju et al., 2023b). Contrary to transitional play, research linking physical with tactical performance (in-, out-of-possession; ball-in/out-of play; offense/defence) during peak match demands is very limited (Ju et al., 2022a). In addition, the WCS concept focuses on only one physical variable at the time, making a training prescription (small-sided games, tactical drills, positional exercises, etc.) highly challenging, difficult to fully reflect match intensity (Bradley et al., 2018b; Carling et al., 2019; Novak et al., 2021; Riboli et al., 2020), which in definition is a multidimensional construct that combines several variables or indicators (Pillitteri et al., 2023).

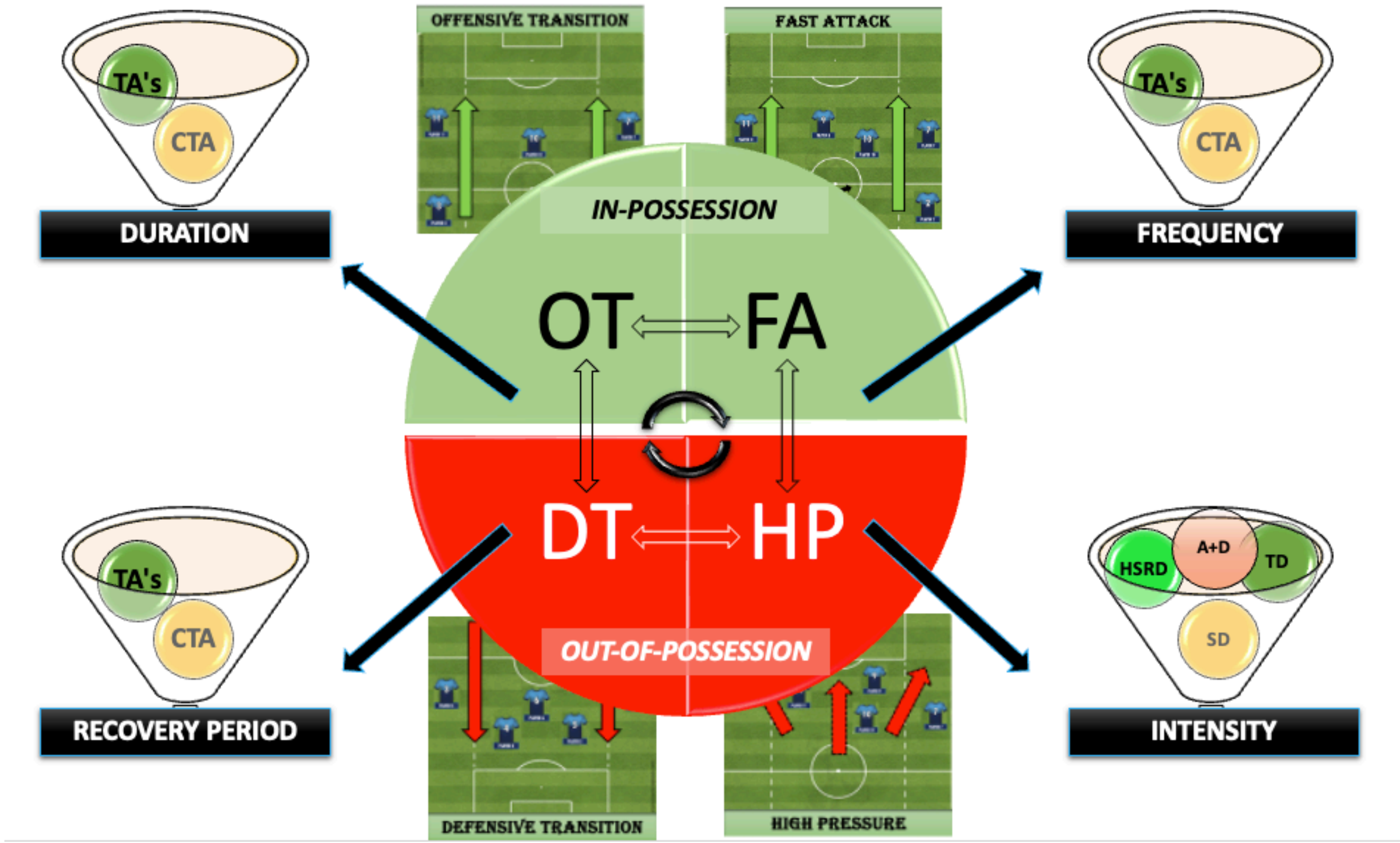


Figure 37. Relationship between tactical action, frequency, duration, recovery, and intensity (m·min^{-1}) during transitions: OT = Offensive transition; DT = Defensive transition; FA = Fast attack; HP = High pressure considering positional specificity. Adopted from Bortnik et al. (2022), (2023c) and (2024).

Note: CTA = cluster of transitional activity occurring < 1-min; TA's = single transitional activities occurring > 1-minute.

In Chapter 3 and 4, offensive activities such as counter-attacks and fast attacks displayed the greatest sprint distance. If coaches were seeking speed and maximum velocity exposure in training, these attacking phases should be applied (Asian-Clemente et al., 2022; Oliva-Lozano et al., 2023c; Vasquez et al., 2023). It is worth stating at this point that nearly half of the game high-velocity distance occurred during transitional play (Chapter 3). Hence, teams using aggressive attacking style of play should pay a special attention to high-speed and sprinting activities during positional attacking exercises, transitional games, and isolated running based drills in which playing position requirements were considered (Martin-Garcia et al., 2018; Oliva-Lozano et al., 2021b). The main target during these exercise modes would be a very quick attack after the ball possession was recovered. Importantly, large spaces behind the defenders should be created and/or additional zones added, enabling attacking players to exploit this space and generate high-velocity actions while conducting technical-tactical movements very quickly (Ju et al., 2022a; Rochael et al., 2023a). Previous literature has mainly demonstrated the importance of offensive transitions and rapid changes from defensive to offensive phases to surprise and outnumber disorganised opposition's defence and create goalscoring opportunities at maximum speed, while providing limited insights about other important factors such as the ones included in the present research thesis (Faude et al., 2012; Gonzalez-Rodenas et al., 2020; Hughes et al., 2019; Lago-Ballesteros et al., 2012; Riboli et al., 2020; Schulze et al., 2021).

Recently, it has been demonstrated that creating numerical superiority (floaters) during counter-attacks in SSG lowered the physical stress of youth footballers in training (Rochael et al., 2023b). Furthermore, enlarging the playing area in 3v2 counter-attack games increases running demands including high-velocity metrics, speed, and rate of perceived exertion (internal load), while smaller pitches generate more accelerations (Asian-Clemente et al., 2023). Indeed, transition games are football specific exercises which ensure high-speed exposure in training with lower variability (CV) compared to SSG and LSG (Asian-Clemente et al., 2022). More work should be done in this area to further explore training in specific football contexts. Alternatively, defensive moments represent out-of-possession phases, which have been associated with higher physical outputs compared to in-possession phases (lower physical intensity per minute) during elite football matches (Jerome et al., 2023; Modric et al., 2023). Interestingly, a recent study has reported that reducing time out-of-possession within a defensive third increased team performance and success (Jerome et al., 2023). In consideration of this, greater efforts and higher rates of distances covered during defensive activities (out-off-possession) may facilitate faster possession regains when recovering the ball, closing down the opposition to prevent conceding a goal, and applying high pressure in the attacking third (Ju et al., 2022a; Tenga et al., 2010; Wright et al., 2011). Yet, different situational variables (match status, match location, quality of opponent to name a few) should be considered when analysing defensive match performance (Fernandez-Navarro et al., 2020). According to the findings of the current thesis, defensive transitions could be used if the main objective of a training session was to impose high running demands including high-speed exposure during tactical parts of football sessions (Oliva-Lozano et al., 2023c). In fact, "recovery" runs, which mostly occur during rapid offence-to-defence transitions, have been linked to the greatest high-intensity distance during peak match demands in football (Ju et al., 2022a). That said, when coaches require a high mechanical load to accumulate greater acceleration distances and generate many high-intensity accelerations and decelerations in tactical training, then high-pressure activities would be a recommended choice based on findings of this research project (Chapter 3-4). Given that studies investigating team and positional physical demands and characteristics during defensive crucial phases of match play are very limited despite their significance in professional football (Bosca et al., 2009; Forcher et al., 2022; Modric et al., 2023; Winter et al., 2017), this research thesis highlights its unique contribution to the current body of knowledge regarding the maximum-intensity periods and their application in football practical settings.

Knowledge about the number of peak intensity periods, their duration and pattern of occurrence has been considered imperative for selecting adequate doses of high-intensity efforts to replicate all physically demanding periods in highly contextualised environment that combines physical and technical-tactical components and includes position specific actions (Ade et al., 2021; Di Salvo et al., 2007; Forcher et al., 2023; Sarmento et al., 2014). Enabling practitioners to set appropriate training targets and effectively prepare players for the demands of competition, increase a chance of successful performance, and lower the risk of injury (Di Salvo et al., 2007; Gabbett, 2016a; Malone et al., 2017b). It is worth noting that a team investigated in this project had a higher than opponents' ball possession (~ 56%) in all games analysed. It might be assumed that to resist this dominant style of play, opposing teams could acquire a defensive tactics focused on staying behind the ball and waiting for an opportunity to counter-attack and exploit the space behind defenders at high intensity (Altmann et al., 2023). This specific tactical strategy could possibly be reflected in the highest number of defensive transitions (DT) found in Chapter 3 and 6 (Figure 38).

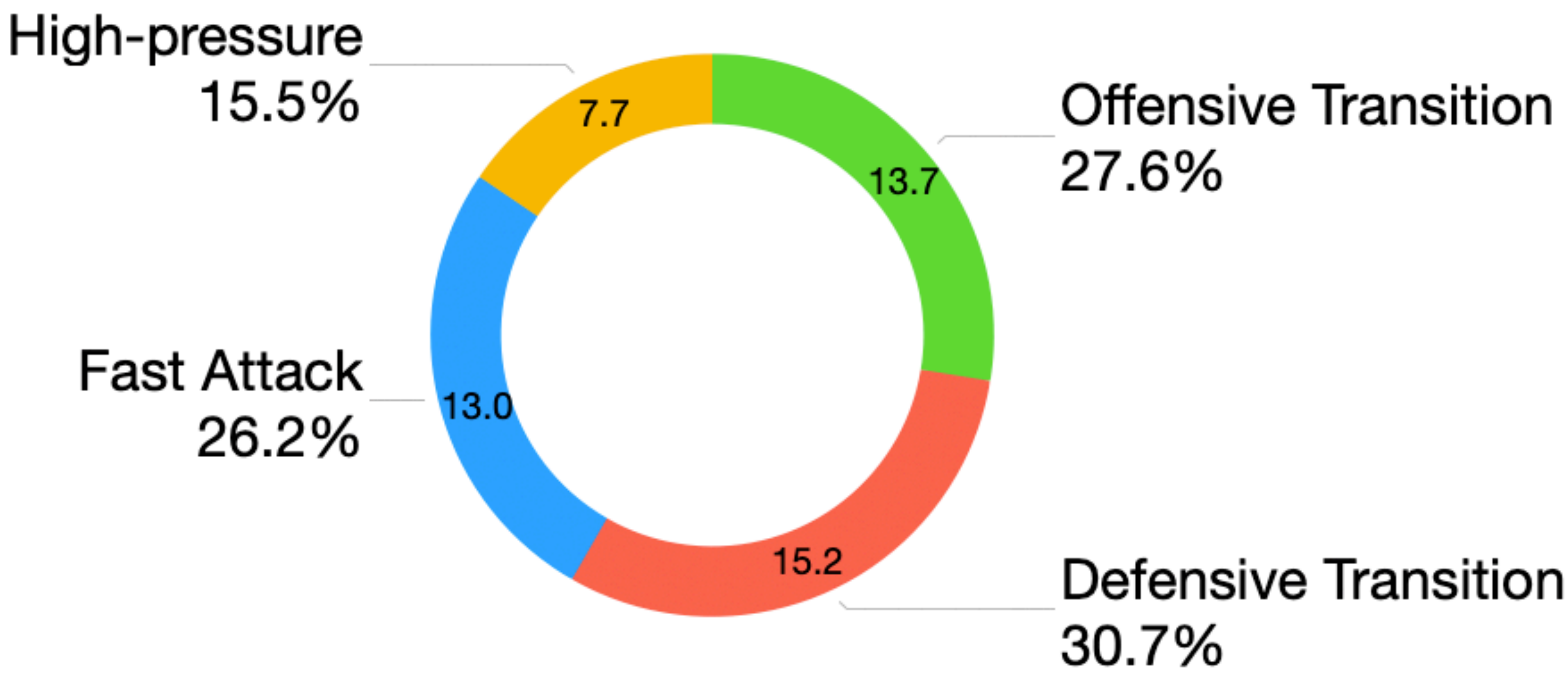


Figure 38. Mean frequency of transitions OT = Offensive transition; DT = Defensive transition; FA = Fast attack; HP = High pressure depicted as a count and percent across 10 official matches. Adopted from Bortnik et al. (2022).

Footballers should receive optimal physical-technical-tactical stimulus in training that reflects the correct type and pattern of action, intensity, duration, and proper recovery periods (work-to-rest-ratio) relative to competition and positional demands (Novak et al., 2021; Riboli et al., 2021a). Thus, analysis of physical metrics that combines technical-tactical aspects of football match performance would be considered imperative to fully comprehend the required action-intensity-duration-recovery relationship (Figure 37) during intensified blocks of activity and ultimately, better inform the training process to maximise football performance and potentially reduce injury risk (Harper et al., 2019; Ju et al., 2023b; Wass et al., 2020). There are no previous studies investigating duration and recovery periods between successive transitional activities in a modern football match. The findings of Chapter 3 revealed that transitional activities lasted on average 10-11 seconds, while peak duration doubled and varied between 22 to 27 seconds (Figure 39), which was in line with others describing the time span of crucial actions performed in professional football (Gonzalez-Rodenas et al., 2020).

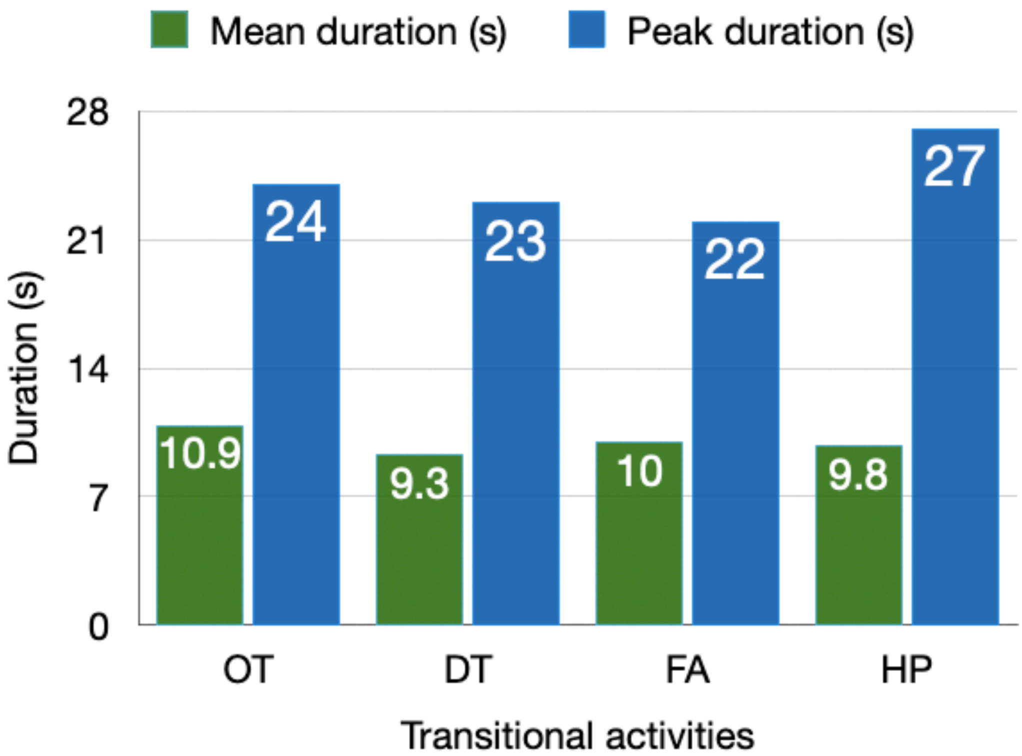


Figure 39. Duration of transitions OT = Offensive transition; DT = Defensive transition; FA = Fast attack; HP = High pressure expressed as a mean (green) and peak (blue) value across 10 official matches. Adopted from Bortnik et al. (2022).

Previous literature in football has defined > 2 high-velocity efforts and accelerations within a period of 1 min as repeated high-intensity efforts (RHIE) (Aughey, 2011; Buchheit et al., 2010; Carling et al., 2012, Gabbett et al., 2013). Based on this notion, Chapter 5 and 6 introduced a novel concept of repeated transitional activities defined as clusters (CTA) and showed that majority of transitions (66%)

turned out to represent RHIE in attack and defence (Aranda et al., 2019), which means that footballers were regularly exposed to repeated short, intermittent actions together over the course of the game (Figure 40 and 51). Interestingly, over 80% of high-pressure activities were repeated (Figure 41), providing new evidence that these defensive actions happen in conjunction with other crucial tactical moments (transitions) in competition (Maneiro et al., 2019). Indeed, the ability to work intermittently and repeat high-intensity efforts collectively as a team over 90 minutes has been found crucial for successful performance in modern football (Carling et al., 2012; Ju et al., 2022a; Wallace et al., 2014). Skillful players that possess a high capacity to repeated high-intensity efforts and tolerate high weekly training and match loads have been highly demanded by coaches in elite football (Hostrup et al., 2023). Chapter 6 revealed that more than 12 CTA lasting ~ 30 seconds were reported over 90-min, while peak number of TA's in a cluster varied between 2 to 7 (Chapter 5). These findings are higher than previously reported (Carling et al., 2012; Datson et al., 2018) giving very strong implications and new evidence for a modern training prescription regarding transitional games and drills in professional football. Additionally, it has been discovered that a recovery period between cluster transitional activities (~ 26 seconds) was > 4 times shorter compared to single TA's (~ 109 seconds) providing a powerful ammunition for practitioners in relation to training design and proper utilisation of work-to-rest-ratios during integrated football drills (Ju et al., 2022a) (Appendix 11).

FREQUENCY (n)	Mean	Minimum	Maximum
Total clusters	12	8	18
Mean TA's in cluster	2.6	2	3.3
Peak TA's in cluster	4.5	2	7

DURATION (s)	Mean	Minimum	Maximum
Cluster TA's	9.9	9	12
Cluster	28	23	42
Cluster peak duration	53	29	94
Cluster TA's recovery period	26	21	32

Figure 40. Frequency (n) and duration (s) of clusters' transitional activities in matches defined as > 2 TA's within 1 minute depicted as mean, minimum, and maximum values. Adopted from Bortnik et al. (2023a).

These findings indicate that speed endurance production training could be effectively used with elite footballers integrating physical, technical, and tactical aspects together to improve performance during blocks of maximum intensity (Bradley et al., 2018a; Mohr et al., 2016). Repeated sprint training consisting of actions below 10 seconds and sprint interval training using all-out efforts lasting ~ 20-30 seconds could also be utilised to prepare players for CTA in competition (Hostrup et al., 2019; Hostrup et al., 2023). It is imperative to highlight that time pressure rule could have a detrimental impact on the quality of technical actions although not affect the physical performance during football specific exercises in training (Rochael et al., 2023b). Essentially, short rest periods between successive high-intensity bouts could deteriorate physical performance (Balsom et al., 1992; Spencer at al., 2004) and modern physical conditioning programmes (team, individual, and/or end-stage rehabilitation sessions) should include transitional activities in their agenda (Carling et al., 2012; Di Mascio et al., 2013) to better prepare for competition demands (Martín-García et al., 2019; Rico-González et al., 2022; Wass et al., 2020; Vázquez et al., 2021), reduce injuries and prevent declines in physical performance in the last stages of match play (Ade et al., 2020; Casamichana et al., 2019; Gabbett et al., 2016b; Malone et al., 2017c; Mohr et al., 2016; Stølen et al., 2005). It is important to add that physiological, neuromuscular, perceptual and performance demands of repeated high-intensity efforts training method are key influencing factors in team sport athletes (Thurlow et al., 2023). Longer sprint distances (>30 m) in larger areas and shorter inter-repetition rest periods (< 20 s) generate higher physiological response and induce higher levels of fatigue. Inversely, shorter distances, smaller areas and longer recovery periods between repetitions cause acute sprint performance improvements and lower physiological strain (Thurlow et al., 2023).

In fact, a plethora of research has shown a positive impact of anaerobic high-intensity activities in the form of speed endurance production training (~ 30 second bouts) on repeated sprints, long-sprint ability, peak velocity, and football performance (Castagna et al., 2017; Mohr et al., 2016; Stolen et al., 2005). More importantly, it has also been reported that position specific speed endurance production drills produced greater intensity within elite EPL youth players (Ade et al., 2021), showing that positional transitional exercises in training that integrate physical, technical, and tactical aspects together could effectively improve and develop all components of football match performance (Bradley et al., 2018a; Ju et al., 2023b). For instance, in practical terms coaches could combine high-pressure actions in the attacking third (numerical superiority) to regain ball possession (~ 10 sec) with a defensive transition (recovery run to its own penalty area lasting ~ 10 sec). Based on the findings from this body of work, a short rest could be applied afterwards in the form of passing the ball between players located in their positions (in-possession around 20-25 sec). Then, this might be followed by a fast attack (offensive action around 10 sec) to exploit a large open space and enter the opponent penalty box with an attempt to score a goal (Figure 57 and 61). This pattern would reflect clusters' characteristics footballers regularly experience in official matches during intensified blocks of activities and fall into a category between sprint intervals and speed endurance production mode, which in combination could potentially improve players' abilities to execute technical-tactical tasks at high-intensity over 90-min (Nobari et al., 2023). This should be further explored in future applied research approaches.

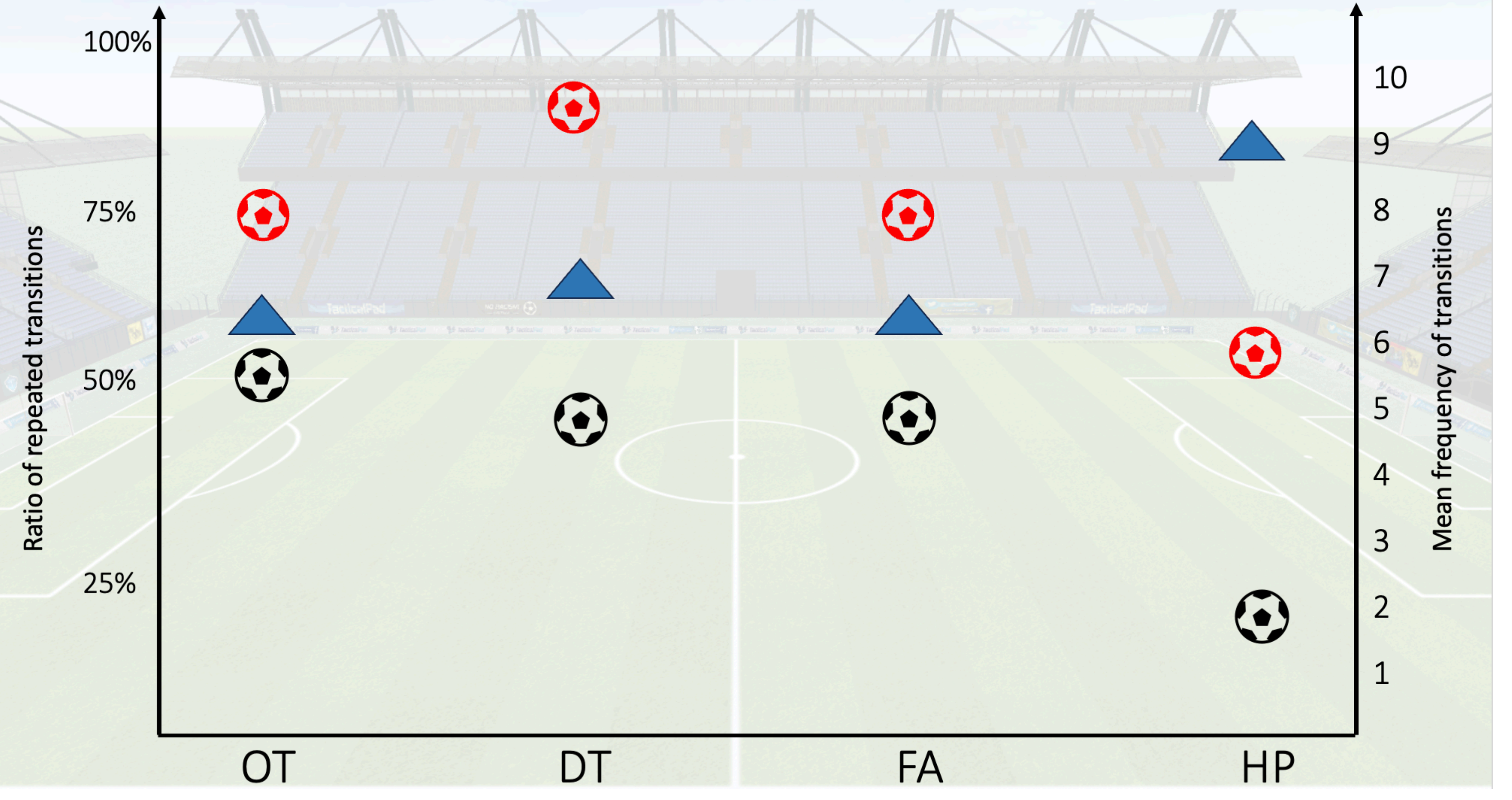


Figure 41. The ratio (%) of repeated transitions = clusters (blue triangle) and the mean frequency of transitions: cluster TA (red ball) and single TA (black ball) during OT = Offensive transition; DT = Defensive transition; FA = Fast attack; HP = High pressure across 10 official matches. Adopted from Bortnik et al. (2023b).

Note: Cluster TA = transitional activity occurring < 1-min; Single TA = transitional activity occurring > 1-minute.

Over the past two decades, research has analysed the 90-minutes physical demands in football extensively and informed that distances covered at varied intensities differed between positional groups (Ade et al., 2016; Anderson et al., 2016a; Barnes et al., 2014; Bradley et al., 2009; Bradley et al., 2010; Borghi et al., 2021; Carling et al., 2012; Carling et al., 2016; Clemente et al., 2020b; Di Mascio et al., 2013; Lago-Peñas et al., 2009; Mohr et al., 2003). A plethora of studies reported midfielders achieving the highest total distance and performing higher volume of high intensity runs separated by a short recovery (< 20 s) (Carling et al., 2012; Dalen et al., 2016; Fransson et al., 2017). In contrast, center backs accumulated the lowest distance including high-velocity actions and had the longest recovery duration between consecutive high-intensity efforts compared to other positions (Di Mascio et al., 2013; Fransson et al., 2017; Lago-Peñas et al., 2009; Mohr et al., 2003). Wide positions (full backs and wingers) and forward players completed greater distances of high-intensity running (Carling et al., 2012; Dalen et al., 2016; Di Salvo et al., 2009; Di Salvo et al., 2012). Moreover, full backs and offensive midfielders generated the highest number of accelerations/decelerations and central midfielders developed greater metabolic power compared to other positional groups (Altavilla et al., 2017). In fact, the activity profile of elite footballers highly depends on their tactical roles and positions, especially regarding high-velocity activities (Bradley et al., 2018a; Dalen et al., 2016; Ju et al., 2023b). Differences across various playing positions during the most physically demanding passages in football have also been reported (Augusto et al., 2022; Rico-Gonzalez et al., 2022; Martín-García et al., 2018; Riboli et al., 2021b). Nevertheless, studies exploring the WCS concept with specific reference to technical and tactical activities are very limited (Carling et al., 2019; Ju et al., 2022a; Martín-García et al., 2018; Riboli et al., 2021b; Wass et al., 2020). The present research thesis is the first that investigated the effect of playing position on physical performance during transitional play and high-pressure activities (Chapter 4) (Figure 42). In contrast to majority of previous studies, generic and general positions (defenders, midfielders, wide midfielders, and attackers) (Andrzejewski et al., 2019; Bradley et al., 2009; Felipe et al., 2019) have been further developed considering players specialised tactical roles such as central defensive midfielders, central midfielders, and central offensive midfielders (Ju et al., 2022a; Ju et al., 2023b). Furthermore, this research thesis compared physical metrics between highly popular and widely used football specific drills to match demands during short 30-second worst-case-scenarios (Chapter 7). It is believed that better knowledge regarding positional differences during crucial high-intensity blocks of activities, would provide better insights on how to best prepare footballers for contemporary game demands. Allowing practitioners to contextualise the physical outputs required in specific drills and ensuring the physical stimulus complements the tactical requirements placed on players by the coaches (Martín-García et al., 2018; Wass et al., 2020).

Figure 42. Complex inter-positional relationships including different offensive/defensive specific tasks in 4-2-3-1 formation during various phases within match play.

