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The Chosen One:
Progression to Elite Professional Football through Physical Performance and Participation

by

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MSc Physical Education and Kinesiology
MSc Sport and Exercise Science & Medicine

a doctoral thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy

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Abstract

The transition from youth academy to elite professional soccer represents one of the most selective stages within player development pathways. Despite substantial investment in academy systems and the recent advances in performance monitoring and talent development research, the post-formation phase seems to remain insufficiently understood. While progression has traditionally been attributed to physical and physiological performance, emerging evidence suggests that opportunity and contextual factors also play a critical role. Existing research has predominantly examined isolated components of player development (e.g. physical performance, load monitoring, and talent identification), yet an attempt for an integrated investigation of how structural opportunity, physical readiness, match utilisation, and training exposure interact to influence progression is currently still missing. Therefore, the overarching aim of this thesis was to investigate talent development during the post-formation phase in elite professional soccer by examining the structural, physical, and performance-related factors influencing progression from late-stage academy environments to sustained first-team participation.

This thesis started off by establishing whether or not there truly is a bottleneck in the youth-to-senior transition. Are talented young academy players really offered limited opportunities to progress to the first team compared to newly signed players from outside the club? To answer this question, study 1 examined structural opportunity by analysing longitudinal demographic data across elite European soccer. The findings revealed that club-trained players represented a limited proportion of first-team squads and accumulated relatively low match involvement, with this trend decreasing over time. Interestingly though, a positive association was identified between club-trained player match involvement and team success, suggesting that the integration of academy players does not compromise competitive performance. These findings indicate that opportunity is shaped by organisational strategy rather than constrained by performance demands.

So, why are academy players given less opportunities to be part of a club's first team? Are their performance standards and capacity not up to par compared to their senior peers? Study 2 investigated physical readiness by comparing physiological characteristics and locomotor performance between academy/reserve and senior players within the same professional environment. The results showed that developmental players frequently demonstrated physical outputs comparable to senior players across key performance metrics. While minor differences were observed, these findings suggest that physical readiness alone does not explain progression outcomes and may function as a prerequisite rather than a distinguishing factor.

Study 3 explored match utilisation through the analysis of substitute performance. Players introduced during matches were capable of maintaining or increasing high-intensity output, reinforcing the importance of high-intensity actions in match performance and outcome. Considering the physical comparability observed in Study 2, these findings suggest that physically prepared players may be capable of contributing effectively when provided with match opportunities. As such, an effective strategy of utilizing substitutions can not only increase intensity levels - which in turn can have a positive impact on match outcome – but also provide opportunities of meaningful exposure for academy players to express performance capacity and to gain valuable experience to support continuous development and sustained senior participation.

Finally, study 4 examined training exposure and load distribution across developmental and senior environments. The findings demonstrated clear differences in training structure, with academy environments emphasising overload and development, and senior environments prioritising recovery and performance maintenance. Additional discrepancies were observed between starting and non-starting players, indicating variable and sometimes suboptimal load exposure. These differences suggest that players may transition into senior environments without consistent exposure to the specific demands of elite competition.

In conclusion, progression to elite professional soccer is not determined by physical performance alone. While physical readiness is necessary, it is insufficient in the absence of opportunity to participate and perform. Instead, progression may be shaped by the alignment between physical performance and participation within structurally constrained environments. These findings highlight the importance of integrating performance capacity with meaningful competitive exposure to support player development during the post-formation phase.

Table of Contents

Abstract 2
Table of Contents 5
List of Tables 10
List of Figures 11
Acknowledgement 13
Author's Declaration 15
List of Abbreviations 16
Chapter 1: Introduction 18
1.1 Historical Development of Sports Science in Soccer 18
1.2 Performance Monitoring in Elite Soccer 22
1.3 Physical and Physiological Standards:
What Does the Game Require Today 25
1.4 Load Management Strategies 29
1.5 Transition Challenges in the Post-Formation Phase 32
1.6 Rationale for the Present Thesis 35
1.7 Aims of the Present Thesis 38
Chapter 2: Methodology 39
2.1 Methodological Approach 39
2.2 Study Design 39
2.3 Study Environment 40
2.3.1 Academy and Reserve Environment 41
2.3.2 First Team Environment 41
2.4 Participants 42
2.5 Measurements 43
2.5.1 Anthropometrics and Body Composition 43
2.5.2 Aerobic Fitness Testing 44
2.5.3 External Load and Performance 45
2.5.3.1 Global Positioning System (GPS) Technology 45
2.5.3.2 External Load Metrics 46
2.5.3.3 Peak Metabolic Power 47

2.5.3.4 Internal Load and Subjective Measures 47
2.6 Statistical Analyses 48
2.7 Summary 49
Chapter 3, Study 1:
Youth-to-Senior Transition in Elite European Club Soccer 50
3.1 Abstract 51
3.2 Introduction 52
3.3 Methods 54
3.3.1 Protocol 54
3.3.2 Analysis 54
3.4 Results 55
3.4.1 Demography of Players 55
3.4.2 Match Time 56
3.4.3 Match Day Squad 56
3.4.4 Regional Differences 57
3.4.5 Top 5 Leagues 58
3.5 Discussion 60
3.5.1 Financial Power 61
3.5.2 Strategies to Protect and Promote Young Players 61
3.5.3 Player Quality 62
3.5.4 Limitations 63
3.5.5 Conclusions 64
3.5.6 Conflicts of Interest 64
3.6 References 65
Chapter 4, Study 2:
Physical Profiling in Elite Professional Men's Soccer: Different Physical Fitness but Comparable Physical Performances Between Academy, Reserve and First Teams 70
4.1 Abstract 71
4.2 Introduction 72
4.3 Materials and Methods 74
4.3.1 Participants 74
4.3.2 Study Design 74

4.3.3 Anthropometry and Physical Fitness 75
4.3.4 Training 76
4.3.5 Match 77
4.3.6 Age-Dependent Effects 77
4.3.7 Analysis of Successful Former Academy Players 78
4.3.8 Statistical Analysis 78
4.4 Results 80
4.4.1 Player Characteristics 80
4.4.2 Physical Performance: Training 84
4.4.2.1 Distance 84
4.4.2.2 Speed 84
4.4.2.3 HR 85
4.4.3 Physical Performance: Match 85
4.4.3.1 Distance 85
4.4.3.2 Speed 85
4.4.4 Physical Performance: Training versus Match 85
4.4.5 Age-Dependent Effects 86
4.4.6 Current versus Former Academy Players 87
4.5 Discussion 89
4.5.1 Physical Profiling 89
4.5.2 Physical Performance in Training and Match 90
4.5.3 Subgroups..... 91
4.5.4 Limitations 92
4.5.5 Practical Applications 93
4.6 Conclusions 95
4.7 References 96
Chapter 5, Study 3:
Substitutions in Professional Elite Soccer Increase Distance and High-Intensity Efforts 102
5.1 Abstract 103
5.2 Introduction 104
5.3 Materials and Methods 106
5.3.1 Experimental Approach to the Problem 106