Chapter 4 revealed that center backs (CB) experienced the lowest absolute and relative physical outputs during TA's, especially regarding high-velocity metrics (HSRD, SD, and A+D), which was in line with previous studies investigating whole and peak match demands in elite football (Martín-García et al., 2018; Oliva-Lozano et al., 2021a). As expected, and previously reported (Ju et al., 2022a), attacking phases (offensive transitions and fast attacks) did not impose high physical stress on this positional group. Although during defensive transitions (out-of-possession) which reflected a rapid switch from offense to defence in larger spaces requiring longer recovery runs, CB achieved the highest number of high-intensity accelerations and decelerations and showed elevated locomotor metrics compared to other phases, which was consistent with others (Riboli et al., 2021b). Interestingly, central defensive midfielders (CDM) along with central midfielders (CM) showed very similar patterns for high-intensity variables during offense-to-defence transitions, suggesting that physical similarities between all groups within match play existed (Figure 43). Hence, similar training modes could be applied for central defensive positions (CB, CDM, and CM) linking their roles together in phases when the ball possession is lost and a rapid transition from offense to defence required. Indeed, for the first time the current research thesis showed that these central positions were found to experience deficits between competition and training in 30-sec maximum-intensity periods for maximum deceleration (Max Dec) (Chapter 7). Certainly, it has been suggested to use maximum acceleration and deceleration values to create high-intensity profiles and individualise load demands more optimally and precisely inform training prescription in football (Harper et al., 2021). During match play, transitional attacking phases alternate with defending actions regularly over 90-min often occurring as repeated high-intensity activities (Chapter 5 and 6). Therefore, if coaches' objective in training was to generate higher locomotor/mechanical load and expose these positional groups to maximum decelerations, then carefully designed defensive transition games and/or tactical transitional exercises, could be applied in team settings. Interestingly, greater Max Dec has been reported without the ball, when team was out-of-possession, suggesting that defensive transitions and high-pressure actions might be an optimal football specific exercise to induce higher values of this metrics in football training (Oliva-Lozano et al., 2023b). Chapter 4 further revealed that full backs (FB) achieved the greatest sprint distance (SD) compared to other positions in all TA's, which was predominantly seen during defensive transitions and fast attacks. Findings consistent with previous work analysing WCS (Martín-García et al., 2018; Martín-García et al., 2019; Riboli et al., 2021b). FB responsibilities in competition is to link defensive and offensive actions over longer spaces performing over and/or underlapping, which results in greater volumes of high-velocity metrics including high-speed running and sprinting (Ade et al., 2016; Ju et al., 2022a; Wass et al., 2020). This information should be considered when planning training for FB. Nevertheless, current literature reports that maximum speed activities over longer distances might not be adequately used in football training (Vázquez et al., 2023) and these important actions have been found to be directly related to the training status and recognised as one of the key indicators of the physical performance in professional football (Krustrup et al., 2003; Mohr et al., 2003). In addition, Chapter 7 discovered that FB were not sufficiently exposed to maximum acceleration (Max Acc) activities during 30-second WCS in training relative to competition, which demonstrates a direction of highlighting this physical ability during position specific training. Rapid acceleration following a change of direction to perform a recovery run (defence) and/or support offensive play by overlapping and exploiting open space, would be a recommended choice for practitioners during a football session to adequately expose this group to the physical demands of modern match play.

Contrary to defensive central positions such as CB, CDM, and CM, central attacking midfielders (CAM) exhibited highest total distance including high-speed running distance compared to all playing positions, mainly during offensive phases of play (Chapter 4). This group has been shown to be involved in running behind the defence line penetrating open spaces and frequently supporting offensive attacks in football matches, which has been linked to greater physical effort and higher intensity (Ju et al., 2022a; Martin-Garcia et al., 2019). Wingers (W) accumulated the highest number of high-intensity accelerations and decelerations (A+D) during offensive phases in-possession of the ball (offensive transitions and fast attacks) and revealed higher mechanical load in defensive phases such as high-pressure activities. Highlighting its positional responsibility to have the ability to apply high pressure on the attacking third to regain possession very quickly after the ball has been lost ("Gegen pressing"). Additionally, wingers displayed the greatest locomotor demands (TD, HSRD, SD) out of all positions during counter-attacks, which indicates the importance of this positional group not only during high pressure but mainly during rapid changes from defensive to offensive transitions that are performed at maximum velocity to surprise opponents, exploit open space, and create goalscoring opportunities (Hughes et al., 2019; Riboli et al., 2021b; Schulze et al., 2021). Finally, attackers (A) experienced lower physical output in defensive transitions (DT) but reached higher metrics during high pressure activities (HP), again consistent with conclusions drawn within literature (Ju et al., 2022a; Oliva-Lozano et al., 2021a; Riboli et al., 2021b). Nearly half of all ball winning turnovers across different European leagues, were a result of high pressing in the offensive (opposition) half, resulting in more goals scored (Hughes et al., 2019; Kubayi, 2020). These findings demonstrate the importance of using attackers along with CAM and W as the first line of defence, aiming to win the ball back and apply high pressure when out of possession (Chapter 4). Coaches might consider exposing these positional groups to high-pressure actions in training during a weekly overloading phase to prepare them physically for these demanding periods and tactically improve their abilities to quickly regain ball possession and effectively block the opponent's attack. On the other hand, when designing tactical high-pressure drills during a tapering phase of the weekly training plan (e.g. MD-2 and MD-1) as shown in Figure 53, these playing positions should be closely monitored to avoid an excessive physical load one or two days before official game.

Chapter 7 discovered that during short maximum intensity periods, football specific drills used by coaches in conditioning sessions failed to replicate high-velocity (HSRD, SD) and maximum deceleration actions relative to match peak demands across all playing positions (Oliva-Lozano et al., 2021b). Undeniably, mismatch between training and competition could potentially fatigue players to a greater extent and place all positions at higher risk of injuries in matches if muscles were not adequately stressed and adapted to specific demands during most demanding passaged experienced in games (Ekstrand et al., 2023; Rhodes et al., 2021). Based on these findings, it could be suggested to use collective high-intensity efforts during transition games, tactical transitional drills, and running based exercises to provide adequate dose of physical stimulus relative to each playing position (Ju et al., 2023b). For instance, central defensive positions (CB, CDM, CM) together with full backs (FB) could initiate a build up playing out of the back, advancing space, and progressing the ball forward to offensive players, while attackers (A) along with wingers (W) applying high pressure and trying to win the ball in numerical inferiority. Suddenly, a turnover in possession could begin a counter-attack during which all players involved in the build up had to react immediately, stop aggressively, and change direction (Max Dec and Acc) to begin a recovery run (HSRD and SD) to their own penalty box to prevent attacking players from scoring a goal. Counter-attack would have to be done very quickly (< 10 sec) and involve CAM in the central area, W linking together with FB in wide areas (over and/or underlapping), and A waiting outside of the box to join the attack and create numerical superiority. This would ensure positional specificity, high-intensity exposure including HSRD, SD, A+D and optimal preparation for physical and tactical demands of crucial periods within a modern match play as depicted in Figure 59 (Buchheit et al., 2023; Modric et al., 2020; Ju et al., 2022a; Rochael et al., 2023a).

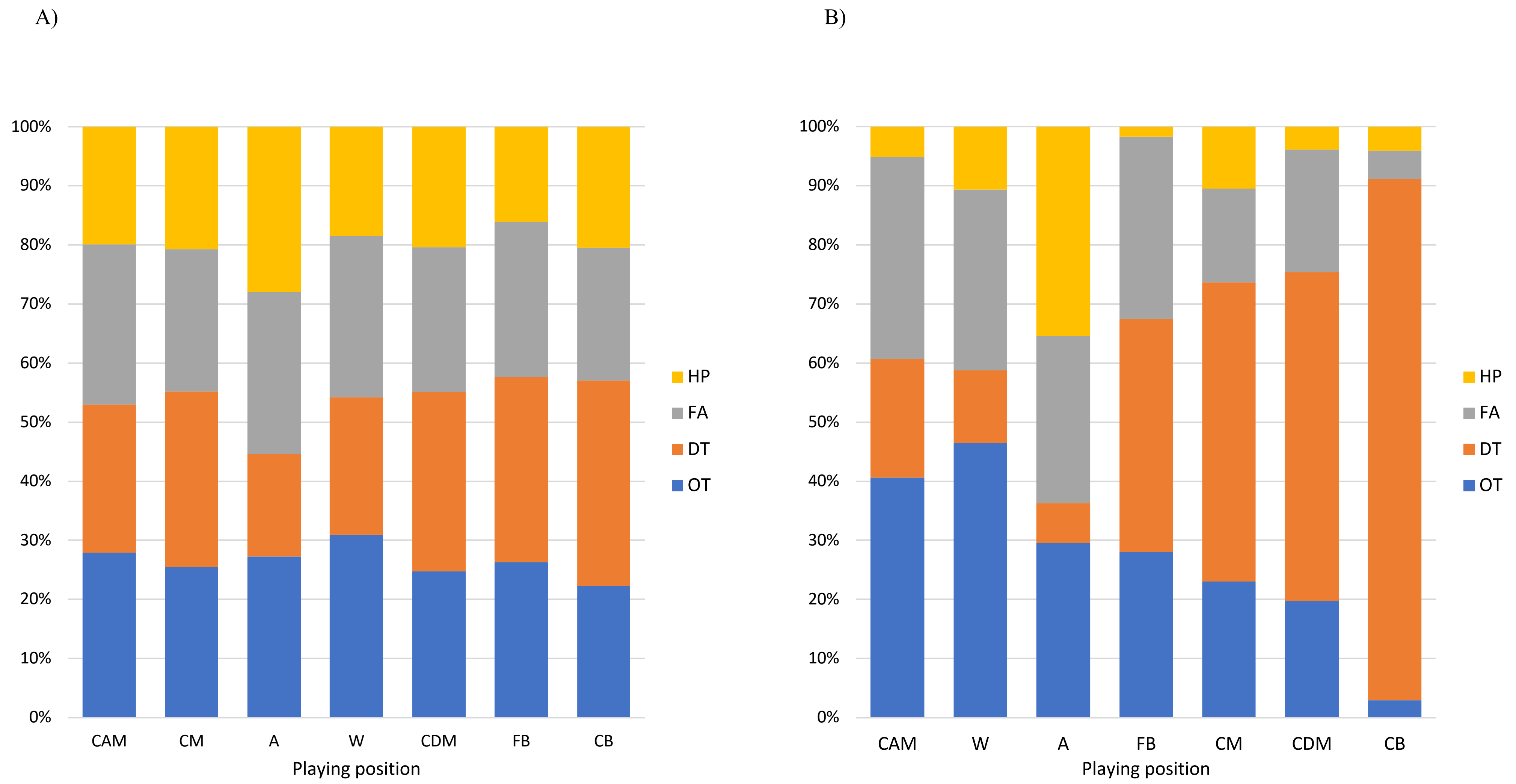


Figure 43. 100% percent stacked charts comparing positions CB (Center Back), FB (Full Back), CDM (Central Defensive Midfielder), CM (Central Midfielder), CAM (Central Attacking Midfielder), W (Winger), and A (Attacker) in a) mean TD ($m \cdot min^{-1}$) b) mean HSRD (> 19.8 $km \cdot h^{-1}$; $m \cdot min^{-1}$), c) mean SD (> 25.2 $km \cdot h^{-1}$; $m \cdot min^{-1}$), and d) mean A+D (> 3 $m \cdot s^{-2}$; $n \cdot min^{-1}$) and the proportional contribution across all transitional activities: OT = Offensive transition; DT = Defensive transition; FA = Fast attack; HP = High Pressure.

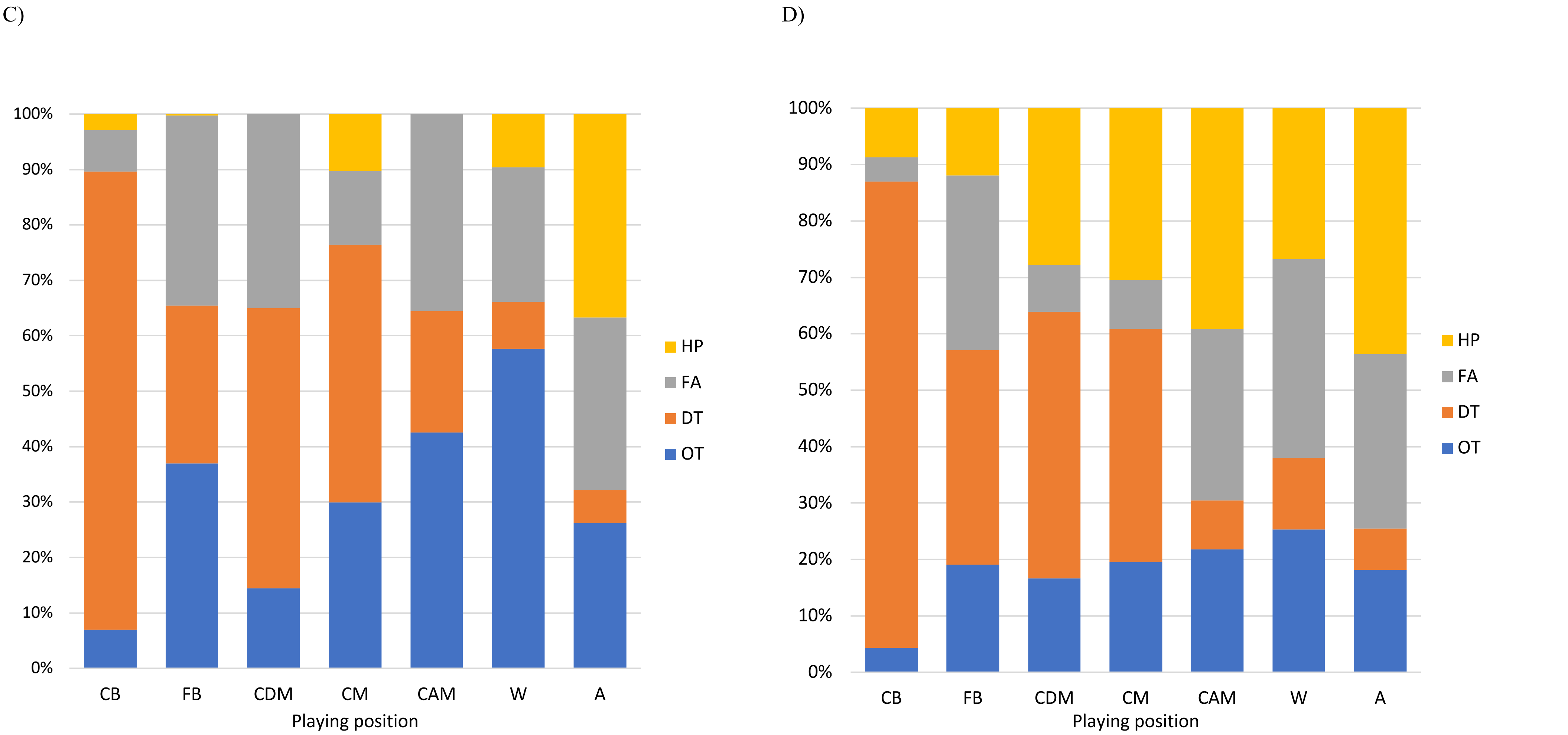


Figure 43 ***Cont.*** **100% percent stacked charts comparing positions CB (Center Back), FB (Full Back), CDM (Central Defensive Midfielder), CM (Central Midfielder), CAM (Central Attacking Midfielder), W (Winger), and A (Attacker) in a) mean TD ($m \cdot min^{-1}$) b) mean HSRD (> 19.8 $km \cdot h^{-1}$; $m \cdot min^{-1}$), c) mean SD (> 25.2 $km \cdot h^{-1}$; $m \cdot min^{-1}$), and d) mean A+D (> 3 $m \cdot s^{-2}$; $n \cdot min^{-1}$) and the proportional contribution across all transitional activities: OT = Offensive transition; DT = Defensive transition; FA = Fast attack; HP = High pressure.**

Previous and current research has attempted to understand associations between different contextual factors (match half, match location, match outcome, opponent quality, style of play, and cultural aspects) and match average physical metrics in professional football (Aquino et al., 2017; Aquino et al., 2020; Bradley et al., 2013; Dellal et al., 2011; Morgans et al., 2024; Oliva-Lozano et al., 2020a; Oliva-Lozano et al., 2020b; Rhodes at al., 2021). Studies exploring the effect of contextual variables on the most demanding passages are limited (Casamichana et al., 2019; Fransson et al., 2017; Oliva-Lozano et al., 2021a; Riboli et al., 2021b). It has been shown that for short time windows (1- to 3-min), away matches imposed higher locomotor and mechanical efforts, winning games generated higher running performance, and playing formation (4-3-3 vs. 3-5-2) differently affected various playing positions such as forwards, wingers, and wide defenders (Augusto et al., 2022; Fereday et al., 2020; Oliva-Lozano et al., 2020b; Riboli et al., 2021b). These findings indicate high complexity of football match play relative to the peak demands and high dependence on many different factors, which should always be considered when analysing WCS performance to optimally transfer this knowledge to practical settings (Augusto et al., 2022; Gregson et al., 2010; Rampinini et al., 2007). Thus, a better knowledge regarding the effect of different contextual and situation factors on short, specific high-intensity periods is paramount for more optimal training prescription in elite male football players (Ju et al., 2022a; Wass et al., 2020).

The present research thesis is the first to explore the impact of match half, match outcome, and 15-minute blocks (intervals) on physical metrics during transitional play and high-pressure activities in professional football. Significant effects of contextual factors on transitions have been discovered in Chapter 5 and 6. The second half period revealed reduced volume-related physical performance during transitions in most metrics including total distance, absolute and relative high-speed running distance, and number of high-intensity decelerations, which was in line with previous research exploring whole and peak intensity demands (Bradley et al., 2013; Oliva-Lozano et al., 2020a). Furthermore, lower running performance has been found in the second 45 minutes in lost matches, while won games revealed increased absolute and relative locomotor variables during transitions. That said, no differences between various match outcomes for accelerations and decelerations have been reported, which was contradictory to previous findings analysing 90-minute performance in football (Rhodes et al., 2021). Moreover, no effect of match outcome and match half have been shown for all metrics per minute, possibly due to a very short duration of transitions and a resulted inability to detect any significant changes during these short periods (Chapter 5 and 6). Previous and current research have associated football technical-tactical performance metrics more closely with success than 90-minute match running data (Oliva-Lozano et al., 2023c; Rampinini et al., 2009). Additionally, as the game progressed in time, physical outputs declined reaching lowest values for total distance, high-speed running distance, relative sprint distance, and the number of decelerations in the last 15 minutes (Chapter 6). In fact, a recent study reported that footballers generated the highest number of high-intensity actions in the first 15-minute blocks of each half, which could suggest a deteriorating effect of time on physical metrics across 90-minutes (Oliva-Lozano et al., 2023a), which has been clearly demonstrated in Chapter 6 of this research thesis.

Previous studies exploring fatigue effects in professional football revealed physical performance differences between both halves and separate 15-minute periods in male and female athletes (Barrera et al., 2021; Datson et al., 2017; Oliva-Lozano et al., 2023a; Oliva-Lozano et al., 2023b). Considering this, fatigue and/or inadequate recovery could explain the phenomenon of declined running performance and an increased risk of injury (Rhodes at al., 2021; Small et al., 2009). Furthermore, the ability to run at high velocity as an important indicator of physical performance in contemporary football (Mohr et al., 2003) might not be optimally stressed in training (Vazquez et al., 2023), which could potentially lead to decreased outputs in the final moments of the game (Oliva-Lozano et al., 2023a). Decreased intensity at the end of match play might be due to the influence of fatigue and its link to reduced glycogen levels (Krustrup et al., 2006; Reilly et al., 2008). Interestingly, an increased total number of sprints in the last 15-minute interval (75-90') compared to other blocks has recently been reported in football, regardless of playing position (Oliva-Lozano et al., 2023b; Oliva-Lozano et al., 2023c), which is consistent with findings in Chapter 6, showing that total number of transitional activities was the highest in the last 15-minutes of competition, despite reduced physical outputs (Figure 44 and Table 23).

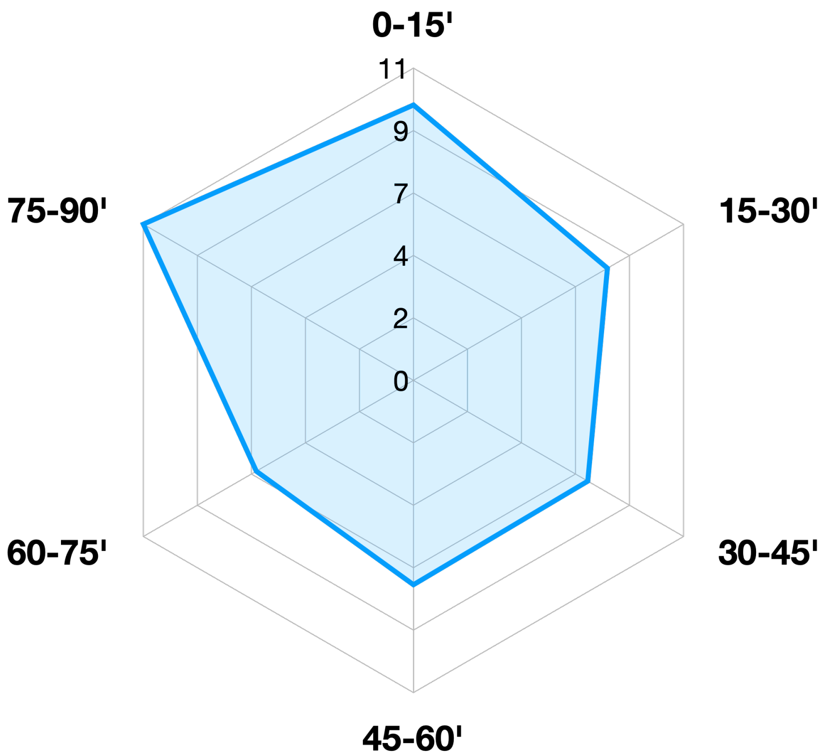


Figure 44. Mean number of all transitions for each 15-minute block in match play across all games analysed.

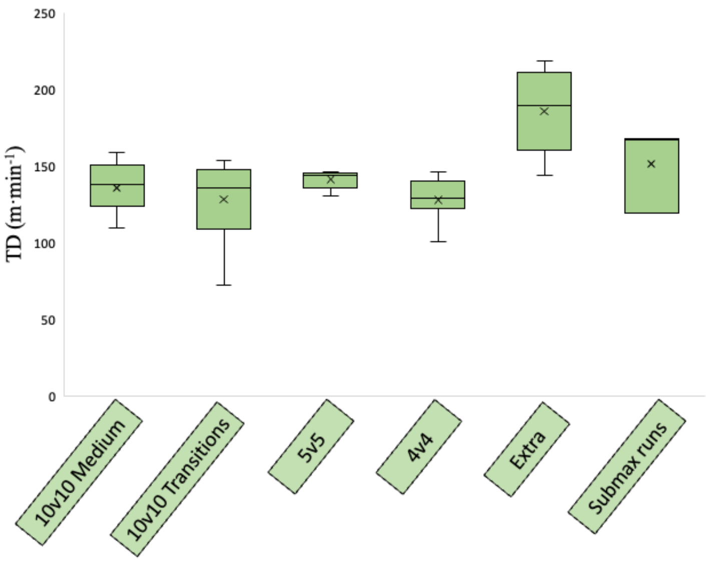
This could probably suggest that other situational variables (e.g. match status, score-line) impacted this phenomenon (Trewin et al., 2017). Footballers are constantly exposed to high-intensity periods full of technical-tactical context over 90-minute (Ju et al., 2022a). Presumably, as the game progresses in time, levels of fatigue increases (Harper et al., 2019; Ju et al., 2022a; Rhodes et al., 2019; Rhodes et al; 2020). In fact, Chapter 6 revealed that volume-related metrics during TA's decreased in the 75-90' interval, which could indicate that lower number of players took part during transitions and/or fatigue impaired their ability to maintain high physical output in the last minutes of competition (Reilly et al., 2008). Certainly, fatigue might have a detrimental effect on collective tactical behaviour reducing team compactness and creating more space for both teams to initiate transitional activities in the last minutes of competition (Ju et al., 2022a). It is worth noting that this body of research has not included nor analysed substitute players physical output during transitional play (Oliva-Lozano et al., 2023c). It could be hypothesised that substitutes might be able to maintain a higher physical stress during the final stages of competition compared to starting players (Chapter 7). Future studies should analyse the physical demands of substitutes in the last 15-minutes of match play during TA's.

Table 23. Total and mean number of TA's registered for each 15-minute block across 10 official games.

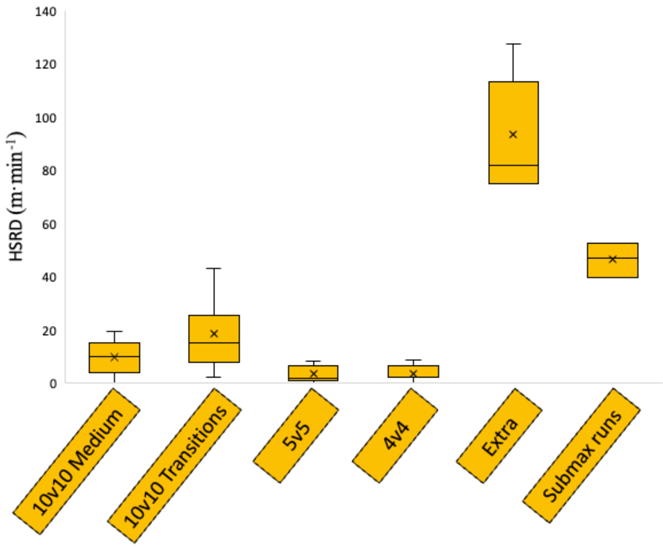
	0-15'	15-30'	30-45'	45-60'	60-75'	75-90'
Game 1	7	2	5	10	2	6
Game 2	6	9	8	11	8	15
Game 3	12	15	7	6	5	10
Game 4	10	10	7	4	8	7
Game 5	12	11	8	10	7	11
Game 6	12	12	4	14	9	17
Game 7	12	6	7	8	4	15
Game 8	8	5	4	4	8	7
Game 9	8	6	12	4	5	9
Game 10	10	3	9	1	8	13
MEAN	**9.7**	**7.9**	**7.1**	**7.2**	**6.4**	**11**

The findings representing 15-minute intervals highlight the importance for coaches and practitioners to properly condition footballers for the last moments of the game. For instance, it has been suggested to use an adequate warm up preparing for maximum-intensity exposure in the first minutes of competition (Oliva-Lozano et al., 2023a) as well as to provide optimal conditioning strategy in training to be able to effectively cope with sprinting actions under fatigue (Oliva-Lozano et al., 2023c). In Chapter 6 and 7, it has been proposed that decreased insights into the current demands of transitional play and shorter than previously explored high-intensity periods, might result in less-than-optimal preparation for the true match demands. The present research thesis for the first time revealed in Chapter 7 that during 30-sec worst-case-scenarios (WCS), football specific drills (various sided and transitional games) used by coaches in conditioning sessions, failed to replicate all locomotor metrics including high-velocity (HSRD and SD) and maximum deceleration actions relative to match peak demands across all playing positions, which was consistent with others (Oliva-Lozano et al., 2021a; Riboli et al., 2023b). Interestingly, A+D demands were adequately imposed in training and even significantly overloaded (30-50%) match demands by using small-sided games (4v4 and 5v5), which has been also reported in previous research (Lacome et al., 2018; Riboli et al., 2023a). These differences between competition and training during the maximum intensity passages in football, might potentially fatigue players to a greater extent, increase injury risk, and inadequately prepare for the physical demands in the last stages of match play (Aiello et al., 2023; Ekstrand et al., 2023; Rhodes et al., 2021). Therefore, it is of high importance that practitioners use a combination of small-, medium-, large-sided games with properly designed transitional drills/games that effectively expose footballers to maximum velocity and sprinting actions during collective training tasks that reflect positional specificity (Ju et al., 2022a; Oliva-Lozano et al., 2023b; Riboli et al., 2023b). In fact, regular mechanical exposure to high-velocity and high-intensity activities might better replicate match peak intensity, and adequately condition players for the crucial phases when goalscoring opportunities are created in football (Beato et al., 2021; Bramah et al., 2023; Faude et al., 2012; Nobari et al., 2023). According to previous and current research, drills that aim to reflect intensity during the most demanding passages in football might be designed for different durations which are usually adopted in practical settings during various sided-games, football specific drills, positional drills, and running based exercises (e.g., 1-, 2-, 3-,5-, 10-min) (Lacome et al., 2018; Oliva-Lozano et al. 2021b; Riboli et al., 2020; Riboli et al., 2023b). In addition, running based drills have been found to be the most potent ammunition compared to other exercises commonly used by coaches for overloading match HSRD and SD demands during 30-sec WCS in training (Figure 45). Indeed, adequate amounts of high-velocity actions and sprinting might impose mechanical strain on the hamstrings giving them an effective vaccine against failure and injury in match play (Bramah et al., 2023; Buchheit et al., 2023). It could be suggested to use these exercises at the end of training to possibly counteract the detrimental effect of fatigue on match performance as the game comes to an end. Repeated sprint training: < 10 seconds all-out short sprint sequences and short high-intensity-interval training: < 30 seconds sub-maximal efforts might be effectively used as a collective conditioning as well as individual top-ups and return-to-play sessions (Buchheit et al., 2013; Nobari et al., 2023; Taberner et al., 2019).

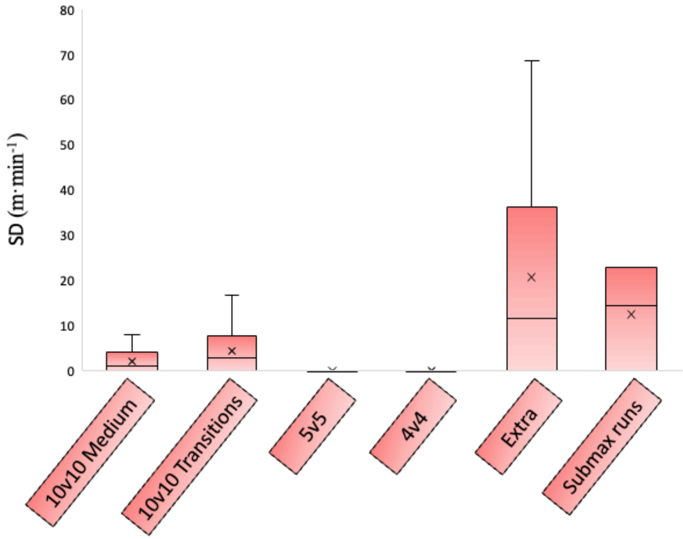
A)


TD (m·min⁻¹)
250
200
150
100
50
0
10v10 Medium
10v10 Transitions
5v5
4v4
Extra
Submax runs

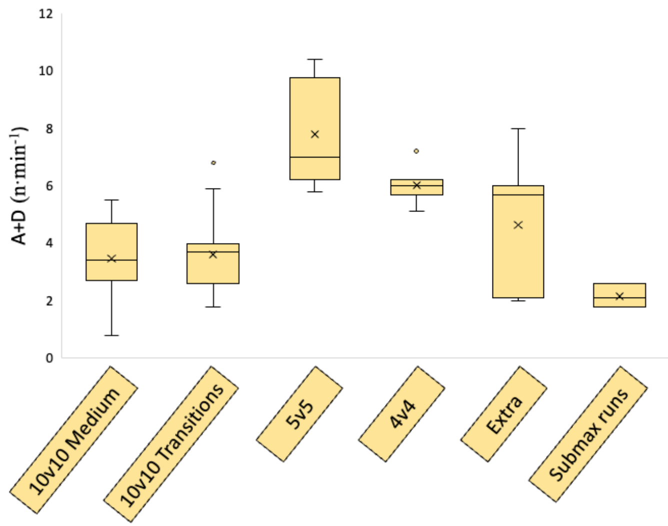
B)


HSRD (m·min⁻¹)
140
120
100
80
60
40
20
0
10v10 Medium
10v10 Transitions
5v5
4v4
Extra
Submax runs

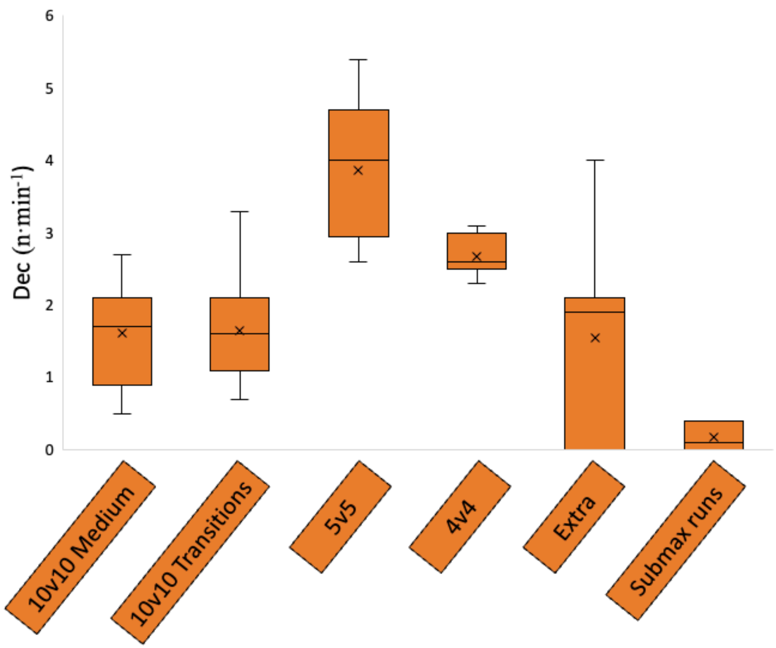
C)


SD (m·min⁻¹)
80
70
60
50
40
30
20
10
0
10v10 Medium
10v10 Transitions
5v5
4v4
Extra
Submax runs

D)


A+D (n·min⁻¹)
12
10
8
6
4
2
0
10v10 Medium
10v10 Transitions
5v5
4v4
Extra
Submax runs

E)



F)

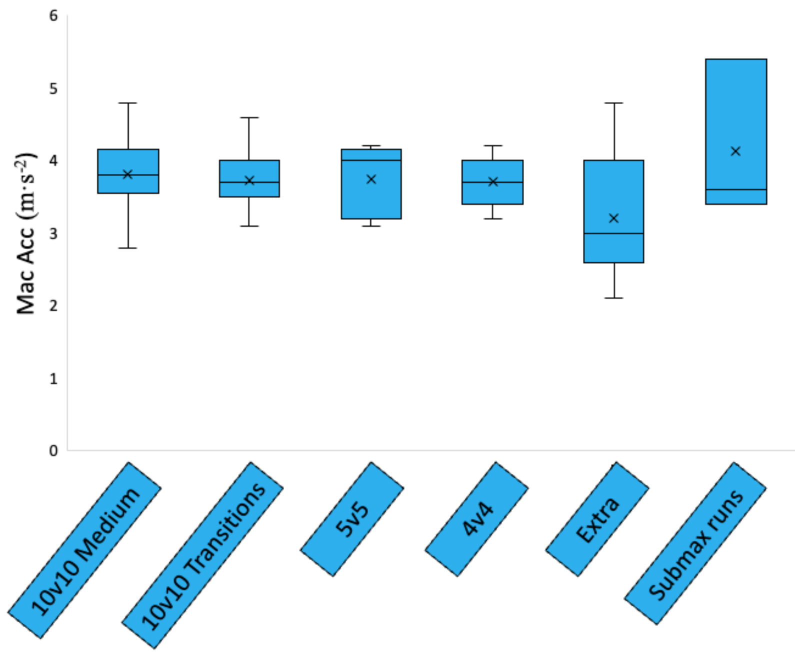


Figure 45. Boxplots with mean and outliers comparing selected drills (Table 16) during 30-sec WCSmean in a) total distance: TD (m·min^{-1}), b) high-speed running distance: HSRD (m·min^{-1}), c) sprint distance: SD (m·min^{-1}), d) number of accelerations and decelerations: A+D (m·min^{-1}), and e) number of decelerations: Dec (m·min^{-1}), and f) maximum acceleration: Max Acc (m·s^{-2}) across 14 MD-3 sessions. Adopted from Bortnik et al. (2023c).

Footnote: Drills include the following: 10v10 Medium, 10v10 Transitions, 5v5, 4v4, Extra, and Submax runs.

Previous studies have compared 90-minute external/internal load differences between starting and substitute players in football (Bradley et al., 2013; Liu et al., 2020; Los Arcos et al., 2017). Given the limited research exploring playing status during the maximum intensity periods (Fereday et al., 2020; Sydney et al., 2023), differences in physical metrics between starters and non-starters have been analysed during 30-sec WCS in Chapter 7. This project, for the first time, explored shorter time epochs in mean and peak periods (WCS_{mean} and WCS_{peak}) and included additional physical metrics such as maximum acceleration and deceleration (Max Acc and Max Dec) for analysis in an elite football team. Greater overall physical effort was found in substitutes during WCS_{mean}, which was consistent with others (Delaney et al., 2018b; Fereday et al., 2020). Footballers entering match play in the 2nd half should be expected to display more aggressive work-rates and pacing efforts compared to starters due to their shorter playing time and a potential high impact on team performance at the end of competition (Ferraz et al., 2018). In contrast, starters might be adopting a conscious or subconscious self-pacing strategy to minimise the physical effort and preserve energy across the entire match duration (Bradley et al., 2013). Interestingly, substitute players were found to cover less distances across various speed zones (TD, HSRD, SD), perform lower number of high-intensity accelerations and decelerations, and achieve reduced values of Max Acc and Dec compared to starters during peak worst-case-scenarios (WCS_{peak}). Furthermore, Sydney et al. (2023) showed lower peak physical demands experiences in substitutes, which might indicate that starters could be exposed to maximum intensity activities most likely in the game opening ~10 to 15 minutes post-kick-off (Bradley et al., 2013; Hills et al., 2022). In conclusion, starters were exposed to maximum intensity (WCS_{peak}), whereas non-starters generated higher effort during the entire bout of activity (WCS_{mean}) (Chapter 7). This could suggest that the gap between training and match play for maximum intensity actions was even greater in substitute players. These novel findings should equip practitioners with tools to design more accurate and optimal training programme (top-up conditioning sessions), use adequate recovery, ensure optimal preparation/readiness for competition demands, provide less discrepancies in total weekly load between starters/subs, and ultimately reduce the risk of injury in both groups (Ekstrand et al., 2023; Hills et al., 2022). Indeed, both starting and substitute players should be frequently exposed to maximum intensity in training (speed, max accelerations, and decelerations) to be able to maintain a higher physical output (non-starters) and withstand peak match demands (starters). It would be reasonable to apply a slightly different approach for both, suggesting repeated sprint training: < 10 sec all-out short sprint sequences for starters to prepare them for the opening of the match and short high-intensity-interval training: < 45 sec sub-maximal efforts for non-starters to improve their abilities to better cope high-intensity maintenance over an extended period of time (Buchheit et al., 2013; Nobari et al., 2023). Furthermore, running based drills called "Extra" (Figure 55) (Chapter 7) could be easily used for substitute and bench players immediately after competition to compensate match demands, overload locomotor and mechanical stress, and accumulate match-like volume for crucial high-velocity metrics to ensure maximum speed exposure which has been shown to provide vaccine against non-contact injuries in football (Beato et al., 2021; Ekstrand et al., 2023; Faude et al., 2012; Thurlow et al., 2023).

Research exploring maximum intensity passages during congested periods in elite football is scarce (Jiménez et al., 2022). The present research thesis is paramount to add to the body of literature regarding this important subject within footballers (Chapter 7). Previous authors investigating intensified match periods in 90-min football have reported reproduced locomotor metrics and similar values in moderate-, high-, and maximum-velocity zones (Carling et al., 2011; Jones et al., 2019). Despite unchanged locomotor variables across the whole game in professional football, the number of accelerations/decelerations, and time spent accelerating/decelerating have been reported significantly lower during congested fixture period (Aruda et al., 2015; Djaoui et al., 2022; Rhodes et al., 2021). Recently, elite football players experienced a higher number of games played in a shorter period due to the World Cup in Qatar, which for the first time, was held in the middle of the season (November – December 2022). Apparently, this congested schedule shortened recovery bouts between matches in domestic and European competitions, imposing mental fatigue (Russell et al., 2019) and very high physical demands on footballers, who could play more than 70 matches per season (Nassis et al., 2020). Because short recovery time between subsequent matches has been associated with high physical stress resulting in fatigue, decreased tactical behaviour, and higher risk of muscle injury, coaches should individualise load prescription, optimise recovery, and use rotation strategy during congested periods (Ekstrand et al., 2023; Julian et al., 2021). Two studies have recently been conducted to investigate possible changes in physical performance during congested fixture periods, however, represent an elite youth football population and revealed no significant differences in various locomotor and mechanical variables (Castellano et al., 2020; Jiménez et al., 2022). This might indicate that players pace their physical effort during 90 minutes to preserve energy for peak intensity periods (Bradley et al., 2013). Contrary to these studies, findings in Chapter 7 revealed that merely mechanical load (A+D and Dec) in WCS_{mean} was reduced during congested period, which was consistent with a recent study that reported decreased number of high-intensity decelerations as the only physical variable subjected to change during an intensified match period (Muñoz-Castellanos et al., 2022). Indeed, congested fixture schedules have been associated with significant decrements of various salivary hormones and elevated levels of fatigue markers in the blood (e.g., creatine kinase), indicating a significant muscle damage, mechanical fatigue and reduced neural drive (Harper et al., 2019; Mohr et al., 2016; Morgans et al., 2014). This could have a detrimental effect on the ability to forcefully accelerate and decelerate the body during football specific actions, which was most likely reflected in reduced number of high-intensity accelerations and decelerations in the present research thesis (Morgans et al., 2024).

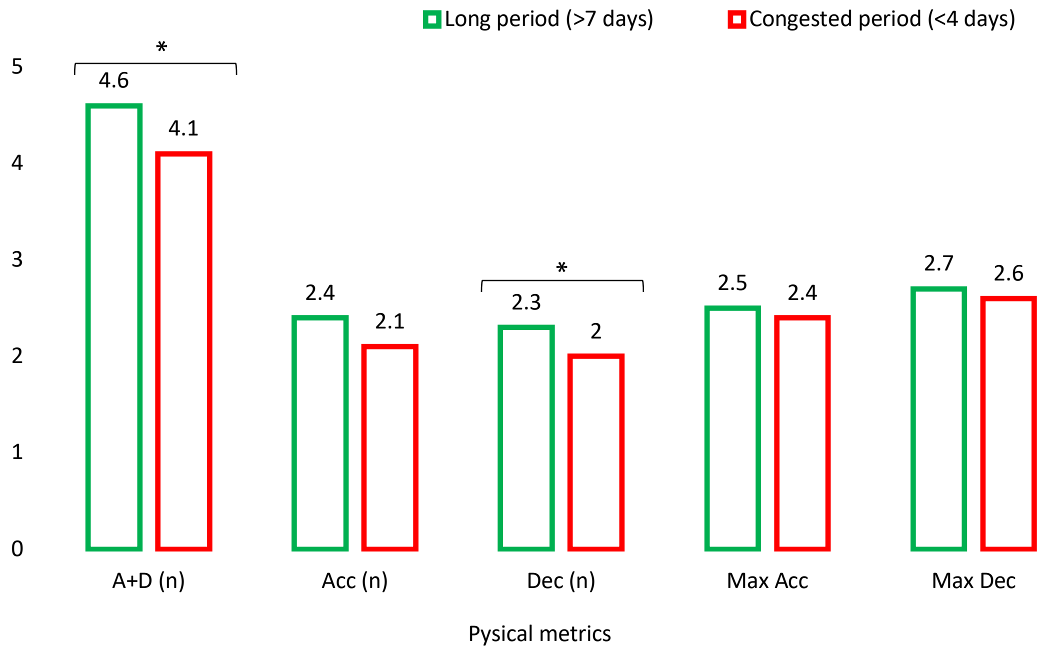


Figure 46. Team mean in periods of long recovery (>7days) and congested period (<4 days) during 30-sec WCS for number of accelerations and decelerations: A+D (n·min^{-1}), number of accelerations: Acc (n·min^{-1}), number of decelerations: Dec (n·min^{-1}), maximum acceleration: Max Acc (m·s^{-2}), maximum deceleration: Max Dec (m·s^{-2}) across 37 official matches. Adopted from Bortnik et al. (2023c).

Note: Significant differences between periods * (*$p \leq 0.05$*).

Lastly, alongside high-velocity running, mechanical load described as accelerations and decelerations have recently been perceived as important indicators of high-intensity demands of modern football training and competition (Ju et al., 2023a; Morgans et al., 2024). Accelerations and decelerations, despite low running speed are repeatedly required in football game (Gaudino et al., 2013; Harper et al., 2021). Rapid changes of direction involving aggressive deceleration and slowing down the center of mass, generates high eccentric muscle actions, which have been found more physically stressful than high-velocity activities (Delaney et al., 2018b; McBurnie et al., 2022). In this sense, the ability to decelerate has been suggested as a reliable tool to assess match physical performance and fatigue in football (Djaoui et al., 2022; Mohr et al., 2016). Further, high-intensity horizontal decelerations that possess unique biomechanical and physiological characteristics have been reported more frequently than accelerations in match play regardless match outcome (Harper et al., 2019; Rhodes et al. 2021). It has been shown in Chapter 4, 5 and 6 that high-intensity decelerations noted a significant decrease in the last stages of competition and had the greatest variability between both halves and 15-minute intervals compared to other physical metrics, possibly because of fatigue (McBurnie et al., 2022). Thus, the importance to adequately impose, manage, and monitor these actions has been highlighted in professional sport settings (McBurnie et al., 2022), enabling coaches to make more informed decisions regarding training design, drills selection, for example. To potentially reduce detrimental effect of fatigue on match performance, lower injury risk, and provide more optimal preparation for the most physically demanding passages (Harper et al., 2019; Rhodes et al. 2021). Based on findings of this research project, it would be suggested on MD-2 and MD-1 to avoid and/or minimise players' exposure to small-sided games and high-pressure activities that could generate high number of accelerations and decelerations (Chapter 3 and 4). Indeed, as previously mentioned in Chapter 7, A+D demands have been found to be adequately used in training mainly by using football specific drills on reduced areas and regularly playing small-sided games in training (Lacome et al., 2018; Riboli et al., 2023a). It is crucial that coaches and practitioners are aware of the physical impact of certain tactical drills usually used to improve offensive and defensive skills on various positional groups, especially in terms of high-velocity exposure and A+D demands. For example, offensive players including attackers and wingers have been shown to be highly stressed with accels and decels during high-pressure activities. Hence, to avoid fatigue 1 or 2 days before competition and reduce the risk of non-contact injuries (Boden et al., 2009; Brophy et al., 2015), coaches could use longer recovery breaks between successive offensive/defensive actions, use lower number of repetitions, use smaller playing areas, and rotate more players for a given exercise. In addition, congested periods revealed a reduced number of high-intensity accelerations and decelerations (Figure 46). Therefore, any activities generating these eccentric actions are not recommended for starters during these intensified periods when a recovery should be a priority and low physical load in training required (Chapter 7). Alternatively, A+D have been described as crucial physical abilities necessary for football performance outcomes and match results (Harper et al., 2018; Harper et al., 2019; Ju et al., 2023a; Rhodes et al., 2019) and footballers should be properly trained on MD+3 and MD-3 training sessions to achieve maximum deceleration values and be able to cope effectively with these mechanical metrics under fatigue (Chapter 7). This would especially apply to non-starters and players returning from injury who should be progressively exposed to A+D during their individual and team RTP programmes (Taberner et al., 2019). Footballers should possess the capacity to effectively dissipate braking loads during maximum decelerations (Harper et al., 2018) and build mechanically robust musculoskeletal structures to be able to resist the damaging nature of frequent high intensity breaking during training and match play (McBurnie et al., 2022).

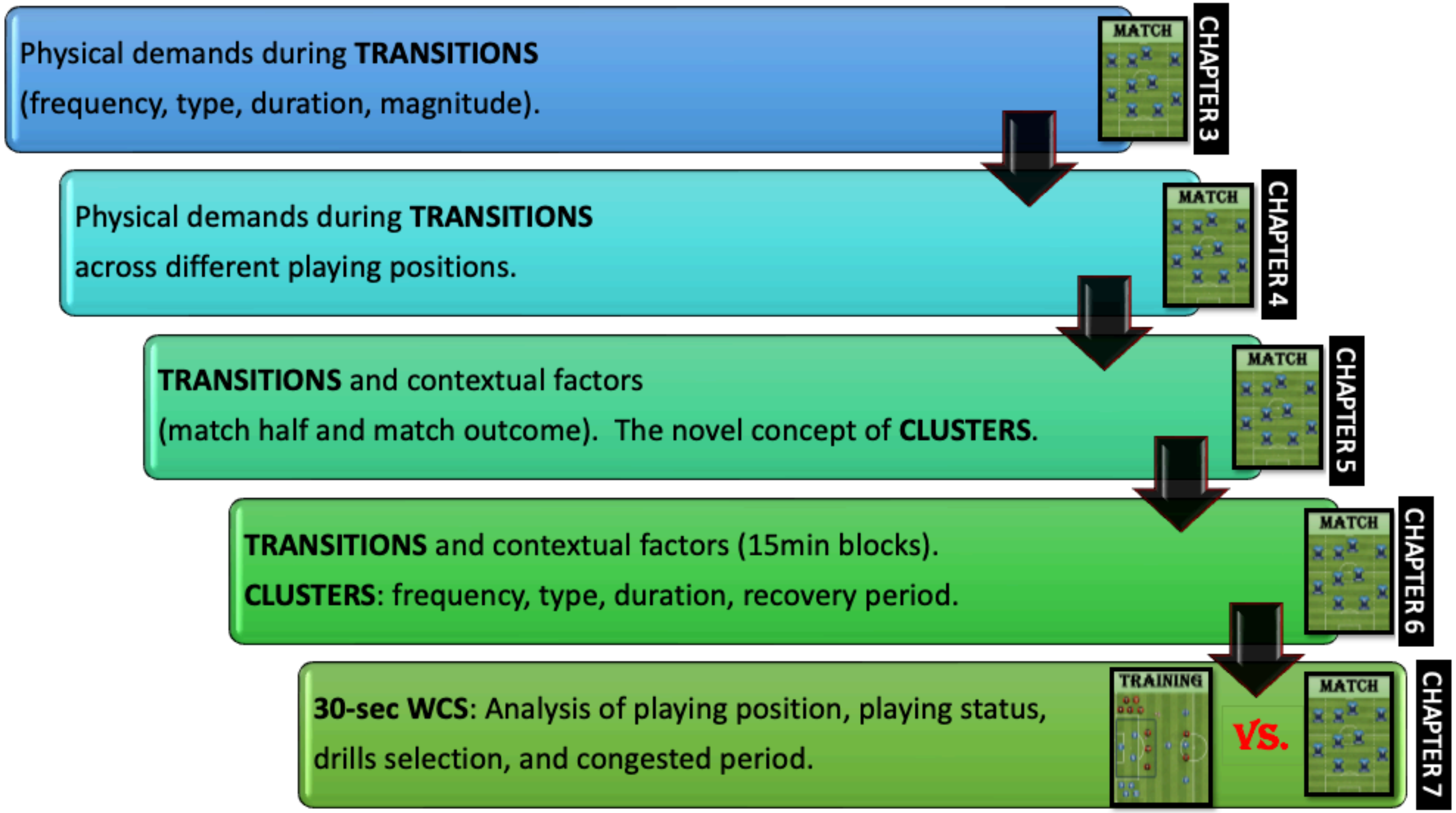


Figure 47. Toward a better understanding of the maximum-intensity contextualised periods in elite football. A list of accompanying progressive studies as part of this body of work, and their main topics.

8.4 Limitations and Future Research Suggestions

The present research thesis added crucial information about tactical phases that occur in match play to the current body of knowledge (Figure 47). Yet, there are some limitations that should be mentioned and outlined in this section. First, it is important to note that Chapters 3 to 6 were completed with one club over the same 10 games (small sample), while Chapter 7 analysed data across 37 official matches and 14 training sessions with another club. Hence, only two elite football teams were investigated. Comparative analysis between different leagues and competitions (World Cup, Champions League, Europa League, etc.) would also be very useful to understand potential differences during transitions across various levels of elite competition. It would be very interesting to explore each Top 5 league characteristics in terms of the frequency, type, magnitude, duration, and recovery period between transitional activities as well as their impact on various physical metrics and positional differences. The future lines of research should include additional technical-tactical variables (shots, crosses, number of passes, numerical superiority, etc.) and team performance measures (goals, chances, successful scoring goals entrance) during offensive transitional activities as shown in Figure 48 (Forcher et al., 2022). On the contrary, additional defensive metrics (possession regains, out-of-possession duration, successful pressures, spaces between players, compactness, team perimeter, etc.) should be explored during defensive team activities (defensive transitions and high-pressure actions) to add more context and better integrate all aspects of match performance during these phases (Figure 48 and Figure 49). The integrated approach to better describe offensive phases in transitions (push up pitch, break into box, run in behind/penetrate, over/underlap, run with ball, move to receive/exploit space, support play) and out-of-possession defensive TA's (interceptions, recovery run, covering, close down/press) would also be very beneficial, especially to better understand specific tactical movement that generates intensity (HSRD, SD, A+D) on each playing position, should be considered in the future research (Ju et al., 2022a). Although thorough analysis of transitional activities in elite football offers various theoretical and practical benefits for training design, it is noteworthy to emphasise that it requires extensive manual work, which is labour intensive. Thus, technologies and machine learning techniques that automatically categorise each tactical phase accurately and integrate additional data into analysis not only in matches but also in training, are warranted to overcome this limitation (Bradley et al., 2018b) such as Footovision presented in Figure 48 and 49.

A)

Figure 48. Team perimeter displaying distances between players in 3D (a) and dynamic pitch control in 2D (b) during fast attack (FA) conducted in official football match. Adopted from Footovision.

B)

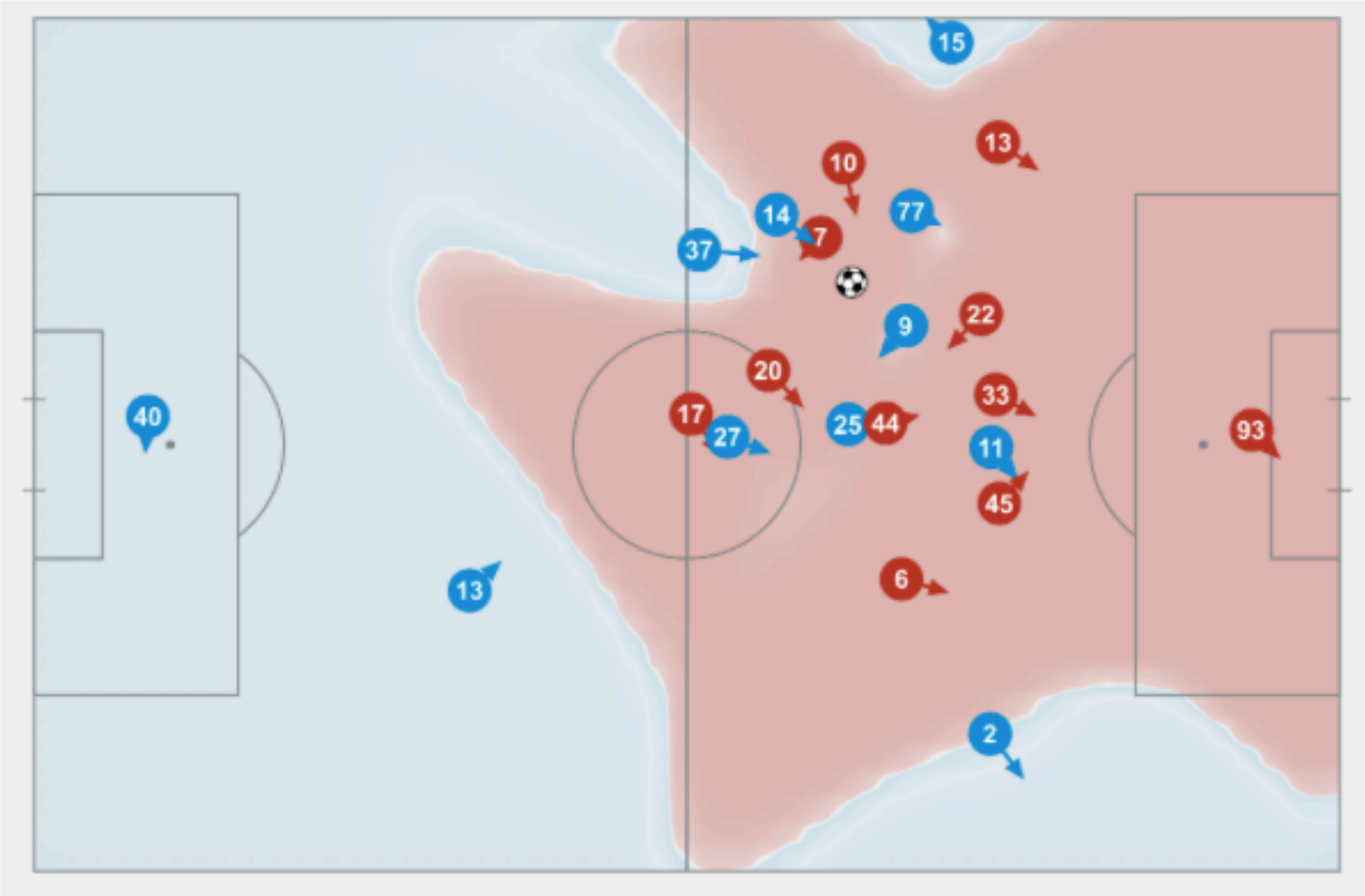


Figure 48 ***Cont.*** **Team perimeter displaying distances between players in 3D (a) and dynamic pitch control in 2D (b) during fast attack (FA) conducted in official football match. Adopted from Footovision.**

A)