5.3.2 Subjects 106
5.3.3 Procedures 107
5.3.3.1 Player Characteristics and Fitness 107
5.3.3.2 Match Observations 108
5.3.3.3 Data Analysis 109
5.3.4 Statistical Analysis 110
5.4 Results 110
5.5 Discussion 115
5.6 Practical Applications 119
5.7 Acknowledgements 120
5.8 References 121
Chapter 6, Study 4:
Mind The Gap: Comparison of External Load and Load Variation Between a Reserve Team in a One-Game Week Microcycle and its First Team in a Two-Game Week Microcycle within an Elite Professional Soccer Club 128
6.1 Abstract 129
6.2 Introduction 130
6.3 Methods 132
6.3.1 Experimental Approach to the Problem 132
6.3.2 Subjects 132
6.3.3 Procedures 133
6.3.3.1 External Load 133
6.3.3.2 First Team Microcycle 134
6.3.3.3 Reserve Team Microcycle 135
6.3.4 Statistical Analysis 136
6.4 Results 136
6.5 Discussion 143
6.5.1 Weekly External Load 143
6.5.2 Within-Week Load Variation 144
6.5.3 Training Monotony 146
6.5.4 Limitations 146
6.6 Practical Applications 147
6.7 Acknowledgements 147

6.8 References 148
Chapter 7: Discussion 154
7.1 Overview of Key Findings 154
7.2 Constraints on Transition:
Structural, Physical and Contextual Factors 155
7.3 Integration: The Post-Formation Bottleneck 158
7.4 Limitations 159
7.5 Practical Applications 160
7.6 Future Research 161
7.7 Conclusion 162
8. List Of References 164

List of Tables

Table 1 Minimum (Min)-maximum (Max) range of match fielding of club-trained players (CTP), expatriates (EXP), and new signings (NS) in Europe's 5 highest rated leagues between 2010-2017 59
Table 2 Player characteristics of elite academy under-18 (U18) and reserve (RES) teams and first team (FT) 81
Table 3 Physical performance during training in elite academy under-18 (U18) and reserve (RES) teams and first team (FT) 82
Table 4 Physical performance during match in elite academy under-18 (U18) and reserve (RES) teams and first team (FT) 83
Table 5 Age-specific physical performance during match in elite academy under-18 (U18) and reserve (RES) teams and first team (FT) 87
Table 6 Former elite academy players that transitioned to first team versus current academy players 88
Table 7 Player characteristics 107
Table 8 Player characteristics of those that play full matches and appear in substitutions 112
Table 9 Typical weekly microcycles for first-team starters, first-team non-starters and reserve-team players 135
Table 10 Weekly cumulative external training load for first-team starters, first-team non-starters and reserve-team players 138
Table 11 Daily external training load for first-team starters, first-team non-starters and reserve-team players 141
Table 12 Training monotony for first-team starters, first-team non-starters and reserve-team players 142

List of Figures

Figure 1 Definitions and relations of the terminology on the categorization of senior players 53
Figure 2 Proportion (%) of senior players per calendar year according to their categorization 55
Figure 3 Graphic representation of the average proportions of senior players during a typical match day squad in elite European soccer, with representative starting 11 and substitute players on the pitch and sideline, respectively 57
Figure 4 Proportion of senior players in Europe's 5 highest rated leagues in 2020 58
Figure 5 Relationship and Spearman Rank correlation between club-trained player (CTP) match involvement and club performance in national league 60
Figure 6 Study design with teams and sub-cohort analyses including player positions, and timings of data capture periods 75
Figure 7 Physical performance in match versus training following comparison of training data in Table 4 versus match data in Table 5 86
Figure 8 Substitution frequencies according to player position and time of substitution; A: substitutions into match (Sub-in); B: substitutions out of match (Sub-out, replaced players) 111
Figure 9 Relative distance in match; A: comparison between players that played full duration of match (Full), players that were substituted out of match (Sub-Out, replaced) and players that were substituted into match (Sub-In) in team and player positions; B: comparison between Full, Sub-Out and Sub-In players in home and away matches 112
Figure 10 Repeated high-intensity efforts in match; A: comparison between players that played full duration of match (Full), players that were substituted out of match (Sub-Out, replaced) and players that were substituted into match (Sub-In) in team and player positions; B: comparison between Full, Sub-Out and Sub-In players in home and away matches 113

Figure 11 Peak metabolic power in match; A: comparison between players that played full duration of match (Full), players that were substituted out of match (Sub-Out, replaced) and players that were substituted into match (Sub-In) in team; B: comparison between Full, Sub-Out and Sub-In players in home and away matches 114
Figure 12 Impact of substitutions on match score; A: per match; B: per individual substitution; C: per individual substitution in different epochs of match 115
Figure 13 Daily external TL plotted as weekly external TL trend lines for first-team starters, first-team non-starters and reserve-team players within their respective weekly microcycles 139

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Thomas

Author's Declaration

I declare that this thesis is the result of my own original work and has not been submitted for any other degree at the University of Glasgow or any other institution.

This thesis consists of the following four original studies – all of which have been published in PubMed-indexed peer-review discipline research journals:

- Study 1: Carpels, T., Scobie, N., MacFarlane, N. G., & Kemi, O. J. (2021). Youth-to-Senior transition in elite European club soccer. *International Journal of Exercise Science*, *14*(6), 1192.

- Study 2: Carpels, T & Kemi, O.J. (2026) Physical Profiling in Elite Professional Men's Soccer: Different Physical Fitness but Comparable Physical Performances Between Academy, Reserve and First Teams. *Open Access Journal of Sports Medicine*, *17(1)*, 2697533.

- Study 3: Carpels, T., Kelly, S., & Kemi, O. J. (2026). Substitutions in professional elite soccer increase distance and high-intensity actions. *The Journal of Strength & Conditioning Research*, 10-1519.