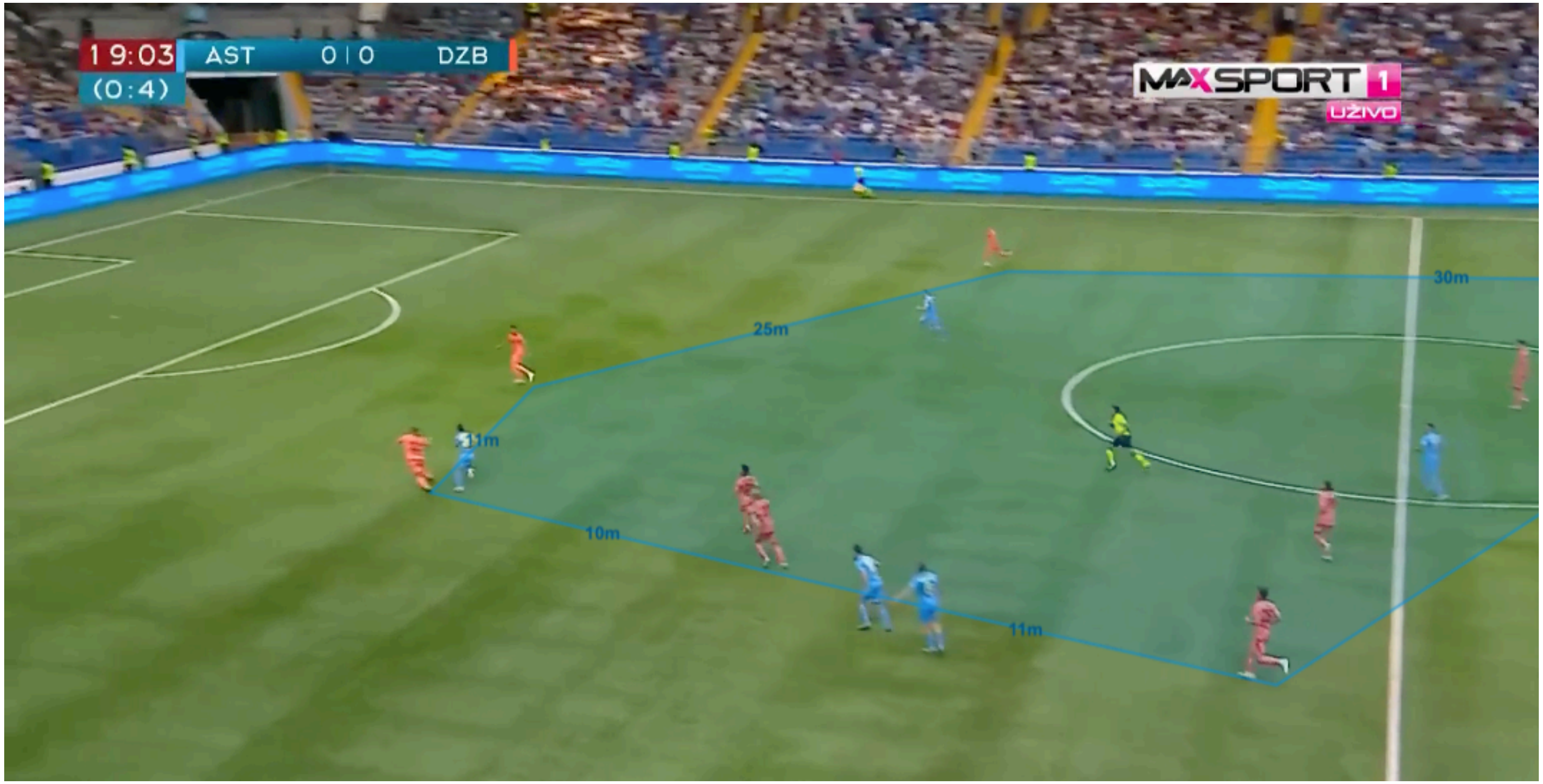


Figure 49. Team perimeter in 3D (a) and team compactness in 2D (b) during a defensive transition (DT) from an official game. Adopted from Footovision

B)

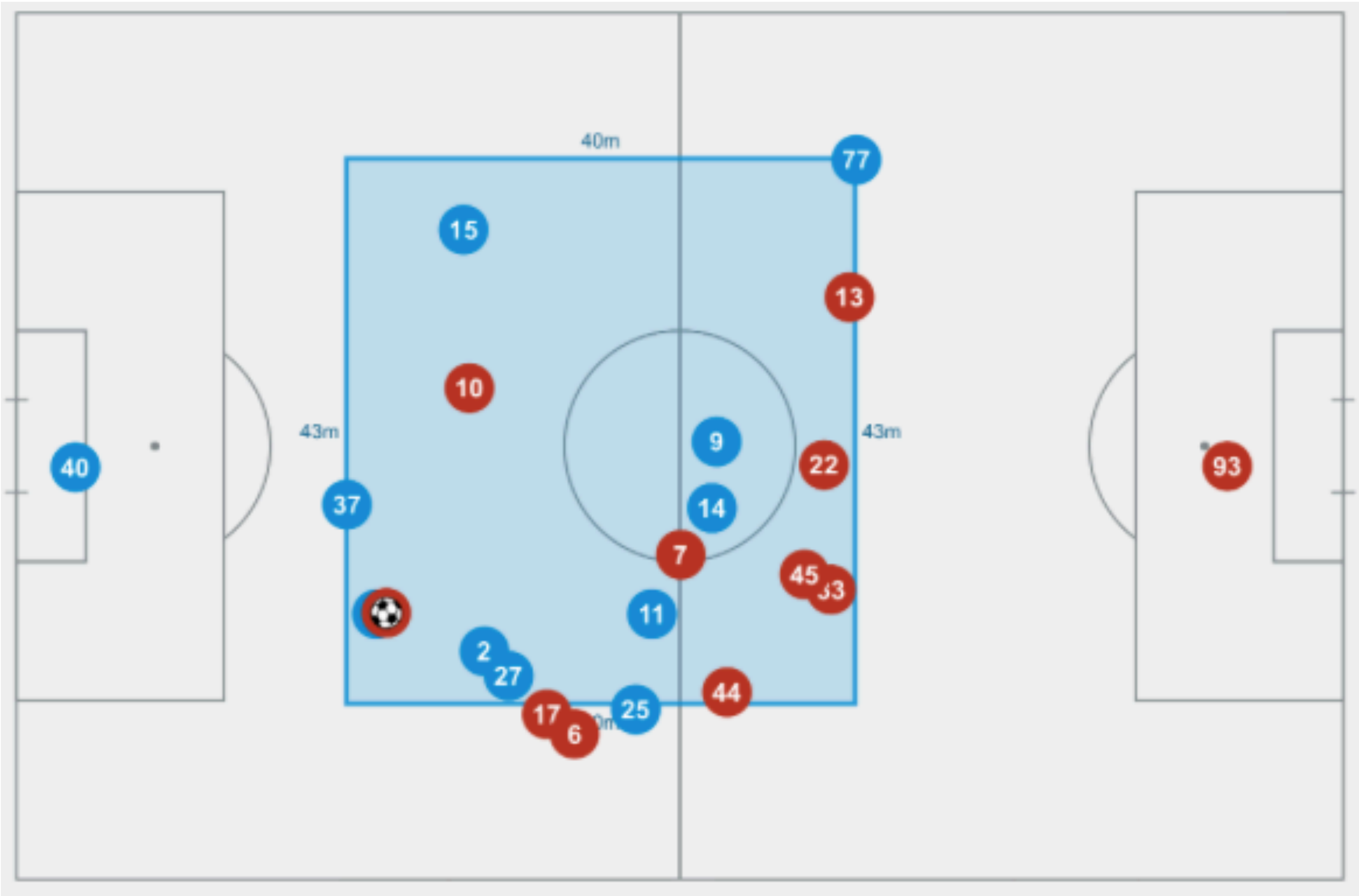


Figure 49 *Cont*. Team perimeter in 3D (a) and team compactness in 2D (b) during a defensive transition (DT) from an official game. Adopted from Footovision.

Second, this research did not analyse positional differences during clusters and future research should do so. Also, more studies are warranted to determine if other factors affect physical data during short maximum intensity passages such as match location, formation, score-line, style of play, opponents' level/ranking, to name a few. Additional consideration should be given to substitution timing and analysis of the impact of substitutions on physical metrics during transitional activities and high-pressure actions since this project failed to do so. Future studies should also compare training across all days of the week (i.e., MD+3, MD+4, MD-2, MD-1) to competition transitional demands and investigate whether these crucial tactical moments are adequately replicated and imposed on footballers relative to positional demands (Asian-Clemente et al., 2022; Asian-Clemente et al., 2023; Carling et al., 2012; Rochael et al., 2023a; Rochael et al., 2023b). Different formats of transitional games, the number of players involved, the playing area during transitions should be compared with the locomotor parameters of matches in future investigations as well (Riboli et al., 2023b).

Another limitation of this research thesis is that most analysed metrics in all studies were absolute and only relative locomotor metrics were included. It is noteworthy to highlight the importance of monitoring players relative to their physical performance capacities (Piñero et al., 2023). Relative locomotor zones might be more appropriate to analyse players' true workload and monitor fatigue during the maximum intensity periods of match play across playing positions except for center backs (Kavanagh et al., 2023). Chapter 4 revealed that relative metrics showed lower variability for sprinting activities compared to absolute zones across all playing positions (33% vs 54%, respectively). Hence, future work should also consider analysing transitional play using not only individual velocity zones but also acceleration / deceleration thresholds to better represent players' individual physical performance and further tailor training to individual physical capabilities (Carling et al., 2012; Harper et al., 2021).

Lastly, internal load (i.e., heart rate and the rate of perceived exertion) were not examined in this project during peak match demands, which could be considered another limitation (Sydney et al., 2023). Hence, an aggregate analysis between internal and external load variables could provide more accurate information and allow more precise comparison between training and match demands. This might give more physiological insights into these phases and hence ensure an adequate internal load stimulus, optimal physiological response in training and a subsequent adaptation to the programme (Impellizzeri et al., 2019). Yet, the discomfort to wear heart rate devices in official matches and impossibility to collect the rate of exertion after these periods in games and training sessions, makes this procedure extremally difficult in elite football settings. Future studies should somehow overcome these obstacles and include internal load in their analysis to fully understand the physical and physiological demands during transitional phases and high-pressure activities.

8.5 Conclusion

The present body of research demonstrates that the key physical metrics are largely elevated compared to the 90-minute averages when contextualised into transitional play and high-pressure activities, representing the maximum physical exposure footballers experience in competition. Modern football training design should consider conditioning players for short blocks of high-intensity / high-velocity offensive and defensive actions that frequently occur together as repeated activities (clusters) during the key phases in match play. This body of work provides important knowledge for practitioners and coaches about the frequency, duration, recovery period, and type of action that generates the highest physical absolute outputs in highly contextual settings integrating physical and technical-tactical components of match performance.

Based on the findings, it is suggested that 90-minute averages should not be used in isolation, rather in conjunction with peak intensity periods to guide coaches training prescription. Differences in physical outputs across various playing positions during these highest physical demands occur and coaches should reflect these position specific actions in training to best prepare all positions for their tactical offensive/defensive responsibilities during peak intensity passages in competition. The strategy to perform repeated high-intensity offensive and defensive activities during an overload phase in a weekly programme (MD+3/-3), may prevent the mismatch between match and training demands, providing optimal physiological stimulus in training, reducing a negative impact of fatigue on match physical-technical-tactical performance in last stages of match play, and ultimately minimising the risk of injuries of each playing position. The mismatch and high discrepancies between match and training overload phase for most physical variables are present in professional football. Practitioners should analyse intensity and physical load imposed on footballers during football specific sessions relative to competition maximum-intensity periods and positional demands. Nonetheless, various contextual and situational factors that affect physical performance should also be considered. For instance, some clubs/coaches prefer to use an aggressive style of play that quickly demands regaining possession and pressing opponents high in their defensive third. This playing philosophy carries unique physical consequences for certain positions and coaches should have a good understanding how this strategy affects their team performance during crucial tactical phases as well as across the whole 90 minutes. In addition, better knowledge about true positional demands during various tactical phases in competition, enables coaches to select the right players who can meet the physical demands and tactical offensive/defensive tasks across 90 minutes in match play. This would be considered very important in terms of players' optimal selection for a given match depending on tactical plan and strategy prepared by coaches.

It is generally recommended to use an approach that accurately mimics high-intensity/velocity demands in all physical metrics, especially high-speed running, sprinting, as well as activities that generate maximum accelerations and decelerations in all playing positions. To reflect and/or overload peak match demands in training, it is suggested to combine football specific drills including various sided and transition games with running based drills that should consider individual physical capacities and positional requirements. Isolated running exercises generate high-velocity actions (high-speed and sprinting) including maximum accelerations and decelerations and should supplement team conditioning programmes. This so called "old-school" approach appears effective in imposing an adequate dosage of intensity necessary to better cope with intensified blocks of activity in competition and potentially having a positive impact on injury prevention. Future studies should explore this by investigating a possible impact of different training modes widely used in professional football on match performance during short WCS including four commonly observed transitional activities (counter-attacks, defensive transitions, fast attacks, and high-pressure action). Furthermore, substitute players should be treated differently in terms of high-intensity stimulus because the gap between training and match play for maximum intensity actions is even greater in this group compared to starters. Maximum intensities in competition usually occurs in the first 15 minutes of match play and non-starters don't experience these periods. Thus, training should include complementary drills stimulating and exposing them to maximum intensity. Substitutes should be able to withstand high intensity in a shorter time window compared to starting players, since they are expected to bring about a positive change in overall team performance when entering the pitch in the second half. This change is usually perceived by coaches as a greater physical effort and higher running performance compared to starting players. Hence, speed endurance production training seems to be an optimal choice to achieve this objective in practical settings enabling subs to tolerate greater physical outputs for a given period and better condition them for these physically stressful blocks of activities. In addition, it is of high importance that position specific physical and technical-tactical differences are present and integrated in modern training design for both starting and non-starting players.

Finally, this research programme highlights the importance of properly and adequately imposing locomotor and mechanical load including maximum decelerations on footballers, emphasising the significance of monitoring high-intensity decelerations in training and matches, especially during a congested fixture period when footballers are faced with many games and high physical stress is present. Indeed, horizontal decelerations that reflect players' abilities to effectively slow down the center of mass with an optimal energy transfer from the ground to the body, is a concept requiring greater attention in multidirectional sports including football and should be further explored. Future studies should determine if monitoring decelerations could be used as a potentially sensitive on field tool to detect neuromuscular fatigue, better inform decisions in practical settings to mitigate injury risk and increase players' availability across the season. These findings might serve high value to coaches, practitioners, and physical therapists in ensuring training demands better match playing demands, especially in crucial tactical moments and phases in elite football. Nonetheless, caution should be taken as these findings are representative of two teams across limited number of games and training sessions and future research should investigate more teams across many different leagues and including various contextual and situational variables.

8.6 Practical Recommendations

The present research thesis provides a deeper analysis of the true physical demands of contemporary football. Coaches could use this knowledge in their training design to improve the ability to reach and maintain maximum intensity across 90 minutes, especially during crucial tactical moments referred to as transitional activities (Appendix 2). These phases have been found to generate maximum intensity repeatedly within a short timeframe, hence they represent specific worst-case-scenarios (WCS) in elite football as shown in Figure 51. It is important to note however that methods proposed in Figure 56 and 57 should never be used by coaches and practitioners as a substitute but rather as a highly contextual addition to widely used running drills (e.g. intermittent running, high-intensity intervals) based on physiological markers (e.g. VO_{2max} and lactate threshold), as intensity indicators in physical preparation and conditioning training in football (Bangsbo, 2015; Weaving et al., 2022). Nevertheless, all training modalities utilised in practical settings should reflect positional specificity and generate appropriate dosage of physical stress represented by different metrics, experienced by footballers relative to their tactical responsibilities during official match play as depicted in Figure 50.

By using current practical recommendations, it is hoped this new evidence would better prepare elite and sub-elite football players for the physical and tactical match demands, counteract the possible detrimental effect of fatigue on match performance, and potentially reduce injury risk across all playing positions. Furthermore, it is hoped the data and findings from this body of work would equip coaches with novel and effective instruments to improve training design and tailor specific positional tasks accordingly in practical settings.

Figure 50. Training modalities in periods with intensified football training that integrates physical aspects in running-based drills (Extra and Submax Runs) and technical-tactical components during transitional play (clusters TA's = repeated transitional activities) relative to positional demands: OT = Offensive Transition (counter-attack); DT = Defensive Transition; FA = Fast Attack; and HP = High Pressure. Adapted from Bangsbo (2015) and Bortnik et al. (2022), (2023b), (2023c), and (2024).

The following section presents seven practical recommendations from this research thesis:

1. Modern training prescription in practical settings should adequately reflect transitional activities that collectively expose players to maximum physical outputs. Practitioners should consider that:

a) Offensive actions (counter-attacks and fast attacks) expose players to maximum velocity activities (sprint distance) as shown in Figure 52. Counter-attacks and fast attacks could be used by coaches in the midweek overload block (MD+3 and MD-3) for team conditioning purposes to achieve near maximum running speed and accumulate sprint distance volumes. They might also be considered a potent vaccine against hamstring injuries and hence could be a better alternative in team settings than isolated running based drills for reducing muscle injuries within football players (Bramah et al., 2023; Buchheit et al., 2023).

b) Defensive transitions (opposition's counter-attacks) impose high running demands including high-speed running distance and generate high-intensity accelerations/decelerations. These activities might be used for substitutes when coaches seek higher volumes of high-velocity metrics in conjunction with increased mechanical load in top-up conditioning and compensatory sessions integrating physical and tactical components as well as considering positional specificity as presented in Figure 54.

c) High pressure activities increase mechanical load on players and might be used to increase accelerations and decelerations demands in team training, top-up sessions and end-stage rehabilitation programmes (Figure 52). Over 80% of all high pressures are repeated actions that occur in conjunction with other transitional activities within a short period of time. During transitional games and tactical drills coaches might consider performing pressing high up in the opponent's half together with other tactical phases. For instance, high pressing should lead to regaining possession and reshaping a team from defensive to offensive structure, then could be followed by fast attack within a short period of time to surprise the opposing team and quickly attempt to enter the penalty area. Examples are proposed in Figure 61 and 63.

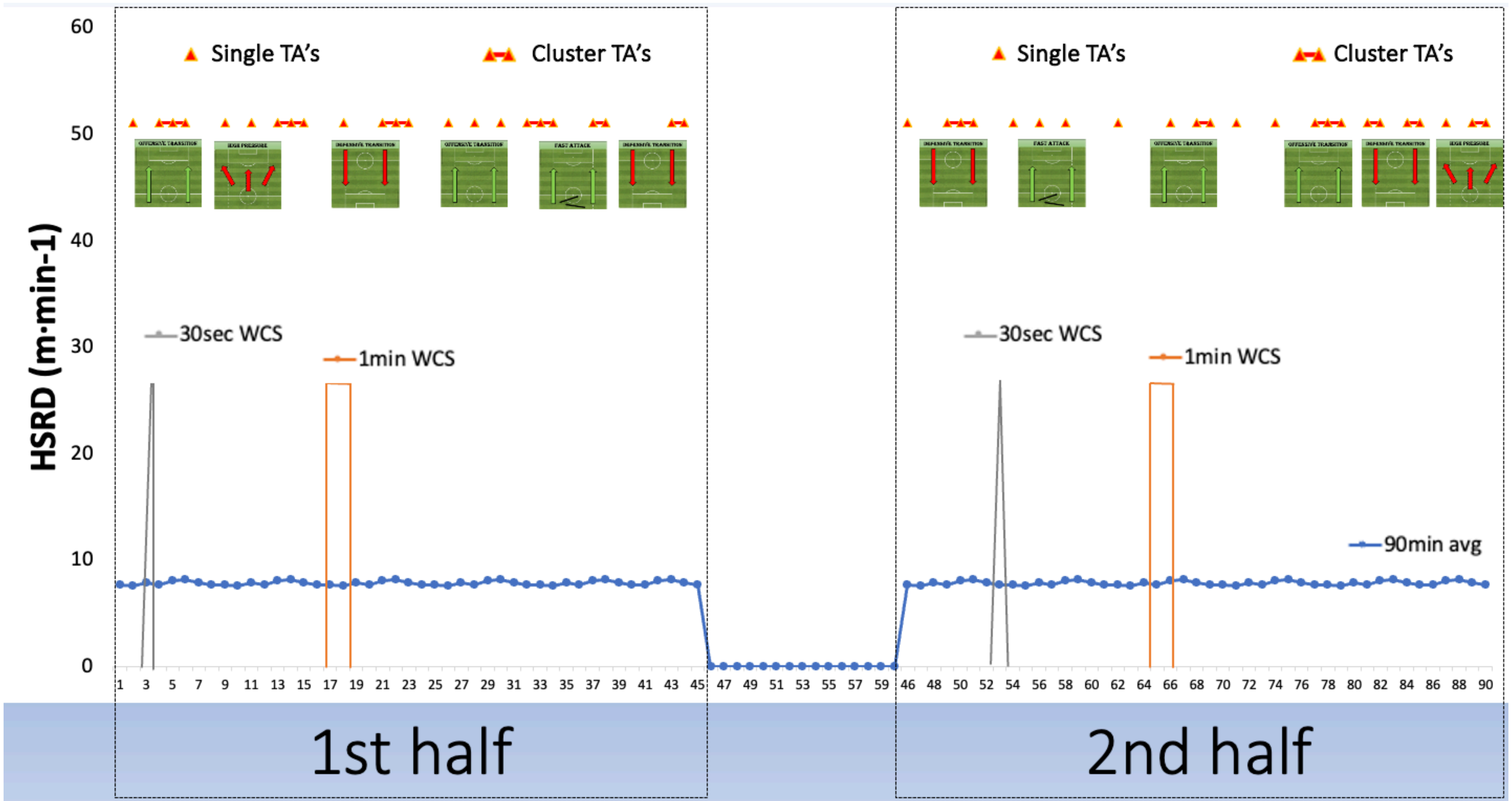


Figure 51. The concept of increased physical demands during transitional play and high-pressure activities in elite football matches. Comparison to 90min averages, 30sec WCS, 1min WCS for high-speed running distance: HSRD (m·min^{-1}). Minimum two repeated transitions defined as cluster TA's occur within 1min as opposed to single transitional activities (TA's) that happen on average every 108 seconds. Adapted from Bortnik et al. (2022) and Bortnik et al. (2023a) and (2023b).

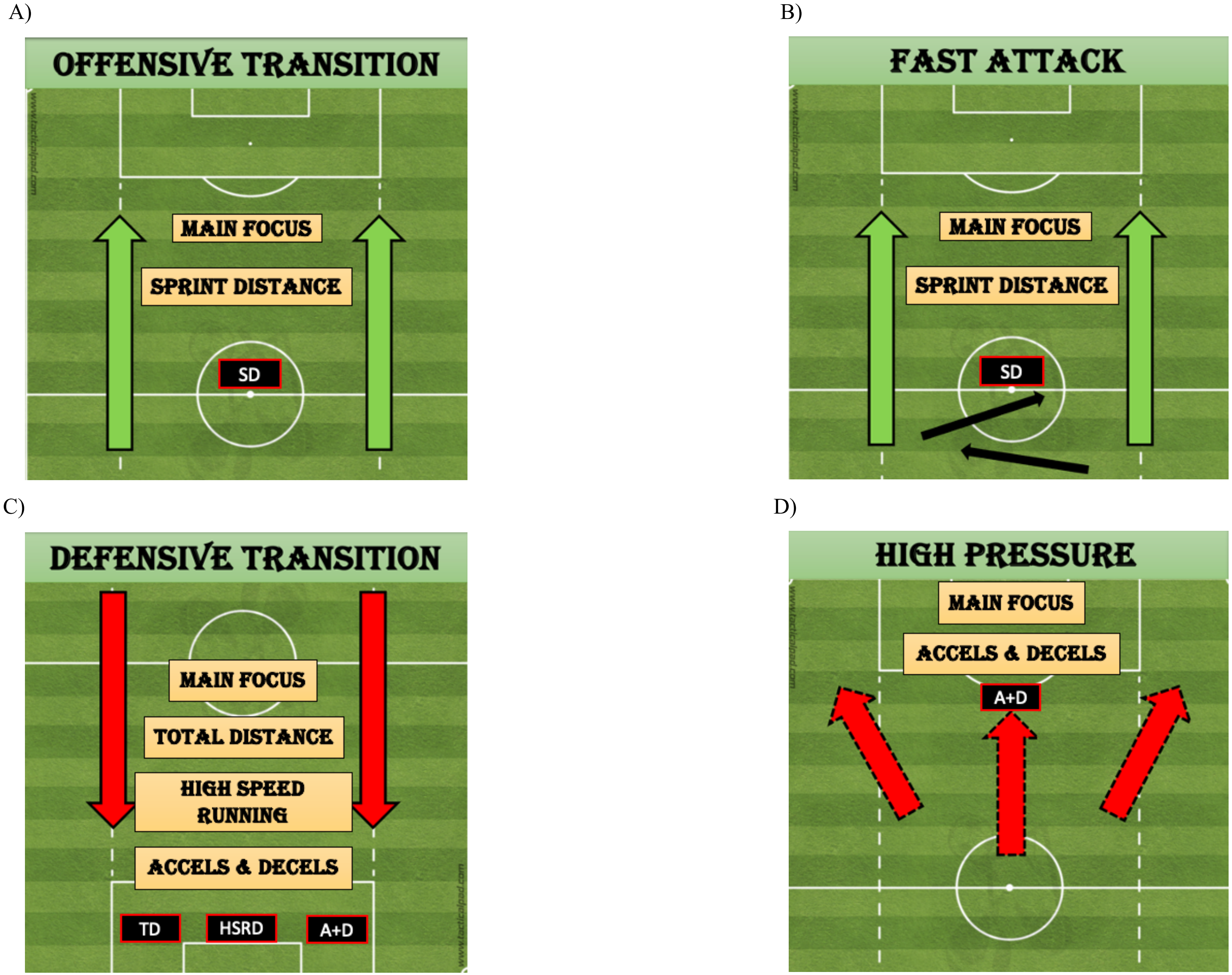


Figure 52. Graphical representation and the main physical focus/outcome of team collective offensive (A+B) and defensive (C+D) transitional activities: A) Offensive transition = counter-attack; B) Fast attack; C) Defensive transition = opposition's counter-attack; and D) High-pressure activity. Adopted from Bortnik et al. (2022).

2. A weekly training plan should include well-chosen fluctuations of volume and intensity to reach desired physical/physiological and tactical outcomes and fulfill all-important weekly objectives prior match play. Practitioners should consider:

a) In football conditioning sessions during an overload phase (MD+3 and MD-3), practitioners might pay more attention to total distances covered including high-velocity running (HSRD, SD) and perform more activities that generate maximum decelerations, regardless of playing position. For this purpose, a combination of transitional activities and transition games played on bigger areas, would be an optimal choice (Figure 53).

b) Weekly tapering strategy that minimises unwanted load and physical stress during tactical games and drills two and one day before competition (MD-2 and MD-1, respectively) and during intensified match periods, would be considered of high importance to coaches and practitioners as depicted in Figure 53 and 54 (Buchheit et al., 2023; Morgans et al., 2023). During these days reduced spaces during tactical drills (counter-attacks and fast attacks) would be highly recommended, players frequent rotations in certain positions included especially during high-pressure activities, and long recovery breaks utilised to minimise physical stress, reduce fatigue, and optimally prepare footballers for the upcoming football match (Thurlow et al., 2023).

c) In addition to football specific exercises including LSG, MSG and SSG that adequately reflect/overload mechanical metrics during the most demanding passages in football matches, running-based drills (Extra and Submax runs) could also be utilised as an effective strategy to minimise discrepancies between training and match peak demands, especially in terms of high-speed and sprinting exposure, which can be seen in Figure 55.

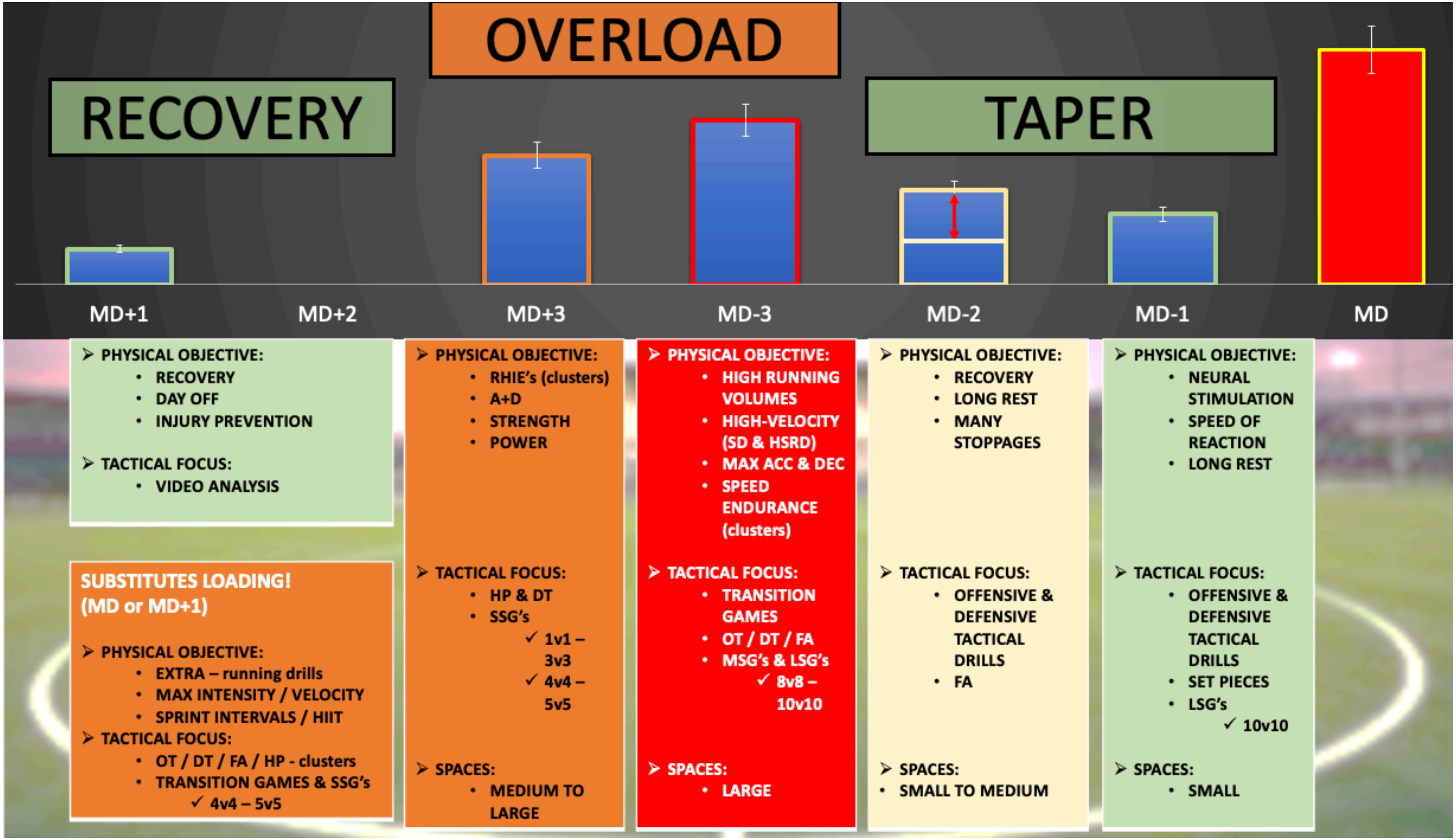


Figure 53. Schematic representation of a daily load across a football training microcycle (1 match per week: MD) highlighting physical and tactical objectives in various proposed training modes (OT: offensive transition; DT: defensive transition; FA: fast attack; HP: high pressure; LSG's: large-sided games; MSG's: medium-sided games; SSG's: small-sided games; HIIT: high intensity interval training; and RHIE's: repeated high intensity efforts). Adapted from Morgans et al. (2023) and Bortnik et al. (2022) and (2023c).

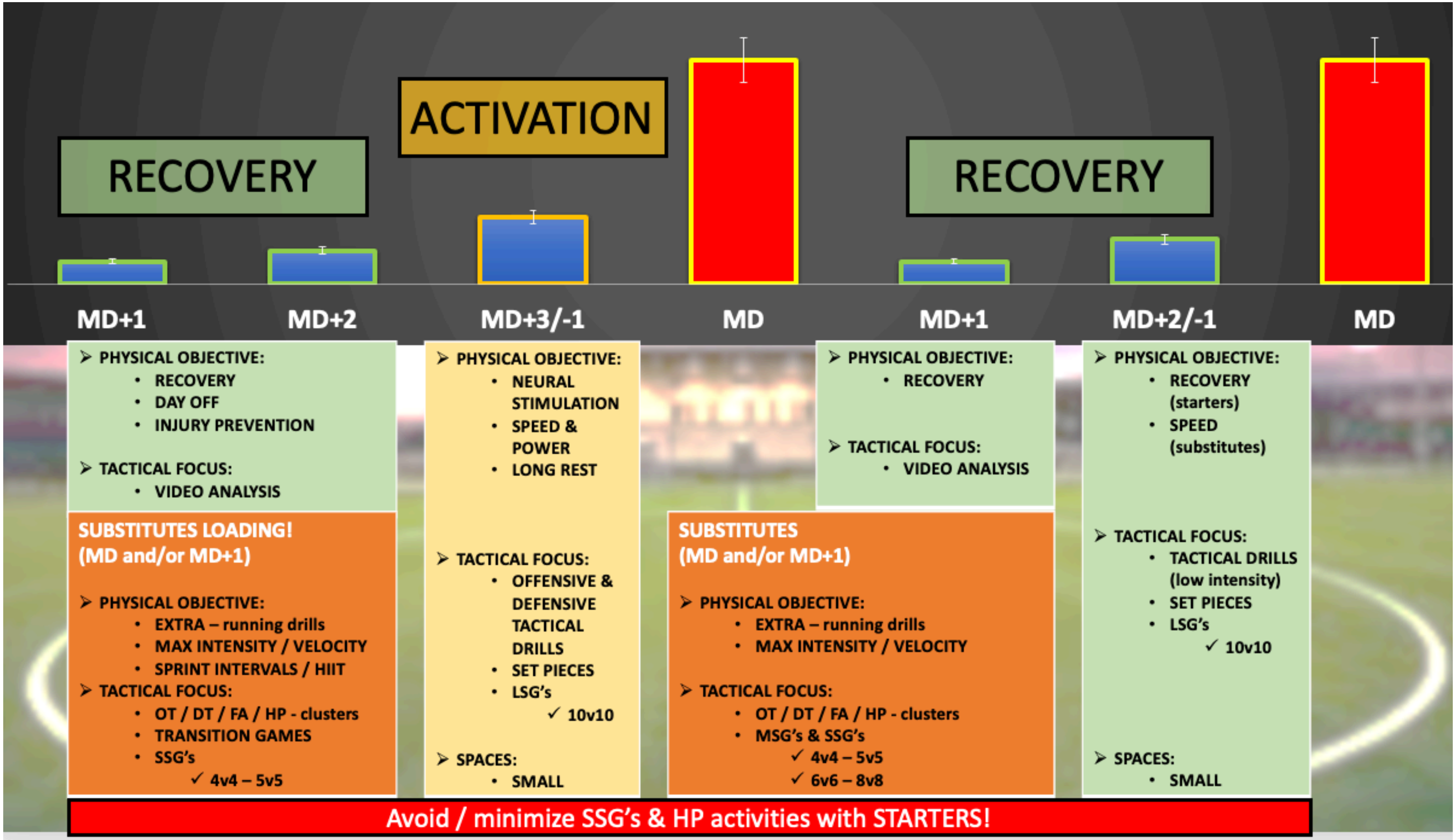
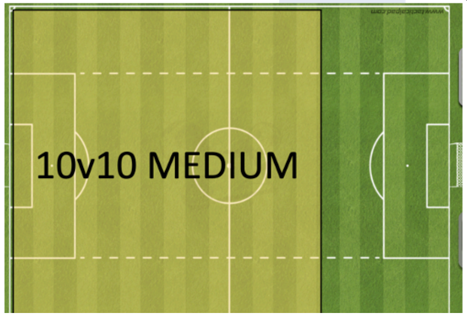


Figure 54. Schematic representation of a daily load across a football training microcycle (2 matches per week: MD) highlighting physical and tactical objectives in various proposed training modes (OT: offensive transition; DT: defensive transition; FA: fast attack; HP: high pressure; LSG's: large-sided games; MSG's: medium-sided games; SSG's: small-sided games; HIIT: high intensity interval training; and RHIE's: repeated high intensity efforts). Adapted from Morgans et al. (2023) and Bortnik et al. (2022) and (2023c).

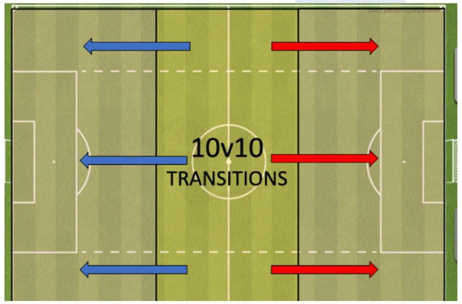
A)

Drills	Exercise mode	Technical-tactical specificity	Area size	Content and characteristics of each drill	Duration / Rest range	Bouts range
10v10 Medium	Large-sided tactical game	High-specificity	Area per player: 170 - 200 m^2 (medium space)	10v10 training games continously played on a medium space with two keepers. Players keep their positions and normal game rules apply.	8 - 20 min 2 - 4 min rest	2 to 3



B)

Drills	Exercise mode	Technical-tactical specificity	Area size	Content and characteristics of each drill	Duration / Rest range	Bouts range
10v10 Transitions	Large-sided tactical game	High-specificity	Area per player: 200 - 250 m^2 (medium - large space)	10v10 intermittent games played on a large space with two keepers. Players on their positions keep a ball possession in a small-medium space and attempt to exploit a free space behind the defense line to quickly get into the opposition box. Five players attack and three players defend in the free space.	3 - 6 min 1 - 2 min rest	4 to 6



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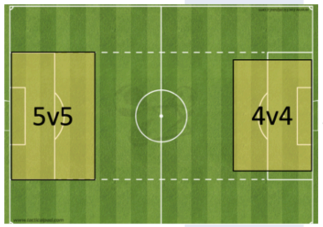
Drills	Exercise mode	Technical-tactical specificity	Area size	Content and characteristics of each drill	Duration / Rest range	Bouts range
5v5	Small-sided game	Moderate - high specificity	Area per player: 128 - 160 m^2 (small - medium space)	5v5 games continously played on a small-medium space with two keepers. Players aren't assigned to playing positions. All balls are distributed by keepers.	3 - 5 min 1 - 2 min rest	3 to 4
4v4			Area per player: 120 - 160 m^2 (small - medium space)	4v4 games continously played on a small-medium space with two keepers. Players aren't assigned to playing positions. All balls are distributed by keepers.	3 - 4 min 1 - 2 min rest	4 to 5



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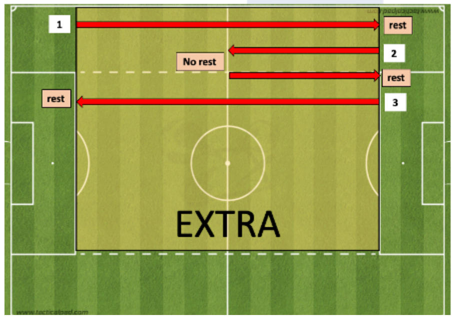
Drills	Exercise mode	Technical-tactical specificity	Area size	Content and characteristics of each drill	Duration / Rest range	Bouts range
Extra	Top-ups - high velocity runing with changes of direction	Minimum specificity	box to box - 75 meters	Box-to-box (around 75m) runs alternated with box-to-half pitch-to-box (around 38m) runs. Each effort lasts between 12-15 seconds and its interspersed with 24 to 30-second recovery period (1:2 work to rest ratio)	12 - 15 sec 12 - 30 sec rest	1-2 sets 8 to 14x



E)

Drills	Exercise mode	Technical-tactical specificity	Area size	Content and characteristics of each drill	Duration / Rest range	Bouts range
Submax runs	High velocity shuttles	Minimum specificity	50-75 meters	Straight-line shuttles lasting 7-8 seconds (22 - 25 km/h) interspersed with 22-second recovery period (1:3 work to rest ratio)	7 - 8 sec 21 - 22 sec rest	1 to 2 sets 8 to 10x

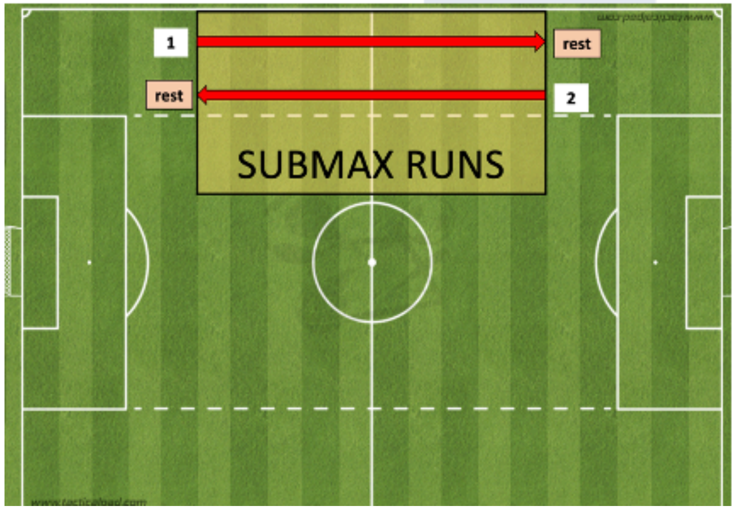


Figure 55. Recommended collective football-specific and team/individual running drills for a weekly overload phase (MD+3 and MD-3) and/or top-up sessions, their technical-tactical level of specificity, area size (area per player: m^2), content & characteristics, duration & rest and bouts range: A) 10v10 Medium; B) 10v10 Transitions; C) 5v5 / 4v4; D) Extra; and E) Submax runs. Adopted from Bortnik et al. (2023c).

3. Starting and non-starting players should be treated accordingly by tailoring technical-tactical and conditioning training to their specific needs, especially during periods of intensified match load (congested period) in competitive season (Figure 54).

a) Repeated sprint training (repeated high-intensity efforts): < 10 sec all-out short sprint sequences might be used for starters to reach peak intensity and short high-intensity-interval training: < 45 sec sub-maximal efforts for non-starters to maintain high physical effort over short duration activities. Also, substitutes should be exposed to maximum intensity and maximum velocity post-match and/or on MD+1 during a compensatory session. Offensive actions such as counter-attacks (OT) and/or fast attacks (FA) might be utilised as well as repeated TA's (clusters) to increase metabolic stress and optimally prepare subs for the match play demands. Furthermore, the running based drills with change of direction (Extra) might be applied during a compensatory session for bench and substitute players.

4. During transition games and tactical drills that include positional specificity, coaches are encouraged to implement high-pressure activities in the opponent's half in conjunction with other tactical actions.

a) For instance, pressing could be followed by a counter-attack and/or fast attack within a short period of time**.** Additionally as depicted in Figure 53, speed endurance production, repeated sprints, and sprint intervals with appropriate work-to-rest-rest ratios during an overload phase (MD+3 and MD-3) that integrate position-specific technical / tactical aspects might be considered during team / individual / return-to-play sessions to replicate the demands of clusters in training and optimally prepare players for the most physically demanding passages in games. It is important to note that space and inter-repetition rest period would dictate intensity/velocity and physiological strain (Thurlow et al., 2023). For example, when coaches seek maximum speed exposure and higher sprint distances (MD+3 and MD-3), then large spaces are recommended for all playing positions. Ideally, transition games and/or tactical drills might be performed on the entire pitch where larger areas could be covered at high velocity.

b) When focus shifts on tactical aspects minimising the effect of physical stress on footballers, then smaller spaces would be a better choice to avoid high-intensity exposure. This would be preferred on days prior official matches (e.g., MD-2 and/or MD-1). In addition, during weekly taper strategies 1 and 2 days before match play, high metabolic stress and unnecessary neuromuscular fatigue is not recommended, therefore repeated transitional activities (clusters) should be avoided, and long recovery breaks provided during these tactical phases in training (Figure 54). For this purpose, more players could be involved on a given position to allow rotation and ensure longer rest between activities.

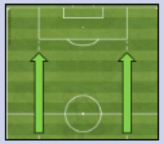
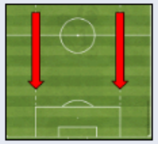
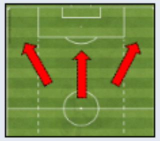
TRANSITIONAL ACTIVITIES (TA's)	GRAPHICAL DISPLAY	TACTICAL PHASE	MAIN PHYSICAL OUTCOME (per·min^{-1})	TOTAL COUNT	REPEATED ACTIONS COUNT & CLUSTER (%)	MEAN / PEAK DURATION	% TA's IN WCS_{1min}
OFFENSIVE TRANSITION (OT)		Offensive (in-possession)	• Sprint distance (SD)	14	8 (61%)	11 / 24 sec	43%
DEFENSIVE TRANSITION (DT)		Defensive (out-of-possession)	• Total distance (TD) • High-speed running distance (HSRD) • Accels & Decels (A+D)	15	10 (66%)	9 / 23 sec	52%
FAST ATTACK (FA)		Offensive (in-possession)	• Sprint distance (SD)	13	8 (61%)	10 / 22 sec	5%
HIGH-PRESSURE (HP)		Defensive (out-of-possession)	• Accels & Decels (A+D)	8	6 (83%)	10 / 27 sec	0% (none)

Figure 56. Practical information for training design regarding technical-tactical and physical characteristics of transitional activities, their repeated pattern (clusters) and occurrence during 1-min peak match demands (WCS_{1min}). Adopted from Bortnik et al. (2022) and (2023b).

5. To reduce declines in physical output during contextualised blocks of maximum intensity in the 2nd half and last stages of match play, coaches and practitioners could apply different transition games, tactical drills (offensive and defensive), and various sided games playing with/without goalkeepers.

a) These training modes performed at the end of training session as well as running based exercises (team settings, formation-specific, and/or individual drills) that fall into a speed endurance production category presented in Figure 57, could be recommended to condition footballers under fatigue and ensure better tolerance for high-intensity moments during the last minutes of competition.

b) High-velocity (high-speed running and sprint distance) and high-intensity activities (accelerations and decelerations) should be closely monitored in relation to different positional groups to avoid under/overloading, especially during a period of congested fixture to assess potential fatigue, inability to recover between matches and higher risk of muscle injury.

TRANSITIONAL ACTIVITIES (TA's)	TACTICAL PHASE	MAIN PHYSICAL/TACTICAL OBJECTIVE	PROPOSED TA's SEQUENCE FOR CLUSTERS	CLUSTERS ACTIVE DURATION	# CLUSTERS	WORK TO REST RATIO
OFFENSIVE TRANSITION (OT)	Offensive 	**Speed of Attack**: • Exploit & penetrate • Break into box • Over/Underlap	✓ INTERMITTENT: OT (10s) → DT (10s) → OT (10s) → 10-20s rest between ✓ CONTINUOUS: 25-30 sec	25 to 45s	2 sets 4-8 clusters	1:2-3 W.T.R.R.
DEFENSIVE TRANSITION (DT)	Defensive 	**Speed of Recovery Run**: • Cover space • Close down • Enter own box • Intercept	✓ INTERMITTENT: DT (10s) → FA (10s) → HP (10s) → 10-20s rest ✓ CONTINUOUS: 25-30 sec			
FAST ATTACK (FA)	Offensive 	**Speed of attack**: • Move to receive a pass • Overlap • Penetrate • Support play	✓ INTERMITTENT: FA (10-12s) → HP (10-15s) → 10-20s rest ✓ CONTINUOUS: 25-30 sec			
HIGH-PRESSURE (HP)	Defensive 	**Aggressive Defense**: • Press • Close down • Intercept • Block	✓ INTERMITTENT: HP (10s) → FA (10s) → DT (10s) → 10-20s rest ✓ CONTINUOUS: 25-30 sec			

Figure 57. Practical information for training design of repeated transitional activities (clusters) during late pre-season training, overload weekly phase (MD+4 and MD-3), and/or group top-ups including compensatory sessions, regarding the main physical/tactical objective, proposed TA's sequence, duration, number of sets and recovery period (work-to-rest-ratio). This reflects the physical/tactical demands during maximum intensity periods in official football matches. Tactical objectives adopted from Ju et al. (2022) and Bortnik et al. (2022), (2023a), (2023b) and (2024).

6. Coaches should always consider playing position when designing training for football players.

a) Center backs (CB) experience the lowest physical metrics during all TA's but achieve elevated physical demands in defensive transitions. These actions should be reflected in positional training mainly during defensive phases. Central defensive midfielders (CDM) along with central midfielders (CM) show very similar patterns for high-intensity actions during offense-to-defence transitions. Similar training modes could be applied for these central defensive positions (CB, CDM, and CM) linking their roles together in phases when the ball possession is lost and a rapid transition from offense to defence required. Additionally, activities generating maximum decelerations would be recommended in training to fully reflect match play demands during short peak intensity blocks. This could be achieved by using rapid changes from offensive to defensive activities (transitions) in team/individual training prescription as shown in Figure 61, 62 and 63.

b) Full backs cover the highest sprint distance during all transitions, especially in defensive transitions and fast attacks. Practitioners could combine attacking and defending actions together during which larger spaces are present and either overlapping actions occur to support play (offense) and/or recovery runs take place to quickly return to defensive positions and rebuild its optimal defensive shape. It is imperative to expose full backs to maximum accelerations during these highly contextualised blocks of activity by focusing on powerful first steps when either initiating a fast attack or transitioning from offensive to defensive phases (Figure 58 and 59).

c) Central attacking midfielders run higher distances including high-speed running during offensive transitions (counter-attacks) and fast attacks. This group along wingers and attackers is responsible for offensive forces of the team, and coaches should mimic their running patterns in training by having them explore and penetrate open areas to receive the ball, enter a penalty box and create goalscoring opportunities (Figure 59).

d) Wingers have the highest number of high-intensity and high-velocity actions during offensive activities such as counter-attacks and fast attacks. They also assist attackers during high pressures on the opposition's half and training should adequately provide these physical-tactical scenarios to best prepare this group for the match demands (Figure 59 and 60).

e) Attackers experience lower physical demands during defensive activities, while reaching higher intensity during high pressure activities and fast attacks as shown in Figure 60. This group might be viewed as the first line of defence in modern football strategy, especially when coaches prefer quick and aggressive possession re-gain on their attacking third once ball possession has been lost. Training should provide opportunities to allow attackers to be properly conditioned for these high-pressure moments. Nevertheless, this group should also be adequately prepared for offensive actions such as fast attacks when open spaces behind defenders are created and a rapid entrance to the box required (Figure 59).

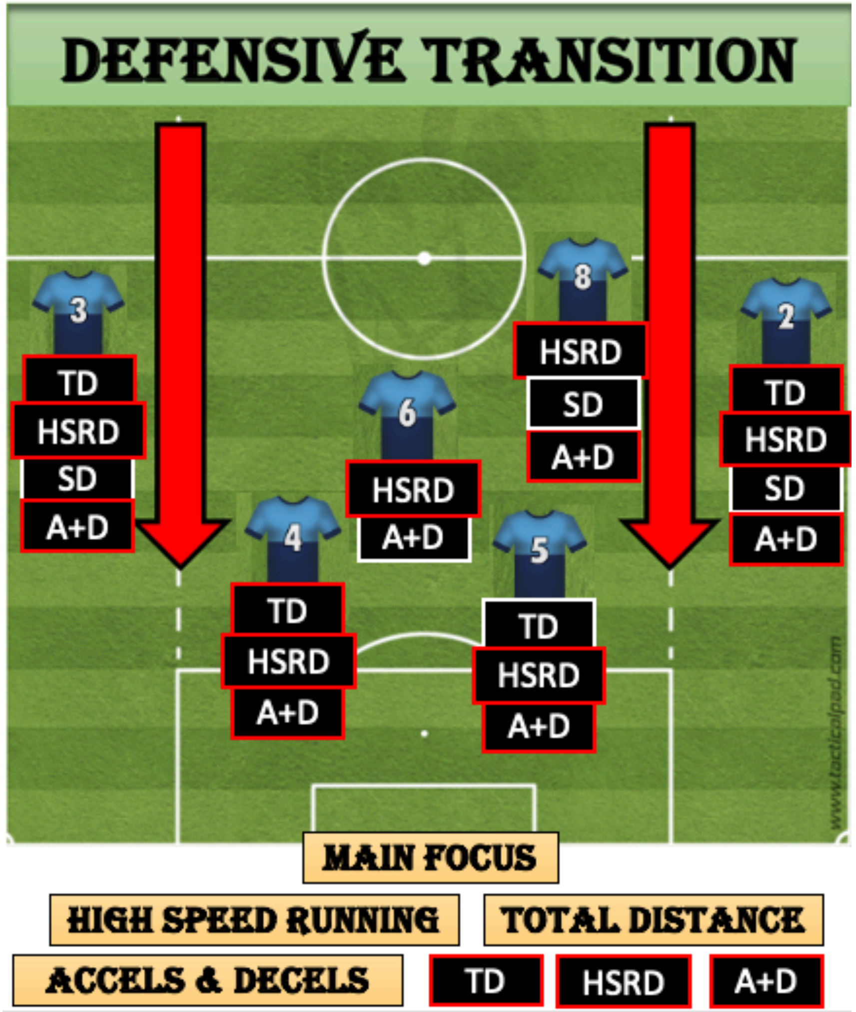


Figure 58. Defensive Transition: its graphical representation, physical impact on various playing positions during competition and main collective physical focus/outcome. Adopted from Bortnik et al. (2022) and (2024).

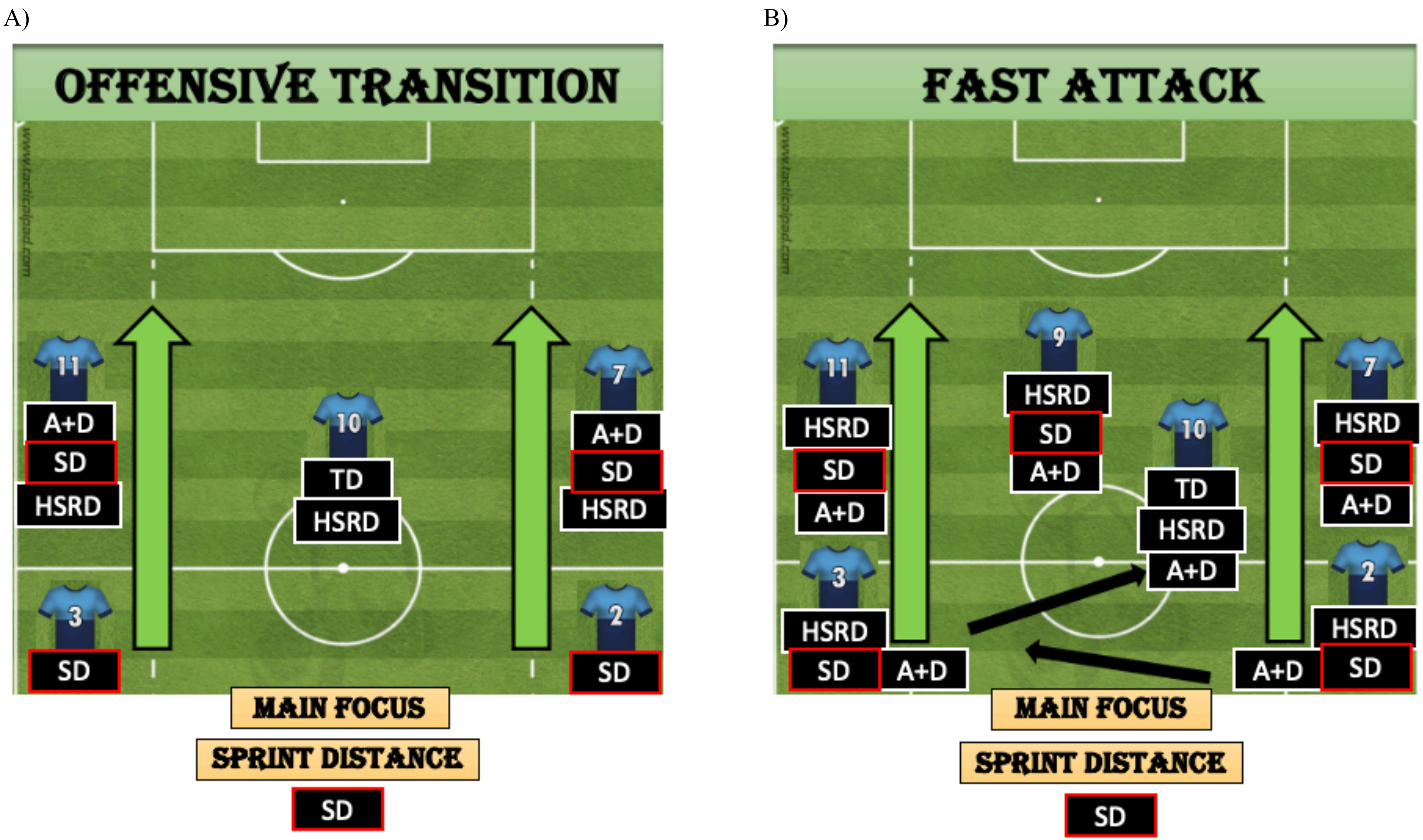


Figure 59. Graphical representation of A) Offensive Transition; and B) Fast Attack: their physical impact on various playing positions during competition and main collective physical focus/outcome. Adopted from Bortnik et al. (2022) and (2024).