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List of Abbreviations

ANOVA	Analysis of Variance
ATP	Association-Trained Player
AU	Arbitrary Units
bpm	beats per minute
CB	Center Back
CF	Center Forward
CI	Confidence Interval
CIES	International Centre for Sports Studies
CM	Center Midfielder
CTP	Club-Trained Player
DBT	Debutant
DM	Defensive Midfielder
DXA	Dual-Energy X-Ray Absorptiometry
ES	Effect Size
EXP	Expatriate
FB	Full Back
FT	First-Team Player
GK	Goalkeeper
GNSS	Global Satellite Navigation System
GPS	Global Positioning System
HDOP	Horizontal Dilution of Precision
HGP	Home-Grown Player
HR	Heart Rate
HR_{max}	Maximal Heart Rate
HS	High Speed
HSD	High-Speed Distance
Hz	Hertz
ICC	Intraclass Correlation Coefficients
IFT	Intermittent Fitness Test
MD	Match Day

MEMS	Micro-Electro-Mechanical Systems
NS	New Signing
NST	Non-Starter
OM	Offensive Midfielder
RES	Reserve-Team Player
RHIE	Repeated High-Intensity Efforts
RPE	Rating of Perceived Exertion
SD	Standard Deviation
SpD	Sprint Distance
ST	Starter
TD	Total Distance
TEM	Technical Error of Measurements
THSD	Total High-Speed Distance
TM	Training Monotony
TRIMP	Training Impulse
U18	Under-18s Player
U19	Under-19s Player
UEFA	Union of European Football Association
V_{IFT}	Maximal Velocity Intermittent Fitness Test
VO_{2max}	Maximal Oxygen Uptake
W	Offensive Winger

Chapter 1: Introduction

1.1 Historical Development of Sports Science in Soccer

Association football or soccer has evolved from a recreational pastime into one of the most physically, tactically, and commercially demanding professional sports worldwide. Alongside this transformation, sports science has become increasingly embedded within elite soccer environments, shaping how performance is understood, measured, and developed. The evolution of sports science within soccer reflects broader changes in the professionalisation of the sport, technological advancements, and an increasing emphasis on evidence-based performance optimisation. This chapter aims to provide the scientific and contextual foundation for understanding performance standards and player development in elite soccer, with a special focus on young player development and progression from academy to first team, ultimately leading to the research aims of this thesis.

Prior to the extensive integration of sports science, performance in soccer was largely evaluated subjectively through observational coaching and descriptive match reporting. Coaches traditionally evaluated player readiness based on technical execution, perceived effort and tactical adherence, with limited quantitative measurement of physical workload. Early academic investigations of soccer performance were limited and primarily focused on physiological profiling outside field of play, particularly aerobic fitness characteristics of players measured in a laboratory or gym or on the field in a non-match context. Early physiological monitoring methods included laboratory-based assessments of aerobic fitness, such as maximal oxygen uptake (VO_2max) and one-repetition maximum (1RM) strength testing as well as isolated field fitness tests measuring endurance capacity (Reilly, 2001). While these methods provided valuable information regarding physical performance and capacity, they offered limited insight into the actual demands experienced during training and competition. Additionally, during the mid to late twentieth century, soccer was predominantly characterised as an endurance-based sport due to the continuous nature of match play and the substantial distances covered by players during competition (Reilly, 1976; Bangsbo, 1994b). Early research

in locomotive demands demonstrated that elite players typically covered between 8 and 11 kilometres per match, leading to the assumption that aerobic endurance represented the primary determinant of performance capacity (Reilly, 1976; Ekblom, 1986). This view was further strengthened by the finding that average VO2max in teams correlated with end-of-season league standing for the same teams, first observed in Hungarian top division football (Apor 1988) and later in other leagues as well (Wisløff et al., 1998).

However, while these early studies provided foundational insights into the energetic demands of soccer, they largely overlooked the intermittent nature of the sport, which would later emerge as a defining characteristic of elite performance. One of the earliest attempts to objectively quantify match demands was through manual time-motion analysis. Researchers recorded player movements and categorised locomotor activities into intensity zones using video-based observation (Reilly & Thomas, 1976). Although pioneering, these methods were labour-intensive and prone to observer bias and low temporal resolution, limiting their practical application in elite performance environments (Reilly & Thomas, 1976). Despite these limitations, early time-motion studies highlighted the intermittent nature of soccer performance by recording frequent transitions between walking, jogging, running, and sprinting. This contributed to a paradigm shift towards recognising soccer as an intermittent high-intensity sport, forming the foundation for later technological and methodological advancements (Bangsbo et al., 2006).

From the late 1980s onwards, advances in physiological testing and match analysis technologies facilitated a more nuanced understanding of soccer performance demands. Research performed during this period demonstrated that, although the total distance covered during matches remained relatively stable, decisive match events were often associated with brief, high-intensity actions such as sprinting, accelerations, decelerations, and changes of direction (Bangsbo, 1994c; Mohr et al., 2003). These findings challenged earlier notions of soccer as a predominantly endurance-based sport and contributed to the recognition of soccer as an intermittent high-intensity sport requiring both aerobic and anaerobic energy system contributions. Bangsbo and colleagues were particularly influential in redefining the

physiological profile of soccer players, demonstrating that elite match play consisted of repeated bouts of high-intensity running interspersed with periods of lower intensity activity (Bangsbo et al., 2006). Subsequent studies further highlighted the importance of repeated sprint ability, neuromuscular power, and metabolic efficiency as key performance determinants (Rampinini et al., 2007; Mohr et al., 2003). This shift in understanding directly influenced training methodologies, leading to the incorporation of high-intensity interval training, sided games, and sport-specific conditioning practices designed to replicate match demands more accurately (Iaia & Bangsbo, 2010).

The late twentieth and early twenty-first centuries witnessed rapid professionalisation across elite soccer, driven by increasing commercial revenues, global broadcasting expansion, and intensified competitive demands (Giulianotti, 1999; Poli et al., 2018b; Nassis et al., 2020). The emergence of specialised performance departments within professional clubs became increasingly common, integrating expertise from strength and conditioning, physiology, sports medicine, biomechanics, psychology, and performance analysis (Carling et al., 2012a; Nassis et al., 2020). This multidisciplinary approach facilitated the systematic monitoring of player development and performance, allowing clubs to adopt evidence-informed training strategies aimed at maximising competitive success while mitigating injury risk. Parallel to this organisational evolution, sports science research in soccer expanded substantially, supported by improved collaboration between academic institutions and professional clubs (Fullagar et al., 2019). Consequently, sports science transitioned from a descriptive discipline to a performance-driven field focused on applied practice.

Perhaps the most transformative advancement in modern soccer sports science has been the introduction of electronic performance tracking systems, particularly wearable athlete monitoring technologies. The widespread adoption of global positioning system (GPS) and global navigation satellite system (GNSS) tracking devices during the early 2000s revolutionised match and training analysis by providing objective, high-frequency locomotor data (Cummins et al., 2013). These

technologies enabled practitioners to quantify external load variables such as total distance covered, high-speed running distance, sprint frequency, and acceleration profiles with unprecedented accuracy. The integration of micro-electromechanical systems (MEMS) accelerometers further expanded monitoring capabilities by capturing multidirectional movement and providing estimates of neuromuscular load (Akenhead & Nassis, 2016). Additionally, optical tracking systems enabled high-resolution positional data during matches (Linke et al., 2018). Collectively, these technologies have enabled more precise quantification and contextual interpretation of performance demands in elite soccer.

1.2 Performance Monitoring in Elite Soccer

In modern elite soccer, the need for accurate and reliable performance monitoring has become increasingly central to both practice and applied research. The introduction of tracking technologies has transformed performance monitoring from descriptive observation to data-driven workload quantification based on objective external load metrics. External load refers to the objective physical work performed by an athlete, typically quantified through locomotor and mechanical variables derived from tracking technologies (Vanrenterghem et al., 2017; Impellizzeri et al., 2019). Commonly measured external load metrics in soccer include total distance covered, high-speed running distance, sprint frequency, acceleration and deceleration counts, and relative workload expressed as distance per unit time (Cummins et al., 2013; Malone et al., 2017). External load monitoring provides valuable insight into training stimulus, match intensity, and player exposure to physical stress. These metrics have been widely used to describe positional demands, compare competitive levels, and identify training benchmarks required for elite performance (Bradley et al., 2009; Bush et al., 2015). However, external load metrics do not directly reflect physiological strain or individual responses to training stimulus. Players exposed to identical external workloads may experience substantially different levels of fatigue or adaptation depending on individual fitness levels, recovery capacity, and psychological state. This highlights a key limitation of relying solely on external load data, particularly when interpreting training effectiveness and readiness.

Internal load represents the physiological and perceptual responses to external workload. Common internal load metrics include heart rate monitoring, blood lactate concentration, hormonal markers, and subjective measures such as rating of perceived exertion (RPE) (Impellizzeri et al., 2005; Foster et al., 2001). Heart rate monitoring is widely used in soccer due to its practicality and ability to reflect cardiovascular strain during exercise, with training impulse (TRIMP) models providing quantification of internal load over time (Banister, 1991). Session-RPE has gained widespread popularity as a simple and cost-effective method for estimating internal load across various sports. This method requires athletes to provide a subjective

rating of activity intensity, which is multiplied by session duration to produce an overall load score (Foster et al., 2001). Session-RPE has demonstrated strong correlations with heart rate-based load metrics and is particularly valuable in capturing perceived effort levels and psychological stress that may not be reflected by physiological metrics alone (Haddad et al., 2017). Importantly, subjective measures may capture aspects of athlete readiness that are not detectable through objective monitoring alone, further supporting their inclusion within integrated monitoring systems.

The concept of integrating external and internal load monitoring has become central to contemporary sports science practice, providing a multidimensional representation of training stress and adaptation. Impellizzeri et al. (2005) proposed a conceptual framework distinguishing between training input (external load) and athlete response (internal load), highlighting the importance of evaluating both components when assessing training effectiveness. This integrated perspective allows practitioners to identify mismatches between prescribed load, actual performance and individual response, which may have implications for both performance adaptation and injury risk.

Load monitoring frameworks have also been applied to injury risk management. Research has demonstrated associations between sudden increases in training load and elevated injury risk, leading to the development of models such as the acute:chronic workload ratio (ACWR) (Gabbett, 2016). While such models have gained widespread popularity in applied settings, their methodological limitations and predictive validity remain debated, with recent research cautioning against their use as standalone decision-making tools (Impellizzeri et al., 2020). In addition to traditional distance-based metrics, recent research has introduced alternative models for estimating energetic demands during soccer performance. The metabolic power approach, proposed by di Prampero et al. (2005), estimates energy expenditure by equating accelerated running on flat terrain to running uphill at constant speed. This model allows practitioners to estimate the energetic cost of accelerations and decelerations, which are not fully captured by distance metrics alone. Subsequent research has demonstrated that metabolic power provides

additional insight into high-intensity activity patterns and energy expenditure during intermittent sports (Osgnach et al., 2010; Gaudino et al., 2013). However, these estimates are sensitive to measurement error and rely on several modelling assumptions, and should therefore be interpreted as complementary rather than definitive indicators of metabolic demand. Despite this however, when metabolic power measurements have been appropriately conducted and interpreted, they have provided important information that at least partly explains the locomotion patterns and kinetics observed during soccer training and matches.

Taken together, the integration of external and internal load monitoring within applied performance frameworks has substantially enhanced the ability to quantify the physical and physiological demands of elite soccer. Additionally, the identification of contemporary performance standards provides benchmarks that are essential for designing effective player development strategies. Nevertheless, it remains unclear whether developing players are consistently exposed to these demands prior to transition to senior competition, highlighting an important area for further investigation. To understand these demands more precisely, it is necessary to examine the physical and physiological requirements of modern elite soccer in greater detail.

1.3 Physical and Physiological Standards: What Does the Game Require Today?

Modern elite soccer is characterised by complex and highly variable physical demands that reflect the dynamic and intermittent nature of the game. While early conceptualisations emphasised total running distance and aerobic endurance as primary indicators of performance capacity, contemporary research informed by the increased ability to measure physical capacity and performance outputs, has demonstrated that success in elite soccer depends on the ability to repeatedly perform high-intensity actions within an aerobic framework (Reilly, Bangsbo & Franks, 2000; Bangsbo, Mohr & Krustrup, 2006; Faude, Koch & Meyer, 2012; Bradley et al., 2014). As competitive standards have increased, physical demands have become progressively more complex, with implications for player development, performance monitoring, and training prescription.