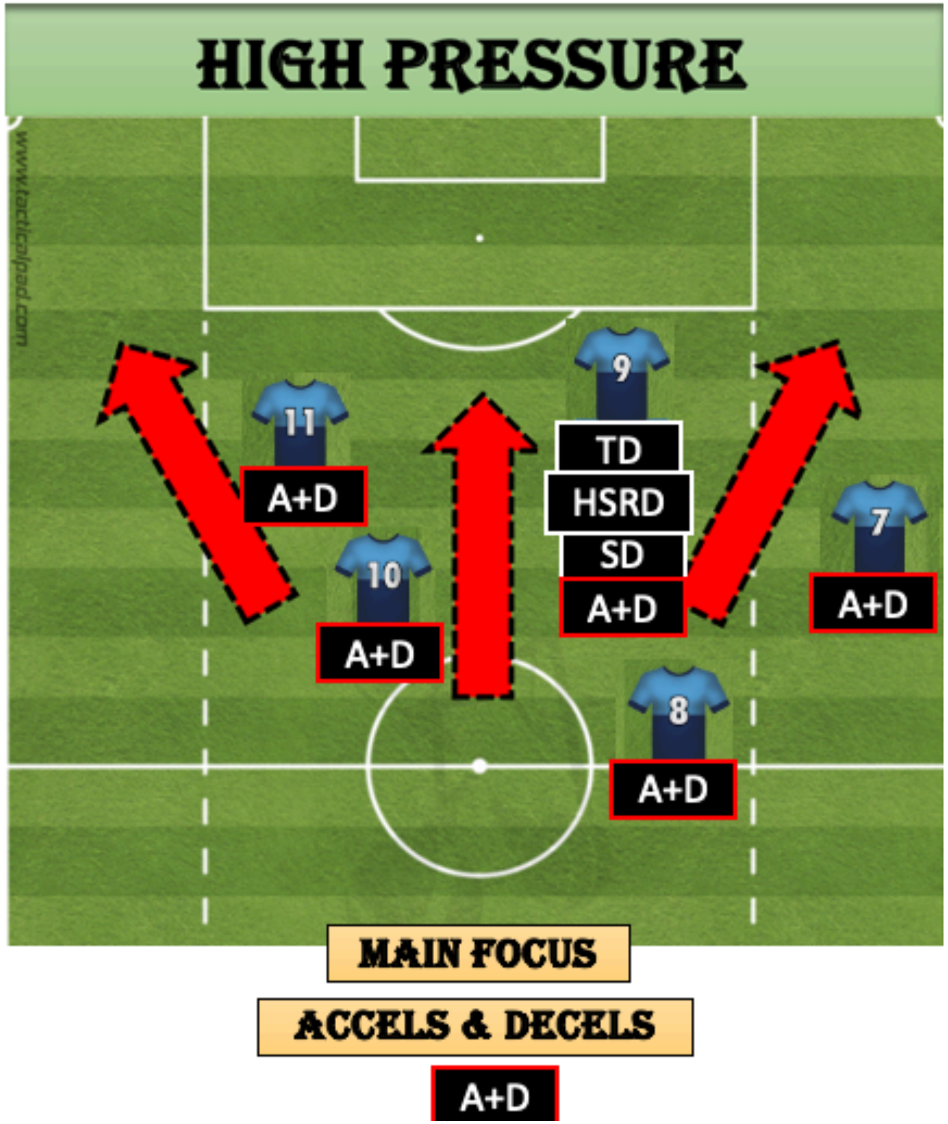


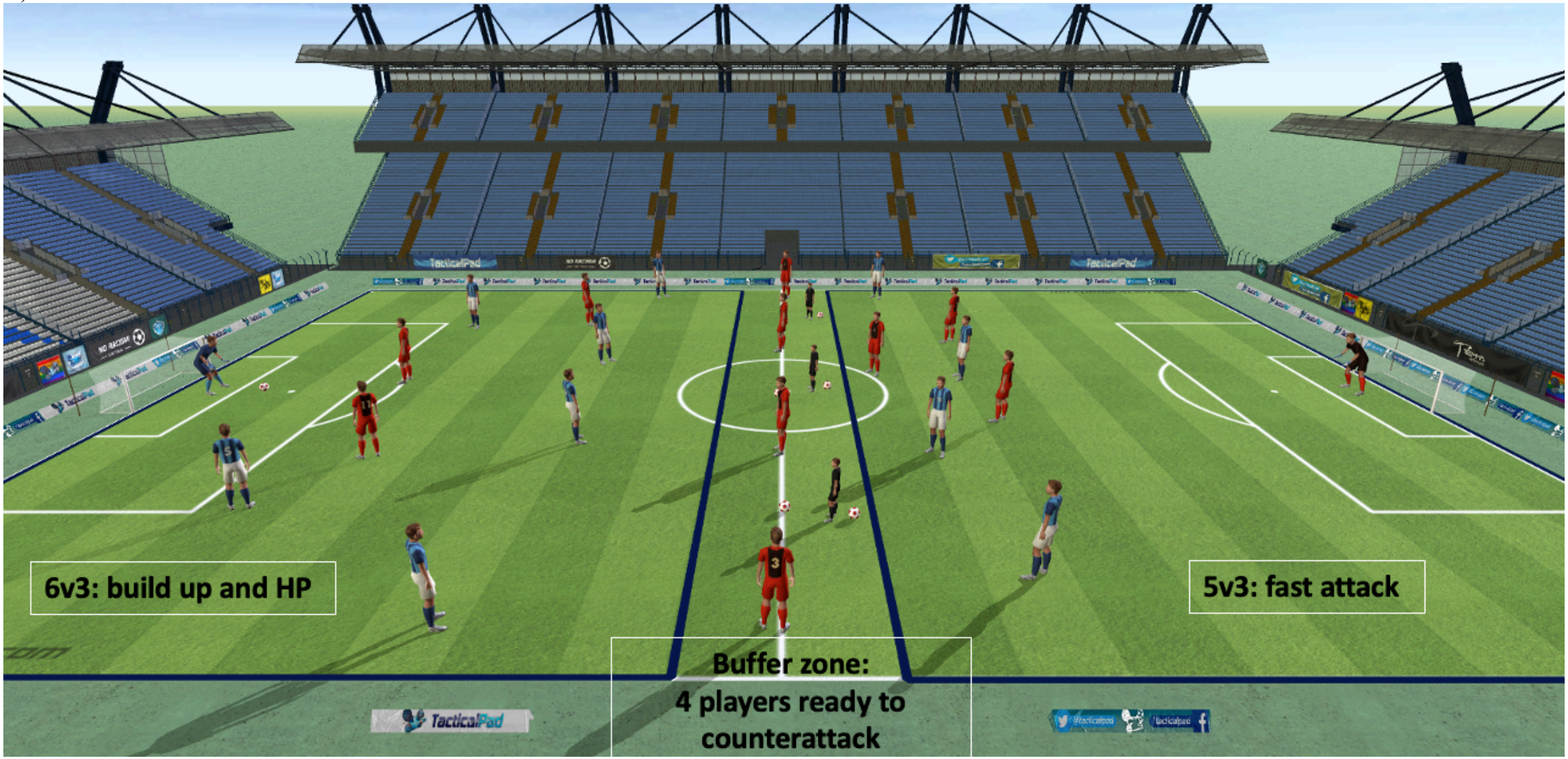
Figure 60. High Pressure: its graphical representation and physical impact on various playing positions during competition and main collective physical focus/outcome. Adopted from Bortnik et al. (2022) and (2024). ***Note: Physical metrics represents the following: a) total distance: TD (m·min^{-1}); b) high-speed running distance: HSRD (m·min^{-1}); c) sprint distance: SD (m·min^{-1}); and d) number of accelerations and decelerations: A+D (m·min^{-1}). The main physical outcome is highlighted in red.***

7. Coaches could use strategies that mimic maximum-intensity physical demands and replicate the positional specificity by designing appropriate drills in training, selecting offensive/defensive activities in/out of the ball possession, manipulating pitch size and the number of players to best prepare athletes for their position-specific role in the modern game and reduce their risk of injury (underprepardness).

a) Examples of team and individual transitional drills and football specific exercises designed to provide high-intensity and velocity exposure for each playing position in training are shown below (Figure 61 to 66).

b) Team and collective tactical drills should be used regularly during a weekly training plan that integrates physical, technical-tactical components of football match play as well as include group and/or individual conditioning, top-up and return-to-play sessions to best prepare all footballers for their specific needs in competition as shown in Figure 55.

A)


6v3: build up and HP
5v3: fast attack
Buffer zone:
4 players ready to
counterattack

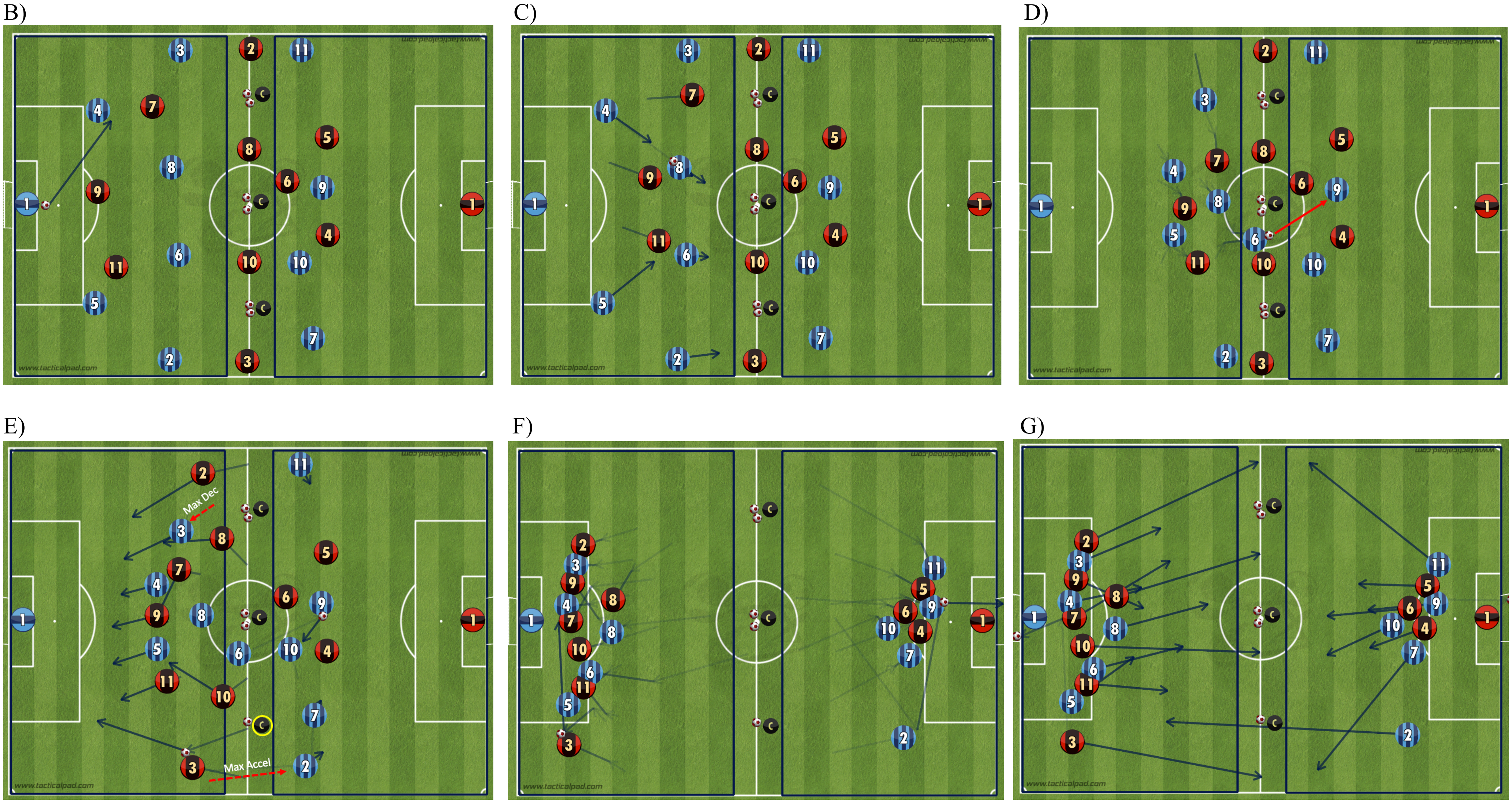


Figure 61. Position-specific collective drill: a) 3D drill set up; b) 6v3 build up and c) high pressure (HP) done by an attacker and wingers; d) advancing ball to the buffer zone to initiate fast attack (FA) on the opponents half; e) counter-attack (OT) and defensive transition (DT): coach initiates attack; 1 full back stays to defend and another joins FA; f) attacking/defending the penalty area; and g) sprinting back to initial position. Perform 2 sets of 6-8 actions (clusters) lasting 20-30 seconds. Use 1:2-3 work-to-rest-ratio. Team activity: 20-22 players.

A)

B)

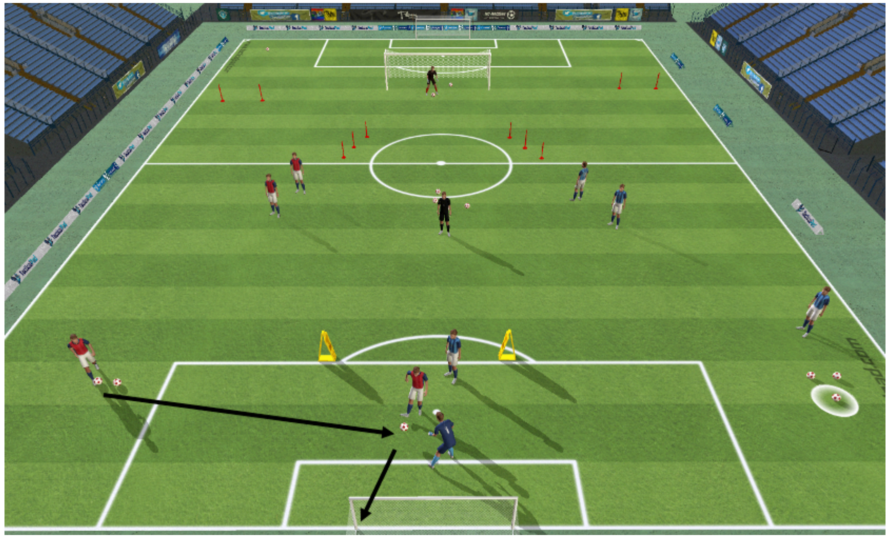
C)

D)

E)

F)

G)



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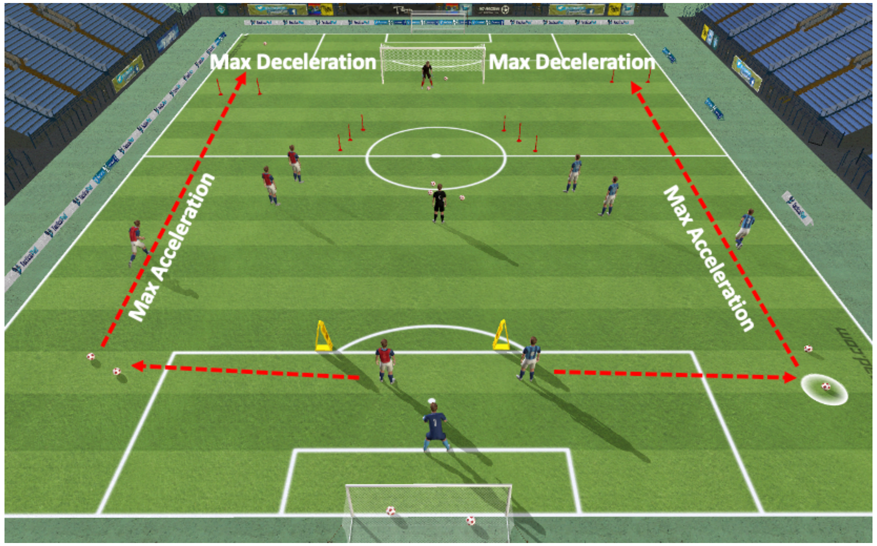

Figure 62. Specific offensive-defensive drill (1v1 and counter-attack): a) 3D drill set up; b) player 1 (left) makes slalom without a ball; c) player 2 (right) makes slalom with a ball and finishes with a double-pass; d) player 1 gets a ball from coach and e) plays 1v1 against player 2; f) players counter-attack (OT) = sprint top the box where g) and h) they receive two cross (left and right); i) wide players after delivering crosses fully accelerate to small goals places on the other half and come a complete stop (max deceleration). Perform 2 sets of 4-8 actions (clusters) lasting 25-30 seconds. Use 1:2-3 work-to-rest-ratio. Group activity: 6-12 players.

A)

B)


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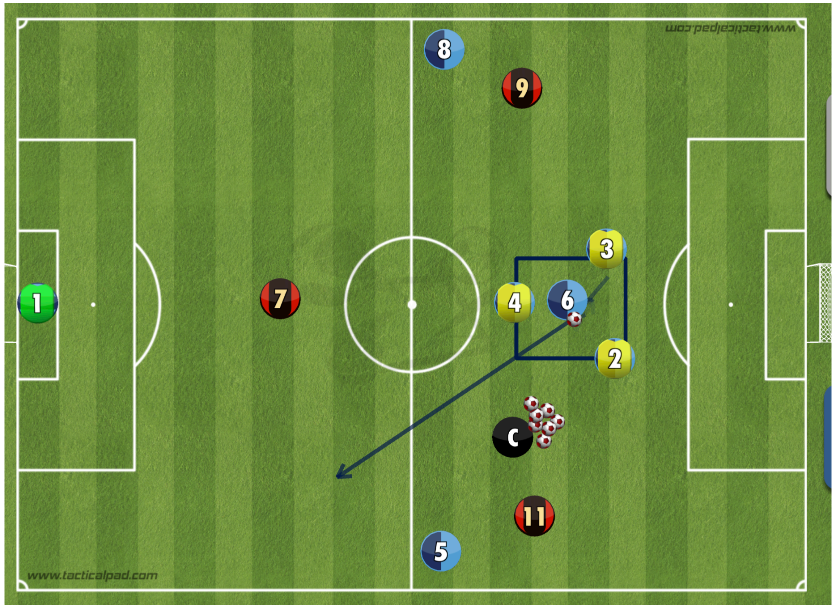
C)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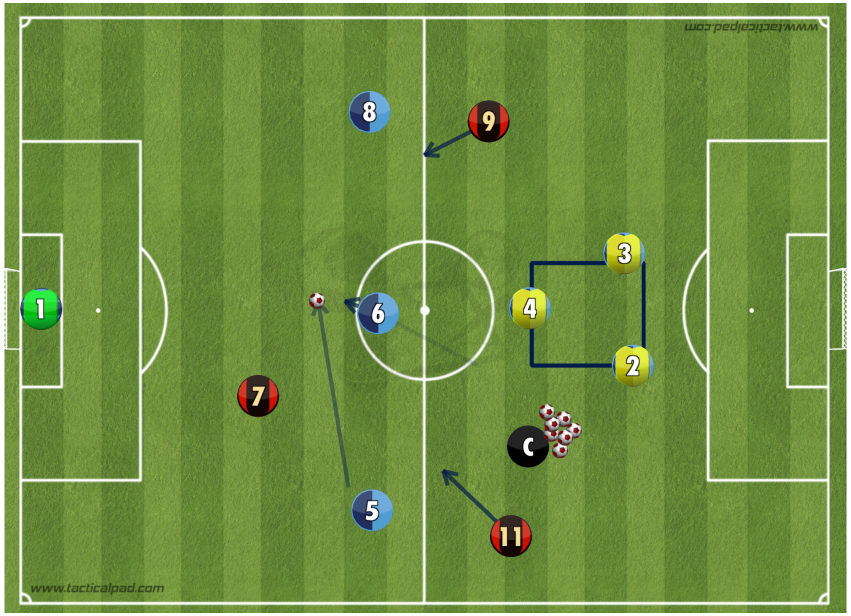
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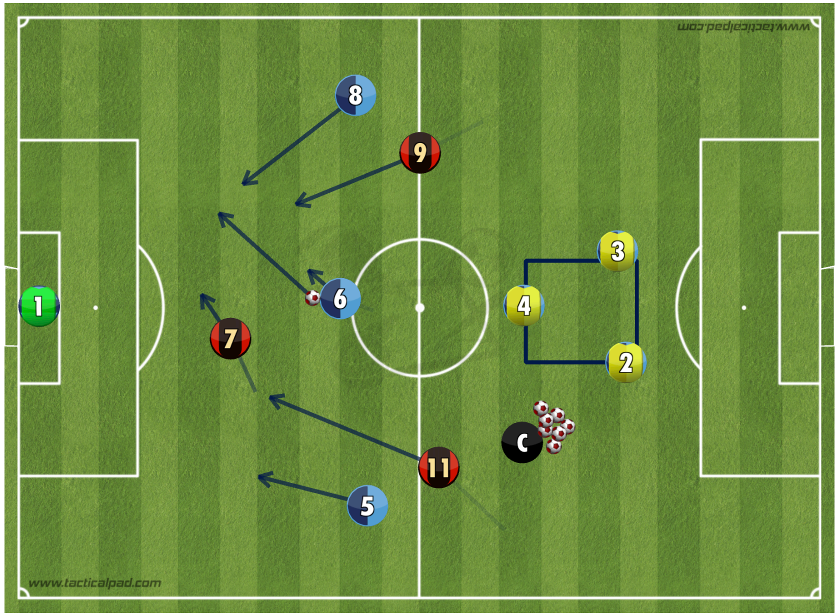
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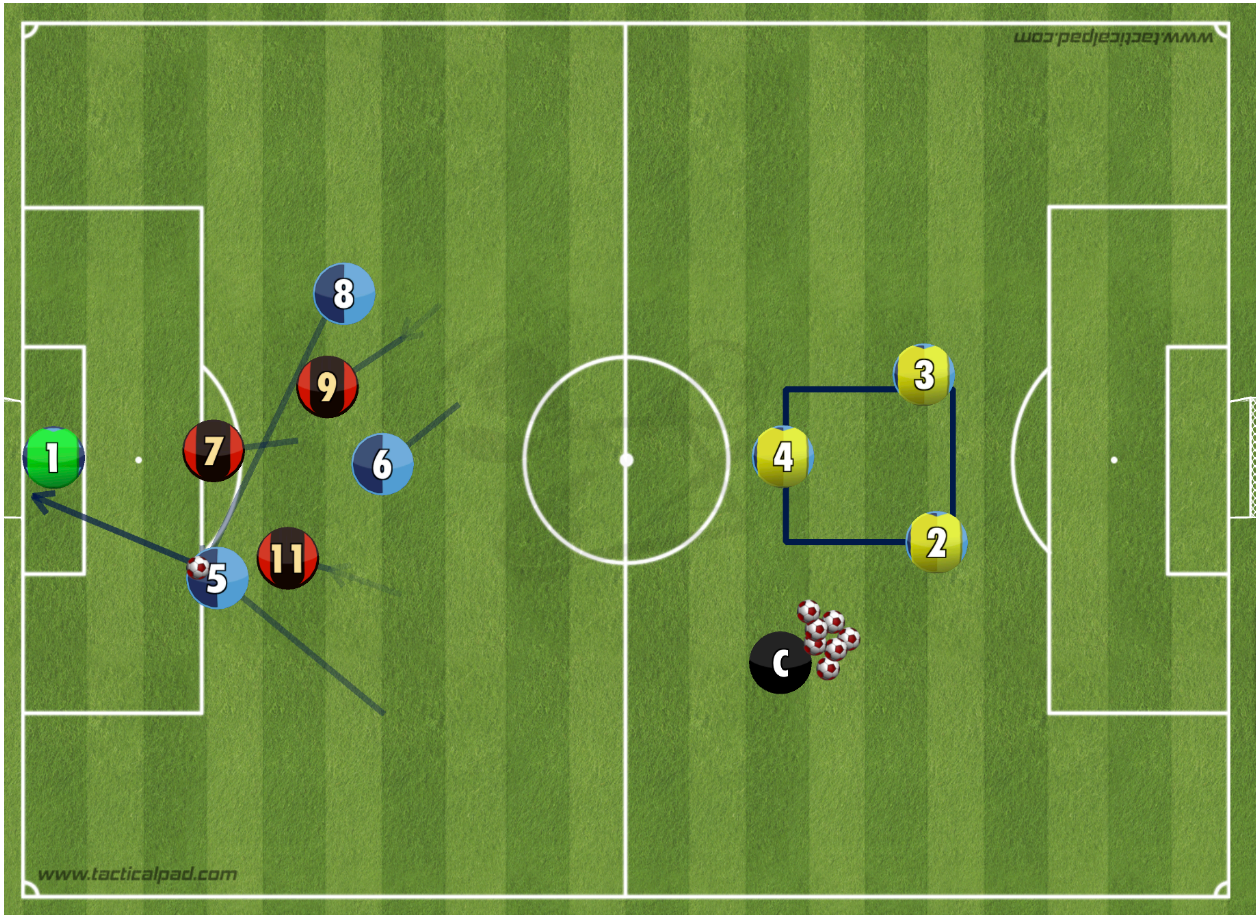
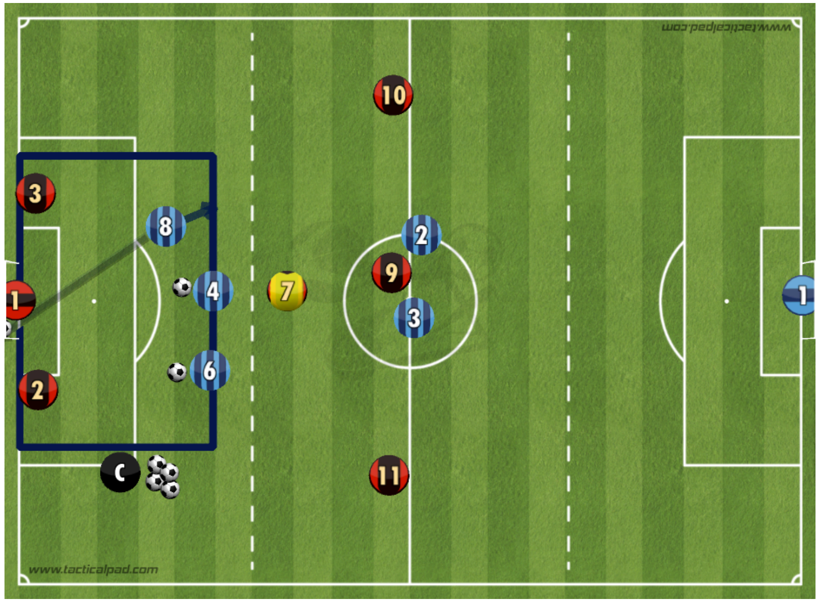


Figure 63. Specific offensive-defensive drill (3v1 high pressure and counter-attack): a) 3D drill set up; b) 3v1 possession where player nr 6 (blue) applies high pressure to win the ball; c) once possession has been re-gained, counter-attack (OT) is initiated; d) 3 blue players counter-attack and 1 red defends (3v1); e) 2 red players are making recovery runs to support defence DT (3v3); f) blue players quickly enter the box to finish an attack, which must be performed as quickly as possible to use numerical advantage in its early phase. Perform 2 sets of 6-8 actions (clusters) lasting 20-30 seconds. Use 1:2-3 work-to-rest-ratio. Group activity: 9-15 players.