Elite soccer players typically cover between 9 and 13 kilometres during competitive matches (as opposed to earlier estimations of 8-11 km; Reilly, 1976; Ekblom, 1986), although total distance covered may vary according to playing position, tactical system, competition level, and contextual match factors (Bangsbo et al., 2006; Bradley et al., 2009; Carling et al., 2008). While total distance remains an important descriptive metric, it provides limited insight into the physiological and mechanical stress experienced by players. Modern performance analysis therefore emphasises the distribution of movement intensities throughout matches, particularly the frequency and volume of high-speed running and sprinting actions, which are widely considered decisive components of elite performance (Mohr et al., 2003; Rampinini et al., 2007). High-intensity running is commonly registered when running at velocities exceeding an absolute threshold of 19.8 $km \cdot h^{-1}$, while sprinting is often classified at velocities exceeding 25 $km \cdot h^{-1}$, although thresholds may vary across studies (Di Salvo et al., 2007; Malone et al., 2017; Gualtieri et al., 2023). Approximately 10–30% of the total distance a player covers during match play is performed at high-intensity running velocities (Mohr et al., 2003; Bradley et al., 2009). Additionally, elite players typically perform 150–250 high-intensity actions during matches, including accelerations, decelerations, changes of direction, and sprint efforts (Varley & Aughey, 2013; Akenhead et al., 2016). Importantly, these

actions often occur during match-defining moments such as goal-scoring opportunities, defensive recoveries and transitional play, highlighting their disproportionate influence on match outcomes relative to their overall duration (Faude et al., 2012). Repeated high-intensity efforts place substantial neuromuscular and metabolic stress on players, requiring both anaerobic energy production and rapid aerobic recovery between efforts (Iaia & Bangsbo, 2010). Consequently, modern soccer performance is characterised by the integration of aerobic capacity, anaerobic power, and neuromuscular efficiency, rather than reliance on a single physiological attribute.

From a physiological perspective, elite soccer requires sustained aerobic energy production combined with frequent anaerobic bursts. Aerobic metabolism supports prolonged match participation and facilitates recovery between high-intensity actions, while anaerobic pathways provide the energy required for explosive movements such as sprinting, tackling, and jumping (Bangsbo, 1994a). VO_2max has historically been considered a key indicator of soccer-specific aerobic fitness. Elite players typically demonstrate VO_2max values between 55 and 70 $mL \cdot kg^{-1} \cdot min^{-1}$, reflecting high aerobic capacity relative to the general population (Helgerud et al., 2001). Higher aerobic fitness has been associated with improved high-intensity running performance, enhanced recovery capacity, and increased match involvement (Krustrup et al., 2005). However, contemporary research recognises that aerobic fitness alone does not fully explain performance variability, and that repeated sprint ability, anaerobic capacity, and neuromuscular power are equally critical determinants of match performance (Rampinini et al., 2007). Neuromuscular demands have received increasing research attention due to the high frequency of accelerations, decelerations, and changes of direction observed in modern soccer. These movements generate substantial mechanical loading and are associated with increased muscle damage and fatigue accumulation (Varley & Aughey, 2013). Consequently, strength and power development have become integral components of elite soccer training programmes to enhance performance robustness and reduce the risk of injury.

It is important to stress that physical demands in soccer are strongly influenced by playing position and tactical responsibilities. Midfield players generally cover the greatest total distance during matches due to their involvement in both offensive and defensive phases of play, whereas wide players and full backs often perform the greatest volumes of high-speed running and sprinting due to their roles in wide attacking transitions and defensive recovery (Di Salvo et al., 2007; Bradley et al., 2009; Rampinini et al., 2007; Barnes et al., 2014; Bradley & Ade, 2018). Central defenders typically perform fewer high-speed actions but engage in greater volumes of accelerations, decelerations, and aerial duels, reflecting position-specific tactical requirements (Bush et al., 2015; Harper et al., 2019; Tierney et al., 2016). In addition to positional variability, tactical systems and playing styles significantly influence physical output. Teams employing high pressing or high-possession strategies typically demonstrate increased high-intensity running volumes, reflecting greater tactical demands for rapid ball recovery and attacking transitions (Bradley et al., 2013). Similarly, match context, including scoreline, opponent quality, and match location, can alter physical performance, with players often demonstrating increased high-intensity activity during losing scenarios or home matches where attacking intensity is typically desired (Lago-Peñas & Dellal, 2010; Castellano et al., 2011). These contextual factors further reinforce the complexity of interpreting physical performance data in elite soccer.

Several longitudinal investigations have demonstrated that elite soccer has become progressively more physically demanding over recent decades. Analyses of professional European leagues have shown substantial increases in high-speed running distance, sprint frequency, and peak running speeds, despite relatively stable total match distances (Barnes et al., 2014; Bush et al., 2015). These trends are believed to reflect tactical evolution towards faster transition-based playing styles, improved physical conditioning practices, and advances in player monitoring technologies. Notably, research examining English Premier League match data across multiple seasons reported increases of approximately 30–50% in high-intensity running distances over a ten-year period (Barnes et al., 2014). Similar trends have been observed across other elite European competitions, indicating that the escalation of match demands represents a widespread phenomenon rather than

competition-specific change. These developments have direct implications for player development, as emerging players must be prepared to meet increasingly demanding physical standards upon transition to senior competition.

Finally, adding to the already increased demands of match play, professional soccer is characterised by congested competition schedules, particularly for teams participating in multiple domestic and international tournaments. Elite players may be required to compete in two or more matches per week during congested periods, reducing recovery time and increasing cumulative fatigue exposure (Dupont et al., 2010). Fixture congestion has also been associated with reduced high-intensity performance, increased injury risk, and alterations in training periodisation strategies (Dellal et al., 2015; Nassis et al., 2020). Training programmes must therefore balance the competing demands of performance preparation, recovery management, and long-term physical development.

1.4 Load Management Strategies

Given the increasing physical demands outlined in the previous section, effective management of training and match load has become a critical component of performance optimisation in elite soccer. Building on training load monitoring frameworks, effective load management strategies are required to ensure players are prepared to meet match demands. The most common and well-known strategy of effective load management is periodization. Periodization represents a central organising principle within modern sports science and refers to the systematic planning, sequencing, and manipulation of training load to optimise performance, facilitate physiological adaptation, and minimise fatigue and injury risk over time (Bompa & Buzzichelli, 2019; Issurin, 2010). In elite soccer, periodization has evolved from traditional linear models derived from individual sports toward more flexible and context-driven frameworks that reflect the intermittent, unpredictable, and competition-dense nature of team sports (Kiely, 2012). Rather than following rigid long-term phases, periodization in soccer is predominantly structured around short-term weekly microcycles aligned with competitive match schedules.

The microcycle, typically representing a 7-day training week, forms the fundamental unit of periodization in professional soccer. Within a standard one-game-per-week schedule, microcycles are generally organised to balance recovery, overload, and tapering phases. The day immediately following competition (MD+1) is typically dedicated to recovery strategies, including low-intensity activity, mobility work, and regenerative interventions aimed at restoring physiological homeostasis (Nédélec et al., 2012). Subsequent days (MD+2 to MD-3/MD-4) are often characterised by progressive increases in training load, with targeted sessions designed to stimulate aerobic, neuromuscular, and tactical adaptation. These so-called acquisition sessions frequently represent the highest external load exposure of the week and are strategically positioned to maximise training stimulus while allowing sufficient recovery before the next competition (Malone et al., 2015; Anderson et al., 2016). In the days leading up to competition (MD-2 and MD-1), training load is typically reduced in a tapering approach aimed at minimising fatigue and optimising performance readiness (Bosquet et al., 2007). In contrast, elite teams competing in

congested fixture schedules - often involving two or more matches per week - operate under substantially different constraints. In these contexts, the microcycle is compressed, and the opportunity to implement high-load acquisition sessions is limited. Instead, training emphasis shifts toward recovery, tactical preparation, and match readiness, with reduced training volumes and increased reliance on recovery strategies (Dellal et al., 2015; Nassis et al., 2020). Consequently, high-potential players aiming to transition permanently from academy to senior environments may experience elevated cumulative match loads combined with insufficient opportunities for targeted physical development. This distinction between one-game and multi-game microcycles is particularly relevant when considering developmental environments, where training structure may prioritise long-term adaptation over short-term performance.

Among the various load monitoring strategies, the ACWR has gained considerable attention as a tool for quantifying changes in training load over time. The ACWR compares short-term (acute) workload, typically calculated over one week, with longer-term (chronic) workload, often represented as a rolling average over three to four weeks (Gabbett, 2016). Conceptually, the model aims to identify rapid increases in workload that may exceed an athlete's capacity to absorb this and thereby increase the risk of injury. Empirical studies have suggested that maintaining an optimal balance between acute and chronic loads may reduce injury likelihood, with both underloading and excessive spikes associated with increased risk (Malone et al., 2017). However, the ACWR has also been subject to increasing methodological criticism. Concerns have been raised regarding its statistical properties, sensitivity to calculation methods, and oversimplification of complex load–injury relationships (Impellizzeri et al., 2020). As a result, while the ACWR remains widely used in applied practice, it is increasingly viewed as a heuristic rather than a definitive predictive model.

In addition to load magnitude and fluctuation, the distribution of training load across time has been identified as an important factor influencing both performance adaptation and injury risk. Training monotony, defined as the ratio between mean daily load and its standard deviation across a given period, reflects the degree of

variability in training stimuli (Foster, 1998). High training monotony indicates relatively uniform daily loads with limited variation, which has been associated with increased physiological strain and injury risk (Foster, 1998; Andrade et al., 2020). Conversely, greater variability in training load - characterised by fluctuations between high- and low-intensity days - is thought to promote more favourable adaptation by balancing overload and recovery within the microcycle. Importantly, monotony provides complementary insight to workload ratios such as ACWR by capturing how load is distributed, rather than simply how much load is accumulated.

Ultimately, an effective periodization structure needs to be tailored to suit each player - one size does not fit all. For practitioners, this is where things get both challenging and interesting, since they need to consider two critical discrepancies. The first one is balancing collective training structures with individual player needs. Team-based training is inherently collective, driven by tactical objectives and logistical constraints, yet individual players experience markedly different physical exposures depending on match involvement, positional demands, fitness status, and injury history. For example, starting players in a congested schedule may accumulate substantial match loads but engage in relatively low training volumes, whereas non-starting players may experience insufficient match exposure and rely on compensatory training sessions to maintain fitness (Carling et al., 2012b). These compensatory sessions often attempt to replicate match demands but may not fully reproduce the contextual and physiological complexity of competitive match play. Consequently, modern performance practice increasingly emphasises individualised load prescription within a collective framework. Secondly, practitioners need to consider players being subject to different periodization structures between different teams. This might be the case for high-potential academy players transitioning into senior squads, where developmental environments prioritise physical adaptation while senior environments prioritise performance and recovery. This discrepancy in load exposure and periodization structure represents a critical challenge within the post-formation phase.

1.5 Transition Challenges in the Post-Formation Phase

Building on the differences in performance demands and load management strategies between developmental and senior environments, how do evolving demands and load management strategies affect players transitioning from academy to senior soccer? Despite substantial investment in academy structures worldwide, the transition from youth development programmes to sustained elite senior participation remains highly selective and complex. Only a small proportion of these players ultimately achieve professional status, and an even smaller percentage progress to sustained participation at elite levels. This disparity reflects the pyramidal structure of elite sport systems, where increasing performance standards and limited opportunities create significant attrition.

While early academy development has received substantial research attention, increasing emphasis has been placed on the so-called post-formation phase, a practical term used in the present thesis to describe the extended developmental period following formal academy training, typically occurring during late adolescence and early adulthood (approximately 17-23 years), as players progress from youth development environments towards senior professional soccer. Although broadly associated with this age range, the post-formation phase is defined primarily by progression beyond formal academy formation rather than chronological age alone. Unlike the youth-to-senior transition, which describes the process of entering senior competition, the post-formation phase refers to the broader developmental period during which athletes continue to adapt after that transition. This developmental period is widely considered one of the most critical stages in elite soccer development pathways (Dugdale et al., 2021). During the post-formation phase, players must adapt to increased training intensity, tactical complexity, physical demands, and psychological pressure associated with professional competition. Additionally, players often experience reduced organisational support compared with earlier developmental stages, as clubs prioritise immediate performance outcomes at the senior level. These combined challenges contribute to high attrition rates and establish the youth-to-senior transition as a critical bottleneck in professional soccer development systems.

As performance standards in elite soccer continue to increase, academies face growing pressure to prepare players capable of meeting the physical, technical, and tactical requirements of senior competition. Research suggests that late-stage academy players must demonstrate performance characteristics comparable to senior players to achieve successful progression (Houtmeyers et al., 2021). Physical development represents a particularly important component of readiness. Players must possess sufficient aerobic capacity, neuromuscular capabilities, and high-intensity performance ability to sustain match demands and compete effectively. Players lacking sufficient physical capacity may struggle to meet these demands, reducing selection opportunities and increasing the likelihood of deselection. However, research also indicates that academy players may demonstrate comparable match performance outputs to senior players despite differences in physiological capacity, suggesting that readiness involves complex interactions between physical capacity, tactical behaviour, and match context (Buchheit et al., 2010; Bradley et al., 2013. This highlights that progression is not solely determined by physical performance, but by the interaction between multiple performance domains.