A)

B)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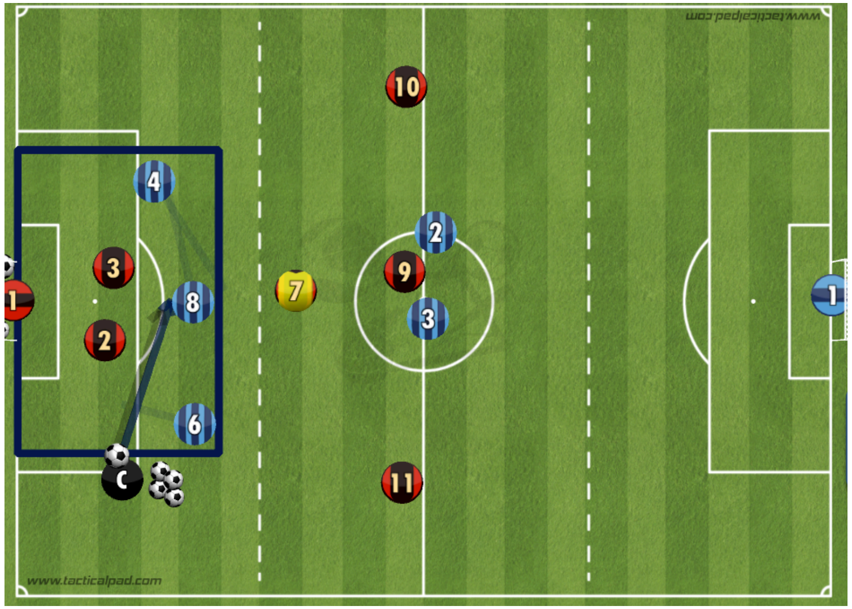
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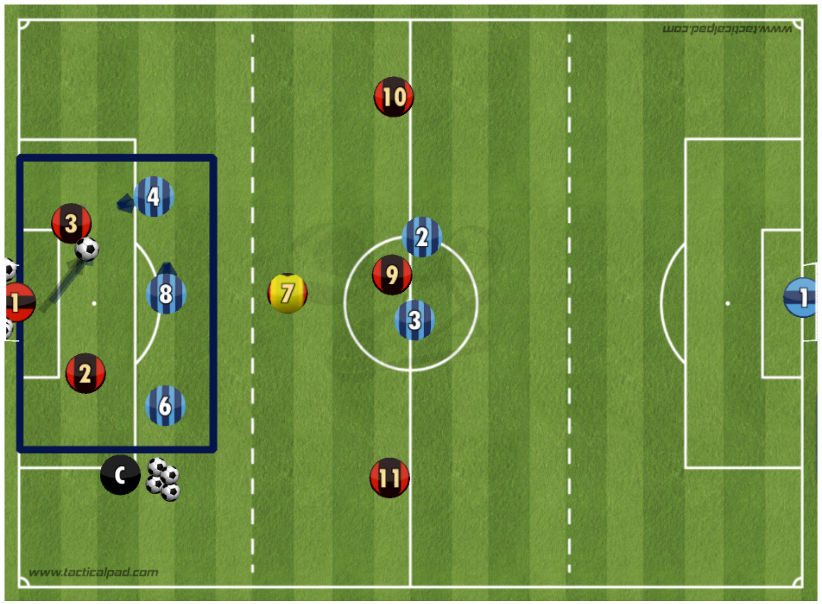
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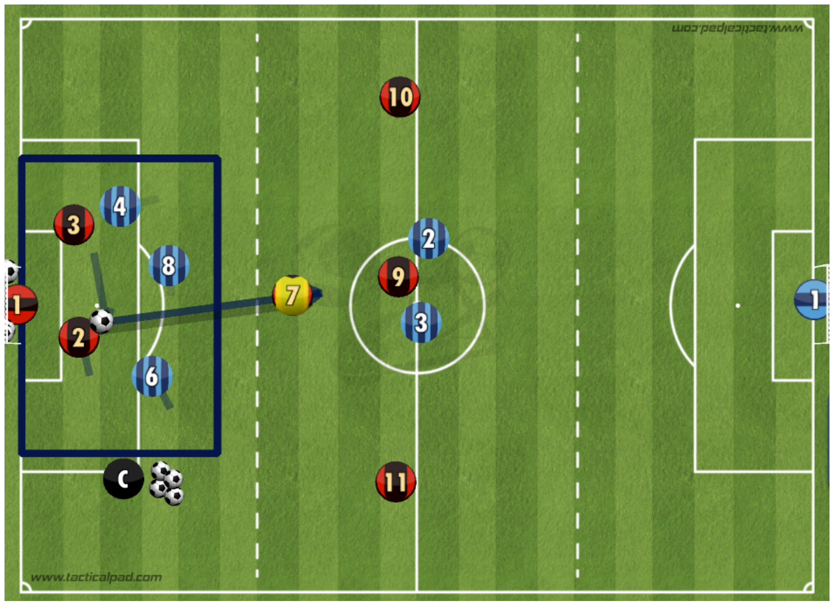
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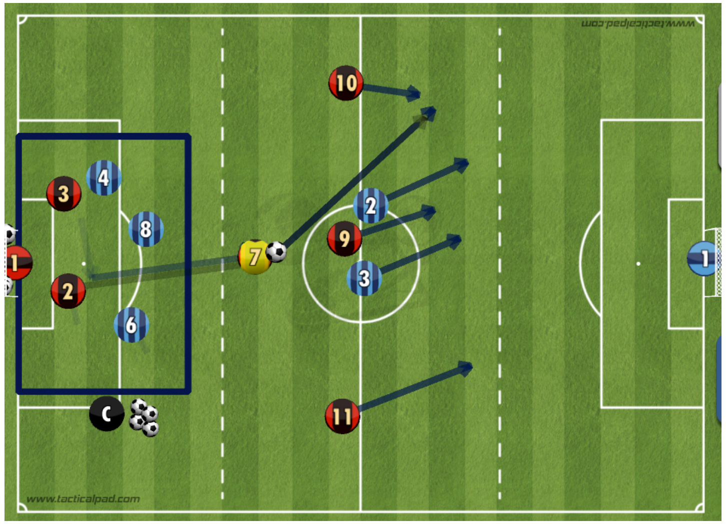

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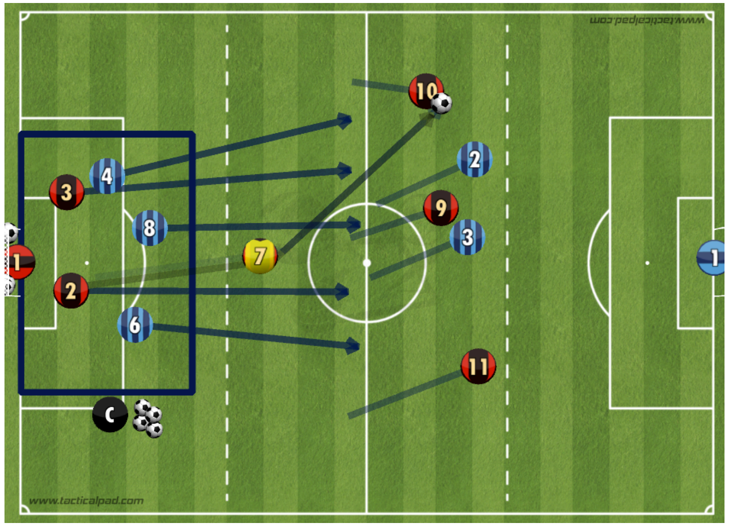

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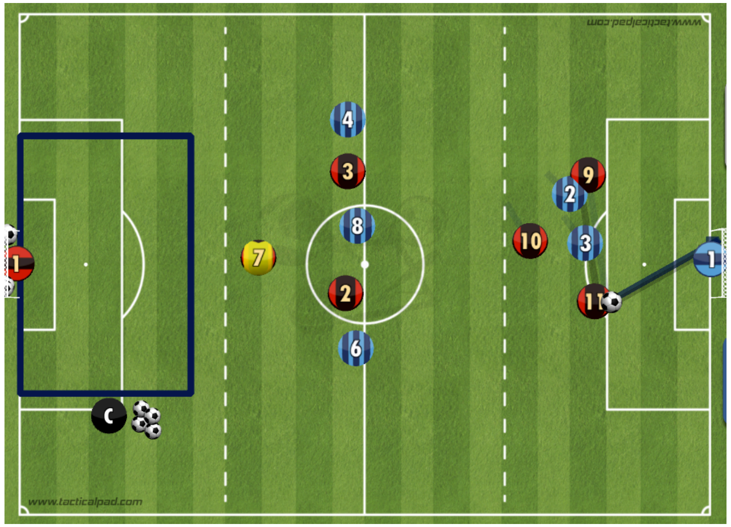

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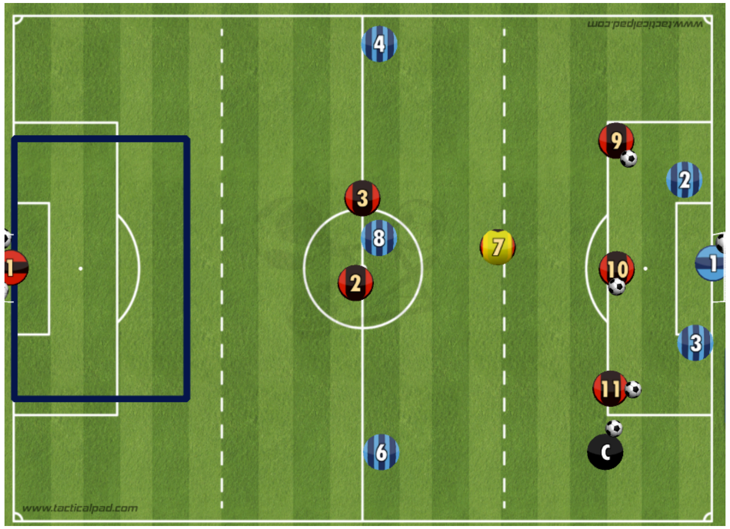
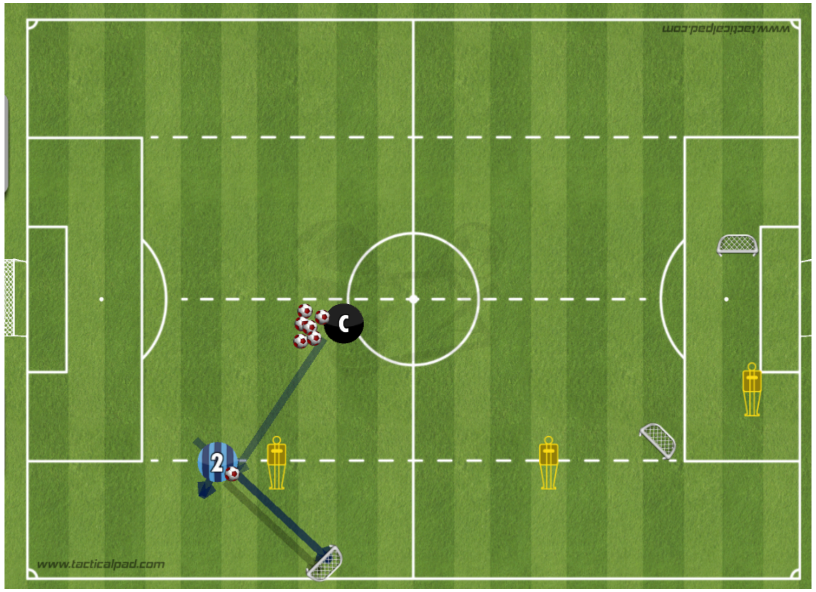


Figure 64. Specific offensive-defensive drill (3v2 high pressure to 3v2 counter-attack): a) 3D drill set up; b) blue players shoot on goal; c) coaches initiates a short 3v2 possession: aim for goals; d) blue players apply high pressure while red players start a build-up and e) look for a free buffer player (yellow) ; f) yellow player initiates counter-attack on the opposition half (3v2); g) players from the box push up until half pitch; h) entering the box and finishing the attack; i) roles change. Counter-attack must be performed as quickly as possible to use numerical advantage and open space. Perform 2 sets of 4-6 actions (clusters) lasting 25-45 seconds. Use 1:2-3 work-to-rest-ratio. Group activity: 10-15 players + 1-2 buffer players (lower physical load).

A)

B)



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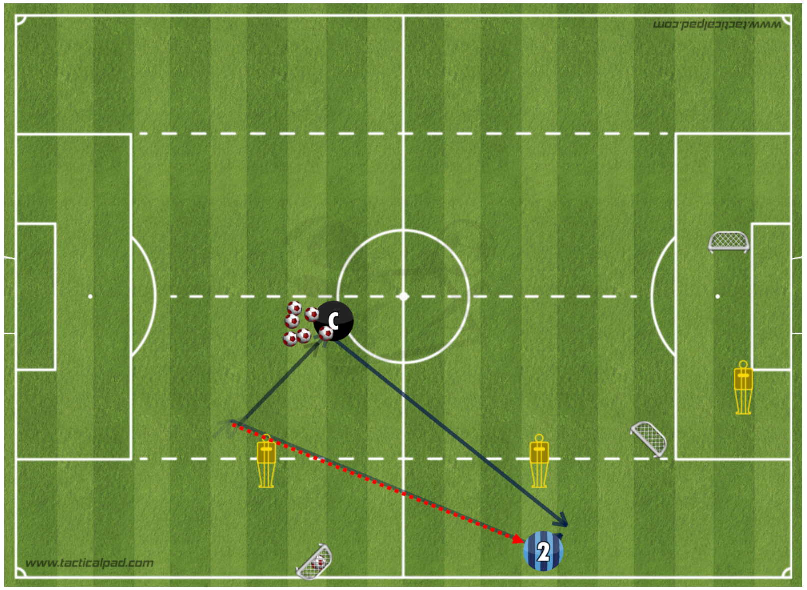

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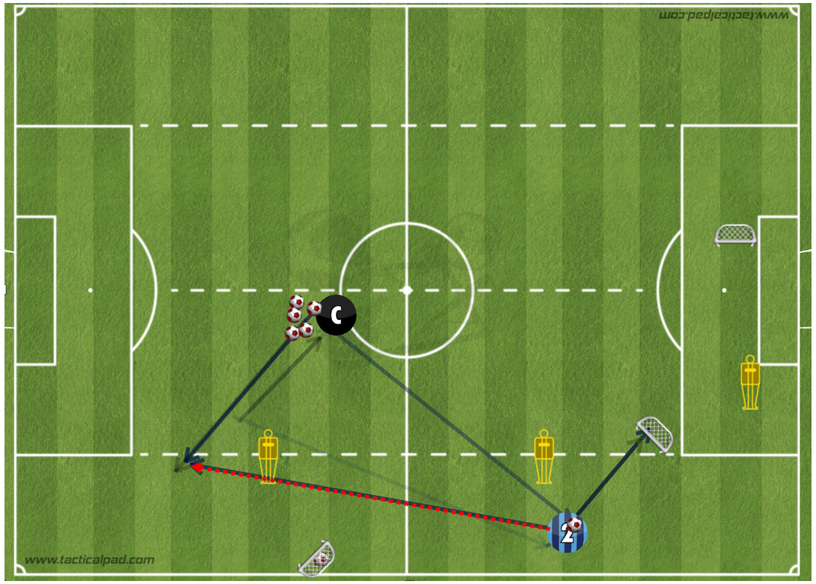

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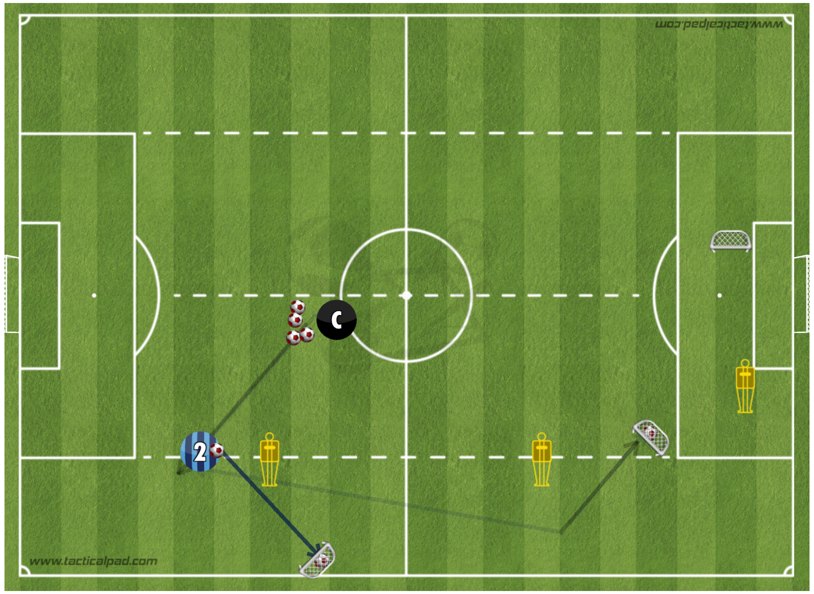

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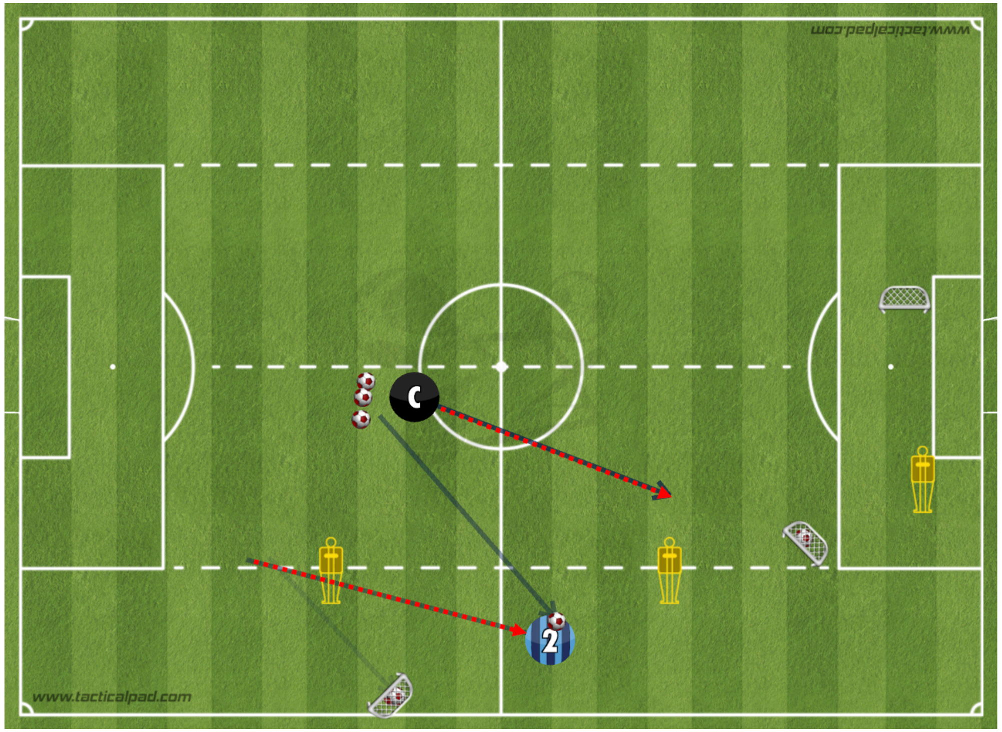
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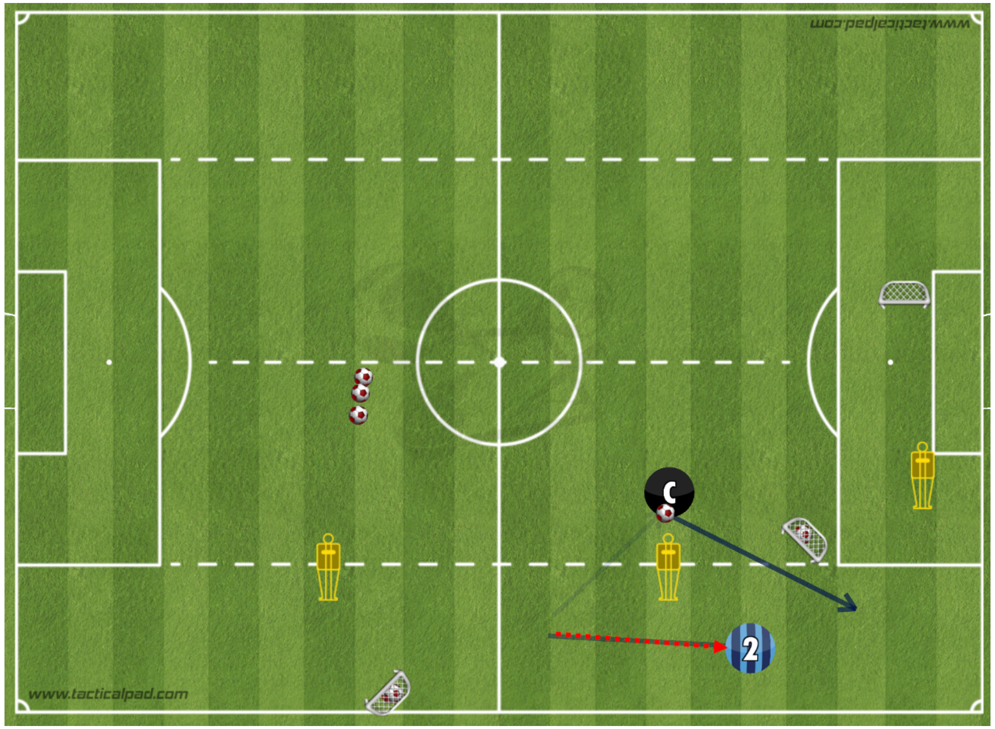
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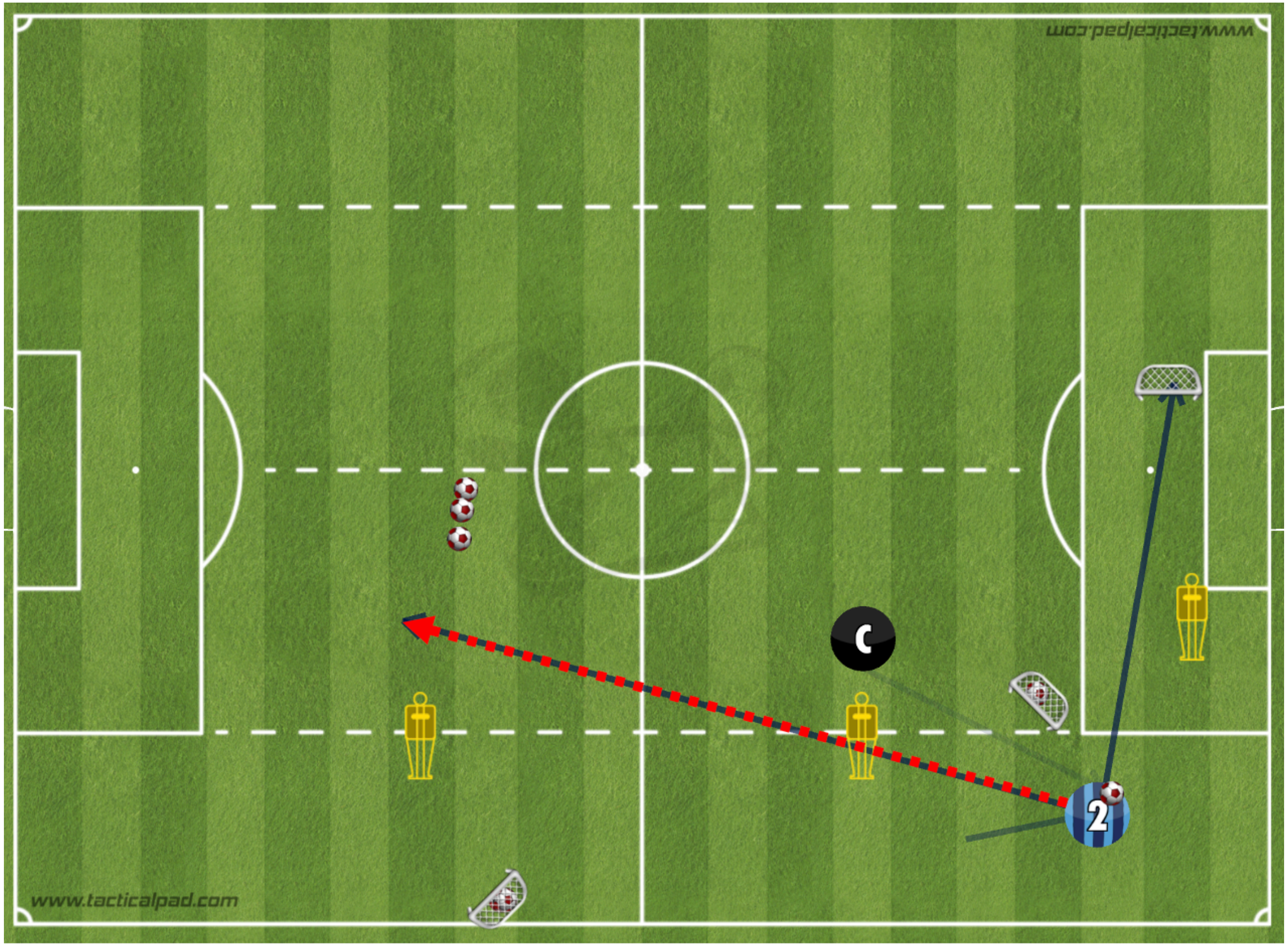
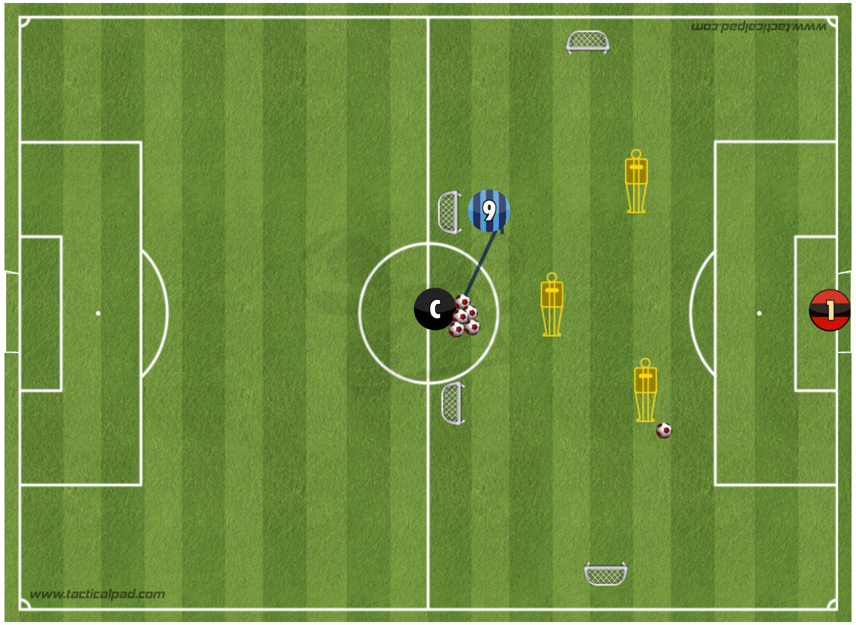


Figure 65. Full back position-specific drill (recovery running DT and crossing in fast attack FA): a) 3D drill set up; b) receive and pass to small goal; c) one touch back pass and running forward to open space; d) control a long ball, pass to small goal, and perform a quick recovery run to initial position; e) short recovery (10-20 sec) then another control and pass to small goal; f) running to open space to get the ball; g) double pass with a coach; and g) cross followed by another recovery run as fast as possible to its defensive position. Perform 2 sets of 6-8 actions (clusters) lasting 25-30 seconds. Use 1:2-3 work-to-rest-ratio. Individual activity.

A)