In addition to physical demands, transition requires substantial tactical and cognitive adaptation. Players must interpret tactical instructions, adapt to dynamic match scenarios, and perform under increased psychological pressure (Morgans et al., 2023). Research suggests that tactical awareness and decision-making ability are key determinants of successful transition (Relvas et al., 2010). While individual development is critical, organisational structures strongly influence transition opportunities. Senior teams operate in performance-driven environments where coaches prioritise immediate success, often limiting opportunities for academy graduates. Match exposure is one of the most influential factors determining transition success, with competitive match play providing exposure to intensity, tactical complexity, and psychological pressure that cannot be replicated in training (Ericsson et al., 1993). Conversely, limited match exposure may delay adaptation and increase the risk of deselection. Despite strategies such as squad rotation during congested schedules and in-game substitution interventions, young players typically receive limited playing time during early senior careers.

To address transition challenges, clubs have implemented intermediate pathways such as reserve teams and loan systems. While these provide opportunities for development, their effectiveness varies depending on context and support (Bridgewater et al., 2011). Nevertheless, these pathways may not fully bridge the gap between academy and senior demands. The youth-to-senior transition can therefore be conceptualised as a bottleneck resulting from the interaction between increasing performance standards, limited opportunities, and multidimensional developmental demands. Despite growing recognition of this phase, empirical research examining how these factors interact remains limited. This reinforces the need for integrated investigation of structural opportunity, physical readiness, match utilisation, and training exposure within elite soccer environments.

1.6 Rationale for the Present Thesis

Given the complex interaction between increasing performance demands, load management constraints, and limited developmental opportunities outlined in the previous sections, the overarching aim of this thesis was to investigate talent development during the post-formation phase in elite professional soccer by examining the structural, physical, and performance-related factors influencing progression from late-stage academy environments to sustained first-team participation. Despite advances in performance monitoring and talent development research, the post-formation phase remains insufficiently understood.

Existing research has predominantly examined isolated components of player development (e.g. physical performance, load monitoring, and talent identification), with limited integration of how (1) structural opportunity, (2) physical readiness, (3) match utilisation, and (4) training exposure interact to influence progression. Addressing this gap requires a multi-level approach that captures both environmental constraints and individual performance characteristics.

Therefore, this thesis sought to address this knowledge gap through a multi-level research approach combining demographic analysis, applied performance monitoring, and physiological profiling. To achieve the overall aim, four interconnected studies were conducted, each designed to investigate distinct but complementary aspects of post-formation development.

1. Structural Opportunity and Talent Progression

Progression from youth academies to senior squads represents one of the most selective stages within elite soccer. Although youth academies are specifically designed to produce professional-level players, only a small proportion of academy graduates ultimately secure sustained senior participation (Relvas et al., 2010; Dugdale et al., 2021). Increasing globalisation of professional soccer has further intensified competition for senior squad positions, with clubs increasingly recruiting players internationally to optimise short-term performance outcomes (Poli et al.,

2018a). While demographic research has described squad composition trends, it has rarely examined how structural opportunity interacts with player development. It remains unclear whether reduced opportunities for academy graduates reflect organisational strategy or underlying performance differences. Understanding this distinction is essential for interpreting transition success. Therefore, the first objective was to examine the effectiveness of the direct youth-to-senior transition pathway within elite European club soccer by quantifying squad representation and match involvement of club-trained players over time. Study 1 analyzed longitudinal demographic trends across elite European leagues to determine the extent to which academy-developed players are integrated into senior squads and competitive match environments.

2. Physical Readiness and Performance Capacity

Research investigating physical performance characteristics of elite soccer players has established clear associations between aerobic fitness, neuromuscular capacity, and match performance output (Rampinini et al., 2007; Faude et al., 2012; Houtmeyers et al., 2021). These findings indicate that physical readiness is a key prerequisite for sustaining elite performance. However, most physical profiling studies have focused on cross-sectional comparisons between competition levels or age groups, often without examining developmental trajectories or progression outcomes. Although differences between academy and senior players are well documented, their relevance for transition success remains unclear. Furthermore, limited longitudinal evidence exists on how academy players progress relative to senior performance benchmarks.

Therefore, the second objective was to evaluate whether academy and reserve players demonstrate physical fitness, anthropometric characteristics, and performance outputs comparable to senior first-team players. Study 2 employed comprehensive physiological and locomotor profiling to compare developmental and senior player cohorts within the same professional environment. Additionally, retrospective comparisons with successful graduates provided insight into characteristics associated with progression.

3. Match Utilisation and Performance Opportunity

Match exposure represents a critical mechanism through which players translate training adaptation into competitive performance. Previous research indicates that match exposure influences both performance outcomes and development. However, the impact of utilisation patterns on physical performance and progression remains unclear. In particular, the role of substitutions as both a performance strategy and a developmental mechanism remains underexplored.

Therefore, the third objective was to investigate how match utilisation patterns, specifically substitution strategies, influence physical performance outputs and competitive match outcomes. Study 3 examined the physical performance characteristics of substitute players compared to full-match and replaced players, while also evaluating the impact of substitutions on match results.

4. Training Exposure and Load Distribution

Training exposure plays a critical role in shaping physiological development and performance readiness. Appropriate distribution of training load is essential for adaptation and injury risk management. Within professional soccer environments, training load distribution is largely determined by competitive scheduling structures, particularly weekly microcycle organisation. Previous research has examined academy and senior training environments separately (Cummins et al., 2013; Malone et al., 2017; Bradley & Ade, 2018), however direct comparisons between developmental and senior environments remain limited. The implications of these differences for transition readiness are not well understood. Furthermore, differences between starters and non-starters may create developmental challenges that have not been fully explored.

Therefore, the fourth objective was to examine differences in training and match external load exposure between reserve-team and first-team players operating under distinct microcycle structures. Study 4 compared weekly external load and within-week load variation between developmental and senior environments to identify potential mismatches in training exposure.

While each study addressed a distinct research question, collectively they were designed to provide a comprehensive and integrated evaluation of post-formation talent development. By combining structural, physical, and applied performance perspectives, this thesis aims to advance understanding of how interacting structural and performance-related factors shape progression to senior elite soccer.

1.7 Aims of the Present Thesis

The overarching aim of this thesis was to investigate talent development during the post-formation phase in elite professional soccer by examining the structural, physical, and performance-related factors influencing progression from late-stage academy environments to sustained first-team participation. To address this overarching aim, four specific objectives were formulated:

1. To examine structural opportunity and talent progression by quantifying squad representation and match involvement of club-trained players within elite European soccer.
2. To evaluate physical readiness and performance capacity by comparing physiological characteristics and locomotor outputs between academy/reserve players and senior first-team players.
3. To investigate match utilisation and performance opportunity by examining the physical performance of substitute players and their influence on match dynamics.
4. To examine training exposure and load distribution by comparing external load characteristics between developmental and senior environments.