B)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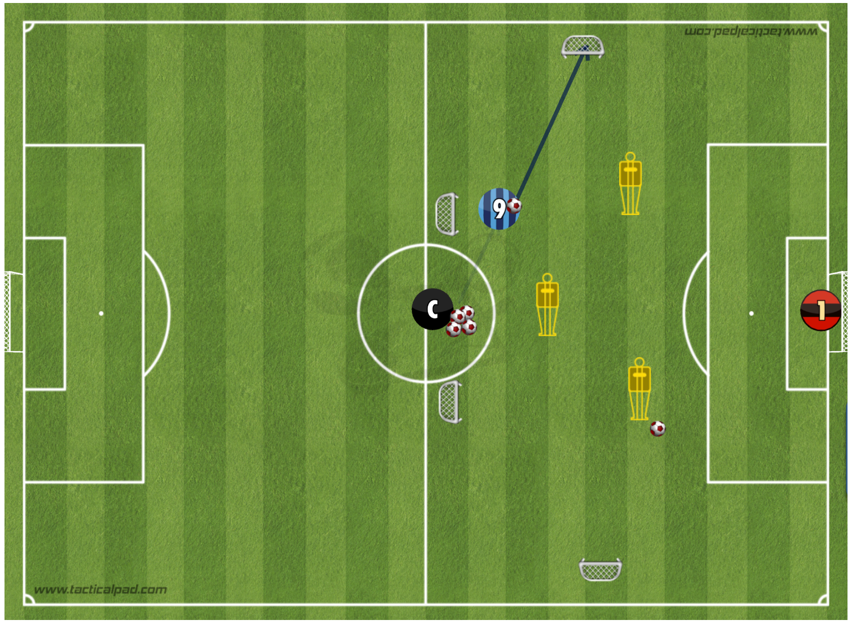
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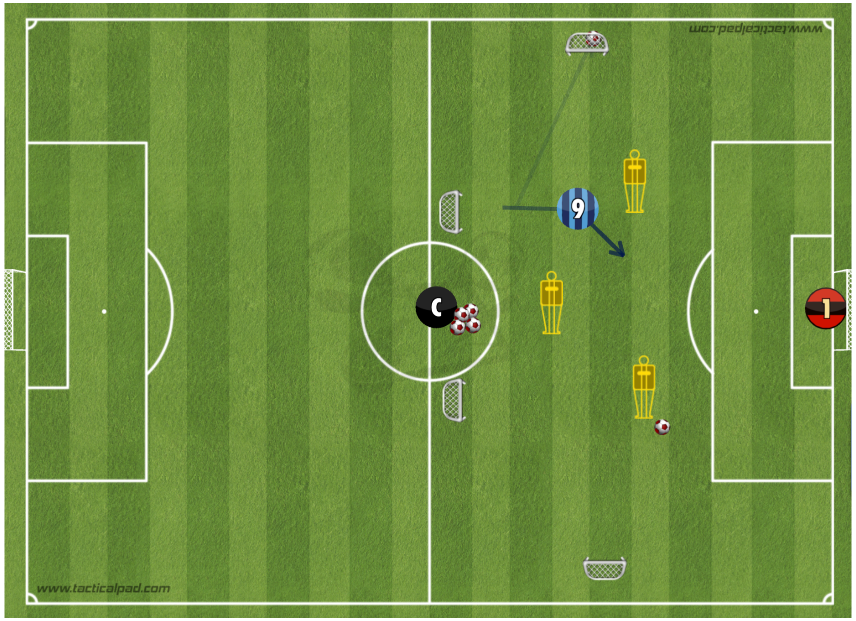
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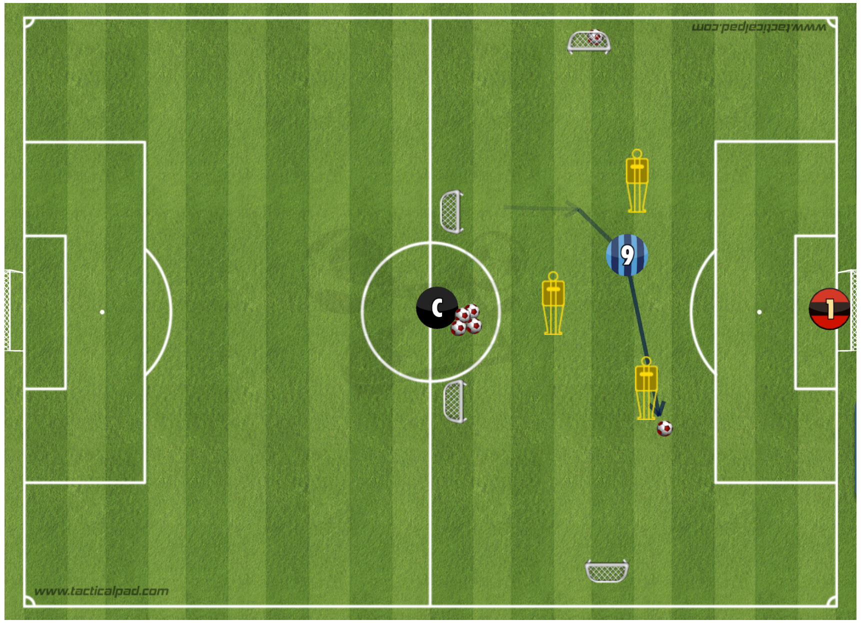
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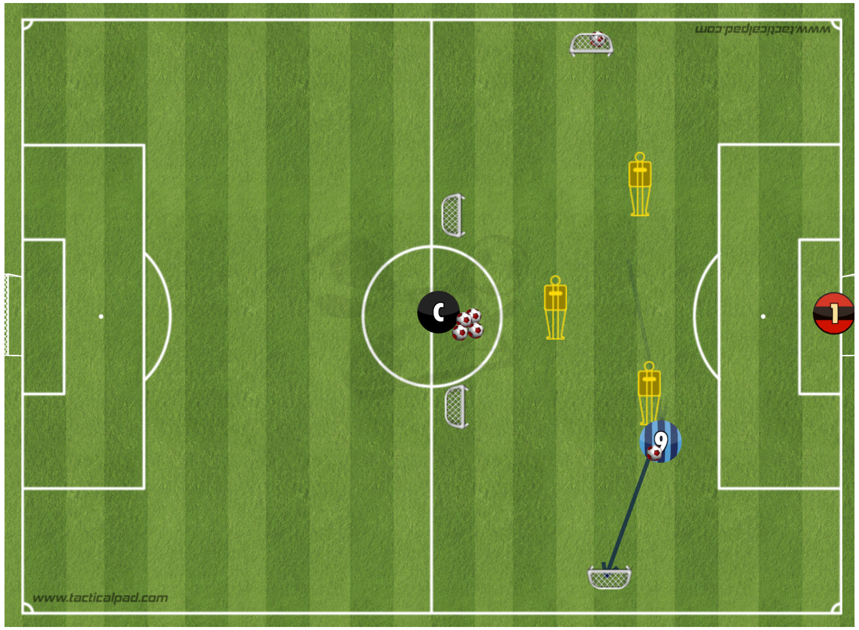
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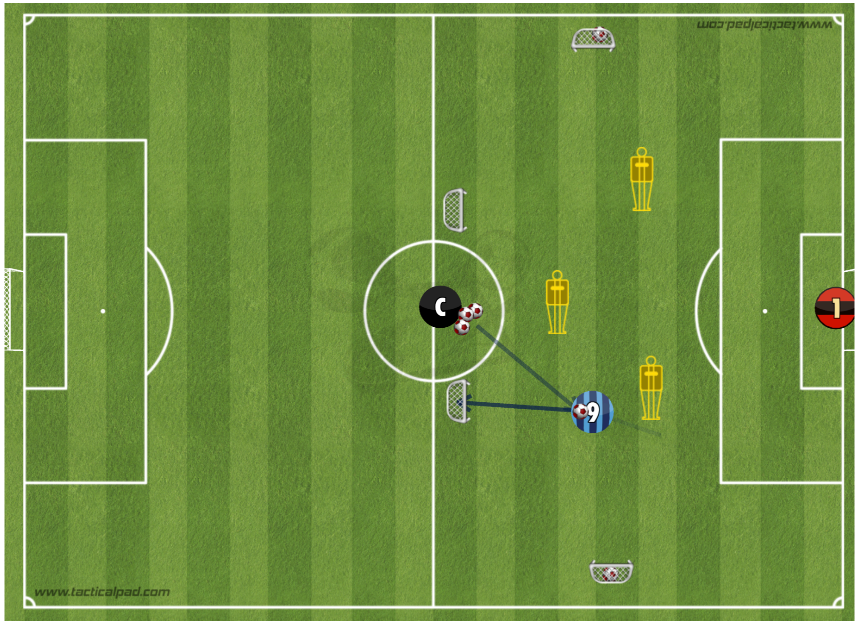
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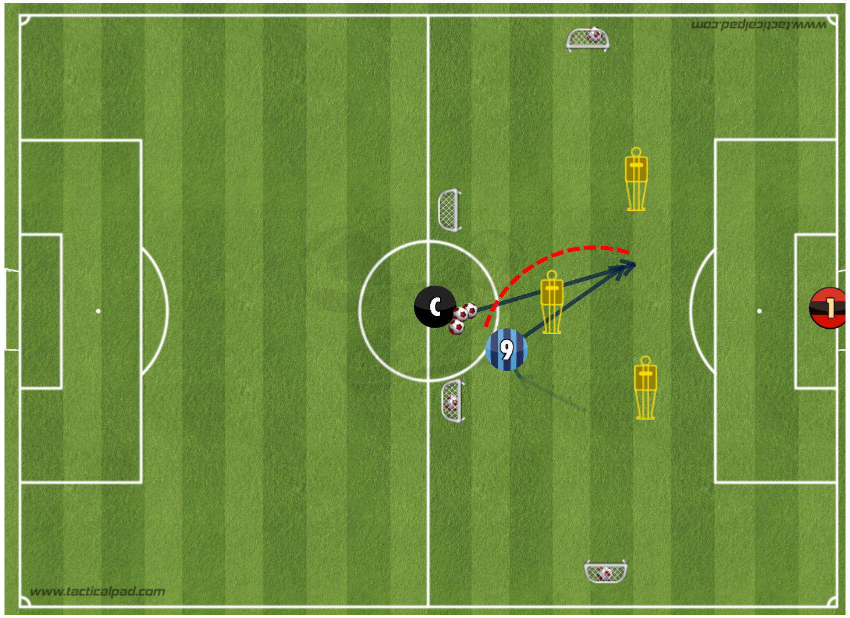
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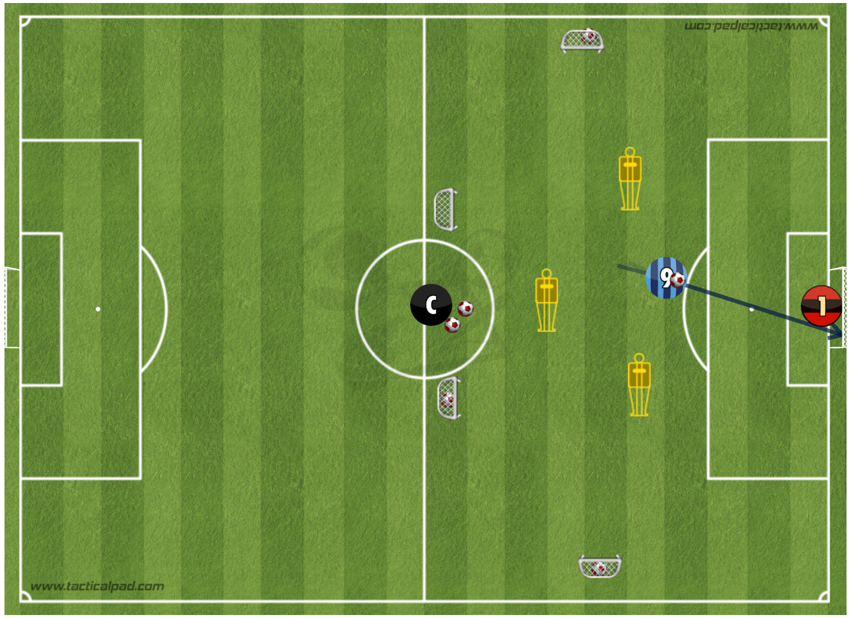
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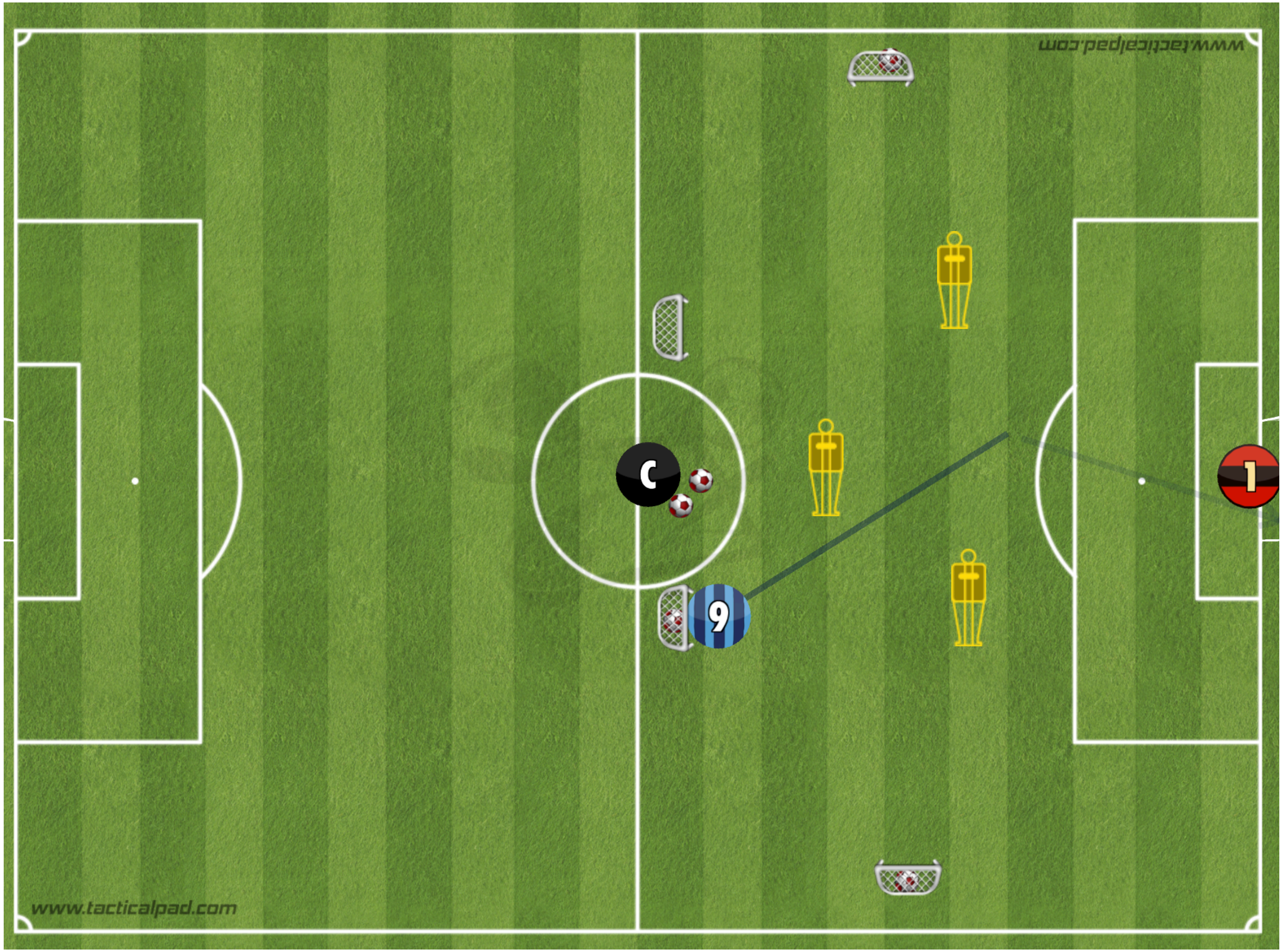

Figure 66. Attacker position-specific drill (high pressure HP followed by a fast attack FA): a) 3D drill set up; b) receive a ball from coach; c) pass to small goal; d) pressure left center back (mannequin); e) pressure right center back to win the ball; f) get the ball and pass to small goal; g) run towards coach and 1-touch pass to small goal; h) make a curve run to get the ball into open space (fast attack); i) shoot on goal; j) run back to another side and rest. Perform 2 sets of 6-8 actions (clusters) lasting around 20-25 seconds. Use 1:2-3 work-to-rest-ratio. Individual activity.

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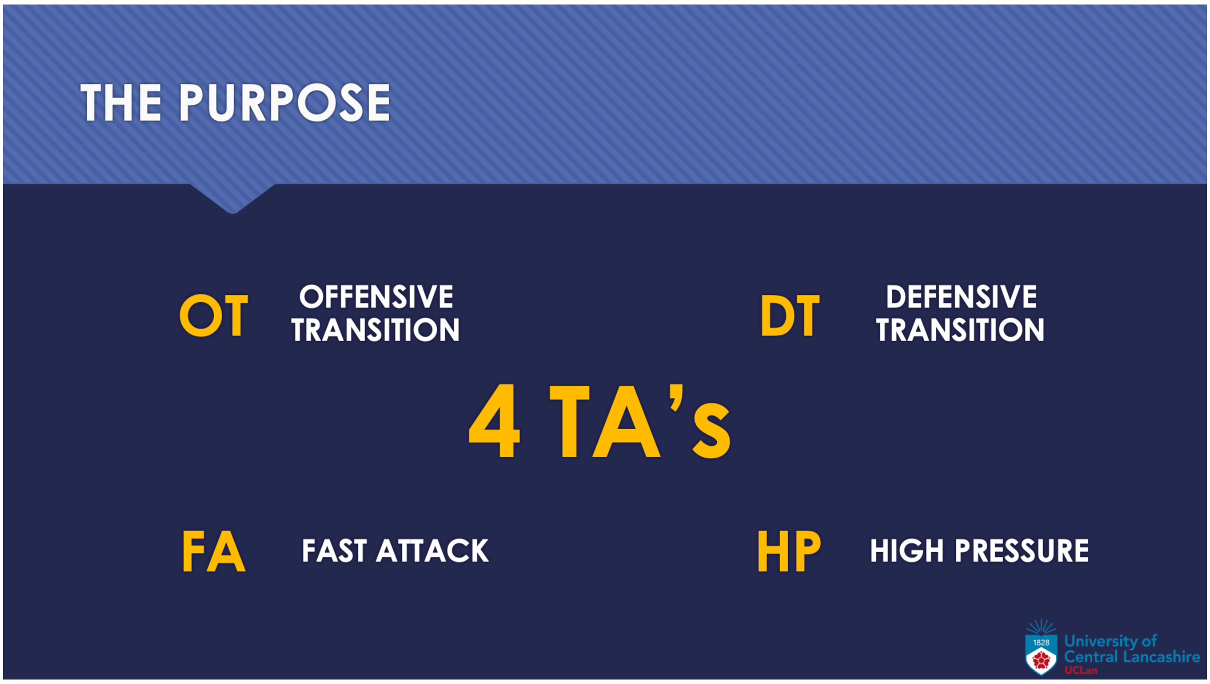
Appendices

Appendix 1. The main purpose of the research project.



Appendix 2. Implications for training design.

Appendix 3. Additional publication.

International Journal of
Environmental Research and Public Health

MDPI

Article

The Effect of High-Intensity Accelerations and Decelerations on Match Outcome of an Elite English League Two Football Team

David Rhodes [1,*], Stephen Valassakis [2], Lukasz Bortnik [1], Richard Eaves [2], Damian Harper [1] and Jill Alexander [1]

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Abstract: Objectives: Previous research has highlighted the frequency of high-intensity accelerations and decelerations in elite football. The influence of these actions on match performance outcomes has not been established. The aim of the present study was to identify the influence of high-intensity accelerations and decelerations on match performance outcomes (i.e., win, draw, lost). Comparisons were also made between team and positional high-intensity accelerations and decelerations recorded within the games. Methods: 26 elite outfield footballers from an elite English Football League (EFL) Two team completed the present study. Global Positioning System (GPS) technology was utilised to quantify high-intensity accelerations and decelerations during 45 games in a competitive season. Magnitude analysis and the effects of results, positions and fixture periods were observed. Results: Significant effects of results, periods and positions were observed ($p \leq 0.05$), with the highest outputs observed in games won. Positionally, fullbacks and centre forwards in a 4–3–3 formation exhibited the greatest frequency of high-intensity accelerations and decelerations. Very large differences were observed between the frequency of high-intensity decelerations compared to accelerations in games won ($g = 2.37$), drawn ($g = 2.99$) and lost ($g = 3.59$). The highest team frequencies of high-intensity accelerations ($n = 3330$) and decelerations ($n = 6482$) were completed in games won. Conclusions: The frequency of high-intensity accelerations and decelerations has a significant impact on match performance outcomes in an elite English League Two football team. Consideration needs to be given to specific conditioning and recovery strategies to optimise high-intensity acceleration and deceleration performance in games. Caution should be taken as these findings are representative of one team within the EFL.

Keywords: soccer; conditioning; high velocity actions; performance; injury risk reduction

check for updates

Citation: Rhodes, D.; Valassakis, S.; Bortnik, L.; Eaves, R.; Harper, D.; Alexander, J. The Effect of High-Intensity Accelerations and Decelerations on Match Outcome of an Elite English League Two Football Team. *Int. J. Environ. Res. Public Health* **2021**, *18*, 9913. https://doi.org/10.3390/ijerph18189913

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Published: 21 September 2021

Appendix 4. Additional publication.

ORIGINAL ARTICLE **EXERCISE PHYSIOLOGY AND BIOMECHANICS**

The Journal of Sports Medicine and Physical Fitness 2023 February;63(2):250-5

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language: English

The effect of pre-match sexual intercourse on football players' performance: a prospective cross over study

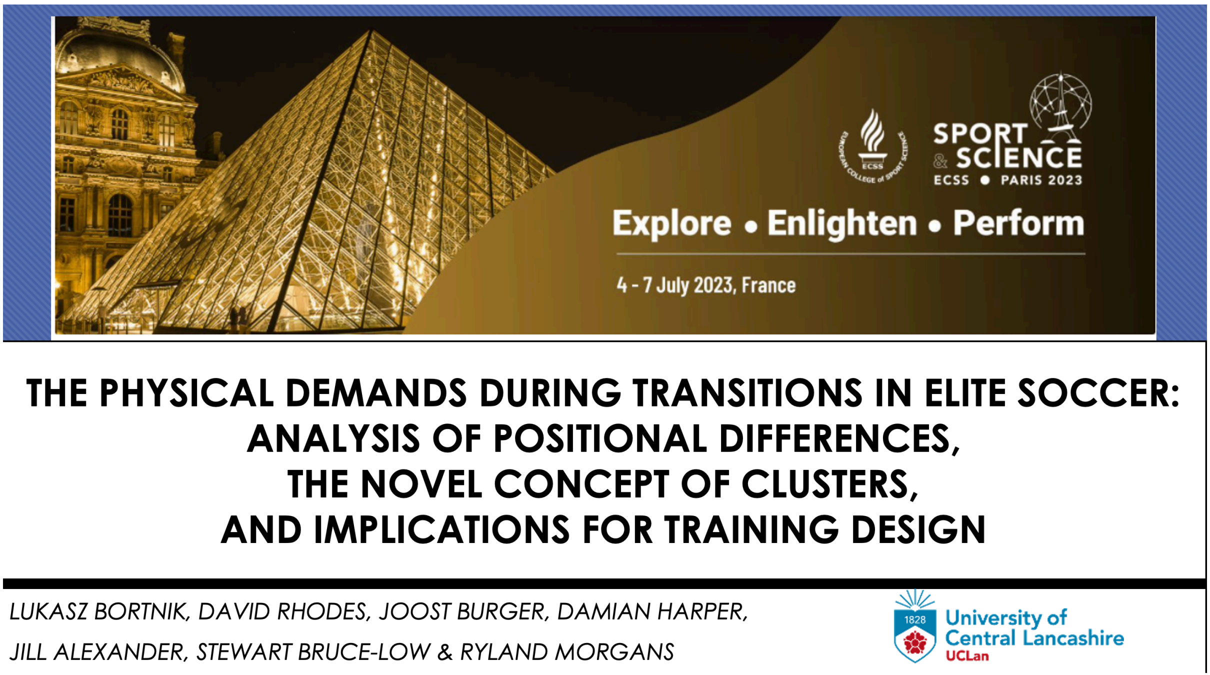
Tal PELEG-SAGY [1, 2], Lior ZELLER [2, 3], Yonatan PERELMAN [2], Luckasz BORTNIK [4], Tomer MAMAN [2, 3], Iftach SAGY [2, 3, 4] ✉
[1] Mental Health Center of Beer-Sheva, Beer-Sheva, Israel; [2] Ben-Gurion University of the Negev, Beer-Sheva, Israel; [3] Department of Rheumatology, Soroka University Medical Center, Beer-Sheva, Israel; [4] Clinical Research Center, Soroka University Medical Center, Beer-Sheva, Israel

HTML **PDF** **Supplementary Materials**

BACKGROUND: Current research suggests that pre-competition sexual intercourse does not influence athletes' performance. Yet, high quality studies in this field are scarce.
METHODS: We aimed to investigate whether sexual activity negatively influences physiological performance. We conducted a prospective cross over study, which enrolled active players from the first team of a football club in the Israeli Football Premier League during the 2018-19 season. We gathered participants' physiological performance using GPS driven data per match. In addition, we assessed sexual activity the night before using telephone interviews at the end of every match. We used a linear mixed models methodology, accounting for each player as a cluster.
RESULTS: We enrolled 14 participants who participated in 88 football matches. The mean age was 29.7 (±3.8) years and the majority were in permanent relationships for longer than 6 months (78.6%). We identified sexual intercourses the night before the match in 9 (10.2%) cases. The average speed during the match was slower when participants had pre-match intercourse (6.5 *vs.* 6.0 Km/h, P=0.02). The results remained consistent when using linear mixed models analysis adjusted for age, for previous belief that a pre-match sexual intercourse may affect match performance and for player as a cluster (P=0.02, 95% C.I -0.85- -0.07). Other parameters were not associated with pre-match intercourse.
CONCLUSIONS: To the best of our knowledge, this study is the first to show that sexual intercourse the night before a football match may have a negative influence on players' performance.

KEY WORDS: Coitus; Football; Athletic performance

Appendix 5. Participation in scientific congress.



Appendix 6. Participation in scientific congress.

Appendix 7. Knowledge exchange activity.

Appendix 8. Approval of the research project.

University of Central Lancashire
UCLan

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01772 201201
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07 December 2020

David Rhodes / Lukasz Bortnik
School of Sport and Health Sciences
University of Central Lancashire

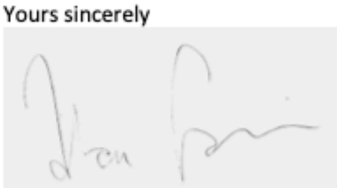
Dear David / Lukasz

Re: Health Ethics Review Panel Application
Unique Reference Number: HEALTH 0104

The Health Ethics Review Panel has granted approval of your proposal application 'Peak physical demands during transitional play in elite soccer'. Approval is granted up to the end of project date. * It is your responsibility to ensure that

- the project is carried out in line with the information provided in the forms you have submitted
- you regularly re-consider the ethical issues that may be raised in generating and analysing your data
- any proposed amendments/changes to the project are raised with, and approved by, the Ethics Review Panel
- you notify EthicsInfo@uclan.ac.uk if the end date changes or the project does not start
- serious adverse events that occur from the project are reported to the Ethics Review Panel
- a closure report is submitted to complete the ethics governance procedures (existing paperwork can be used for this purpose e.g. funder's end of grant report; abstract for student award or NRES final report. If none of these are available, use the e-Ethics Closure Report pro forma).
- As part of your approval please provide the Research Governance Unit regular feedback on the conditions which prevail to ensure the research team are adhering to the regulatory conditions imposed as a result of COVID-19.

Yours sincerely

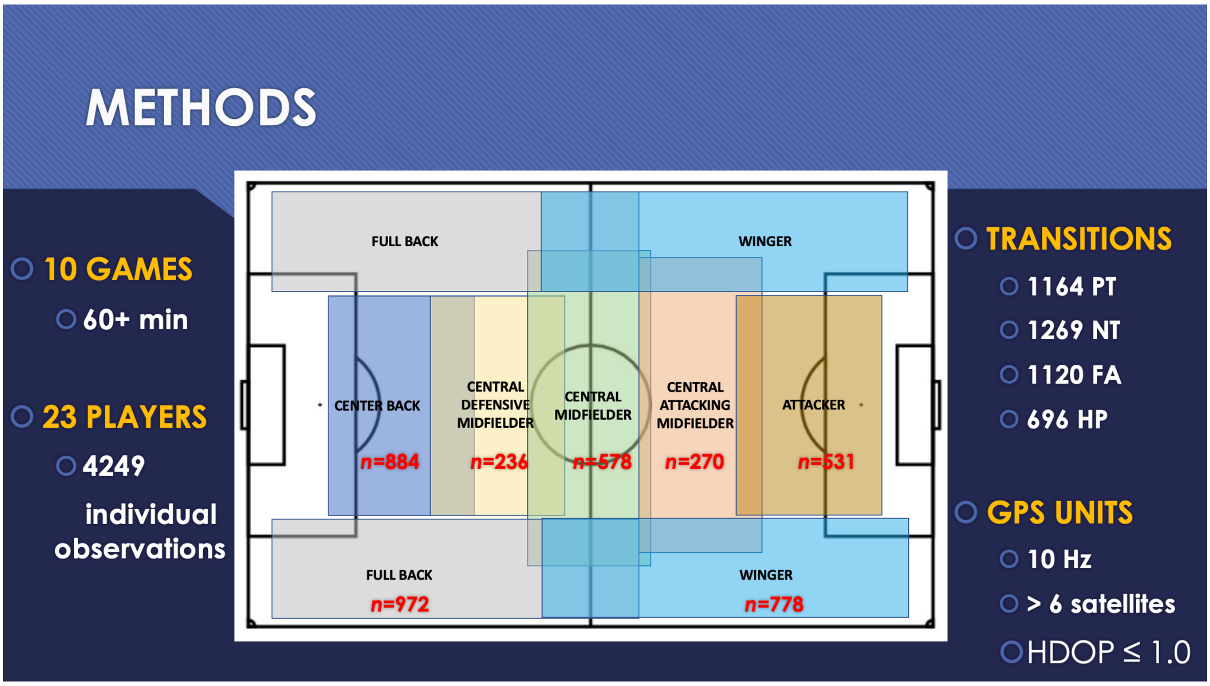


Alan Farrier
Deputy Vice-Chair
Health Ethics Review Panel

* for research degree students this will be the final lapse date

NB - Ethical approval is contingent on any health and safety checklists having been completed and necessary approvals gained as a result.

Appendix 9. Methods used and experimental design.



Appendix 10. Descriptions and definitions of tactical dimensions.

Variable	Definition	Categories
Initial penetration	Degree of offensive directness in the first three seconds of the team possession:	**1. Penetrative action:** passes or dribbles towards the opponent's goal past opponent player (s) performed during the first three seconds of the ball possession [22].
		2. Non-penetrative action: any technical action towards any direction that does not past opponent player (s) performed during the first three seconds of the ball possession.
Initial opponent pressure	Distance between the player/s with the ball (first attackers) and the immediate pressing opponent player(s) (first defender(s)) during the first three seconds of the ball possession.	**1. Initial pressure:** one or several opponent players pressure the attackers within the first 3 seconds of the possession (the defender(s) are always located within 1.5 meters of the first attackers [22].
		2. Non-initial pressure: there are not any players that pressure the attacker (s) during the first 3 seconds of the possession.
Duration of the attack	Duration of the offensive sequence in seconds.	**1. Very short** (0–10 sec).
		2. Short (11–20 sec).
		3. Long (21–30 sec).
		4. Very long (31 or more seconds).
Type of attack	Degree of offensive directness [19, 20, 22, 23] in the offensive process.	**1. Combinative attack:** a)the possession starts by winning the ball in play or restarting the game, b) the progression towards the goal has a high number of non-penetrative and short passes, c)the circulation of the ball takes place more in width than in depth [23] and the intention of the team is to disorder the opponent using a high number of passes and slow tempo (Evaluated qualitatively), d) the opposing team has the opportunity to minimize surprise, reorganize his system and be prepared defensively.
		2. Direct attack: a) the possession starts by winning the ball in play or restarting the game, b) the progression towards the goal is based on one long pass from the defensive players to the forward players (evaluated qualitatively), c) the circulation of the ball takes place more in depth than in width and the intention of the team is to take the ball directly near the goal area to have opportunities of finishing by using a reduced number of passes and high tempo, d) the opposing team has the opportunity to minimize surprise, reorganize his system and be prepared defensively.
		3. Fast attack: a) the possession starts by winning the ball in play or restarting the game, b) the progression towards the goal has a high number of penetrative and short passes, c) the circulation of the ball takes place in width and depth [23] and the intention of the team is to disorder the opponent with a reduced number of passes and high tempo (evaluated qualitatively), d) the opposing team has the opportunity to minimize surprise, reorganize his system and be prepared defensively.
		4. Counterattack: a) the possession starts by winning the ball in play, b) the progression towards the goal attempts to utilize a degree of imbalance right from start to the end with high tempo [19], c) the circulation of the ball takes place more in depth than in width and the intention of the team is to exploit the space left by the opponent when they were attacking, d) the opposing team does not have the opportunity to minimize surprise, reorganize his system and be prepared defensively.

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Note: Adopted from Gonzalez-Rodenas et al., 2020.

Appendix 11. The novel concept of clusters.