Chapter 2: Methodology

2.1 Methodological Approach

The post-formation phase of talent development in elite professional soccer represents a complex, multi-level process where progression and success are determined by wide-ranging interacting factors such as structural policy, contextual influences and individual player quality (Wylleman et al., 2013; Mills et al., 2012; Barth et al., 2022). To investigate the physical standards required for young players to match in order to progress permanently from a post-formation environment to sustained first-team participation, this thesis designed a strategy that integrated a (1) system-level, longitudinal demographic analysis; (2) club-level observational monitoring of external load and match performance; and (3) player-level physiological and anthropometric profiling. Considering the complexity of this investigation and the fact that elite professional soccer environments impose substantial ethical, logistical, and competitive constraints on research design, a pragmatic, multi-method research approach was adopted, enabling commonly used practices in applied sports science settings which ensured high ecological validity while also preserving acceptable levels of scientific rigour (Bishop et al., 2006; Halson, 2014).

2.2 Study Design

Multiple study designs were used across the thesis, each aligned with the specific research question addressed.

Study 1 employed a longitudinal observational design, analysing secondary demographic data from elite European soccer leagues across a 12-year period (2009–2020), provided by the CIES Football Observatory. Such a design was deemed most appropriate for identifying long-term trends in recruitment strategies, squad composition, match involvement and competitive success (Singer & Willett, 2003; Barth et al., 2022). Additionally, the sample size enabled analysis across multiple

leagues, seasons, and competitive contexts, providing a level of external validity unattainable through single-club studies.

Studies 2, 3 and 4 used observational cross-sectional and prospective longitudinal designs within a single elite professional soccer club. These designs are widely accepted in elite sports science research (Carling et al., 2012a; Halson, 2014; McLaren et al., 2018), in contrast to experimental or intervention-based randomized control trial designs which may disrupt performance preparation or violate ethical principles (Bishop et al., 2006) and would not have been permitted by the club. Additionally, these designs allowed repeated measurement of players under authentic training and competition conditions, improving internal sensitivity.

All applied studies conformed to the Declaration of Helsinki. Ethical approval was granted by the University of Glasgow College of Medical, Veterinary and Life Sciences Ethics Committee. Written informed consent was obtained from all players and/or from their parents or guardians if and when applicable, with details provided in the individual studies.

2.3 Study Environment

To facilitate appropriate interpretation of the findings, it is essential to contextualise the environment in which the data were collected. All data included in this thesis were obtained within an elite professional football club competing in the Scottish Premiership and participating in international competition through the UEFA Europa League. Data collection spanned three competitive seasons: two full seasons (2017–2018 and 2018–2019) and one partial season (2019–2020), which was cut short due to the COVID-19 pandemic. Across this period, data were collected from academy (U18s)/reserve and first-team squads, with both academy and first-team players training full-time at the same club training complex. While operating in separate designated areas of the facility, both environments had access to comparable high-performance infrastructure, including strength and conditioning facilities, medical and rehabilitation services, and performance analysis support. This shared infrastructure ensured a high degree of consistency in available resources

across developmental and senior levels, while organisational separation allowed for environment-specific training and performance practices.

2.3.1 Academy and Reserve Environment

The academy and reserve environments operated within a structured development framework aligned with the club's overarching football philosophy, while allowing variation in coaching approaches across age groups and seasons. Across the data collection period, coaching and backroom staff (i.e. sports science staff, medical staff, performance analysts) remained relatively stable compared to the first-team environment, supporting continuity in player development. Training and coaching practices were oriented towards long-term progression, emphasising technical development, tactical understanding, and physical adaptation, with greater tolerance for performance variability. Playing style was broadly aligned with the first-team model to facilitate progression, as well as the academy's sports science strategy. With the exception of the two-game weeks during which the academy team participated in the 2019-2020 UEFA Youth League, training load was organised and performed within stable weekly microcycles, generally involving one competitive match per week. This enabled the inclusion of higher-load training sessions targeting aerobic capacity, neuromuscular qualities, and repeated high-intensity performance, with planned overload forming a central component of the development process. Match exposure was more evenly distributed than in the first team, although still influenced by performance and developmental objectives. The reserve team provided an intermediate competitive level, exposing players to increased physical and tactical demands within a development-focused context.

2.3.2 First-Team Environment

The first-team environment operated within a performance-driven framework characterised by high competitive pressure. During the observation period, two managerial changes occurred, resulting in variations in tactical approaches, coaching strategies, and training methodologies. Competitive demands were shaped by domestic league and European participation, leading to fluctuating schedules and

periods of fixture congestion. These constraints influenced training structure, with a greater emphasis on recovery and match readiness, particularly during congested periods, limiting opportunities for high-load training. Playing style was closely linked to managerial philosophy, with variation across seasons, but generally characterised by structured positional play, high-intensity transitions, and periods of high pressing. Coaching strategies prioritised tactical discipline, efficiency, and immediate performance outcomes, with limited tolerance for variability. Match load constituted the primary source of physical exposure, particularly for starting players. Non-starting players experienced reduced match involvement and relied on compensatory training sessions to maintain conditioning. However, these sessions were limited in their ability to replicate the intensity and variability of competitive match play.

While both academy/reserve and first team squads operated within the same organisational structure and shared access to comparable facilities and support services, clear differences were evident in objectives, coaching stability, and load distribution. These contextual distinctions are important to consider for interpreting differences in training exposure, match utilisation, and the challenges associated with transitioning from academy to senior elite soccer.

2.4 Participants

Study 1 involved no direct participant recruitment as it examined anonymised publicly available demographic data from reports of the CIES Football Observatory, dating from 2009 to 2020. The dataset provided seasonal counts and proportional metrics from club-trained players, association-trained players, expatriates, new signings and debutants across 31 European national top-division competitions, with a focused sub-analysis on Europe's five highest-ranked leagues.

All participants across studies 2-4 were male professional soccer players, registered at the same elite professional club across the 2017-2020 season, competing in domestic and international competitions. Subjects included late-stage academy players (i.e. Under-18 and reserve-team players) and senior first-team players. Inclusion criteria exclusively considered players that were registered as full-time

within the academy or first team and available for full participation during training sessions and games. Players returning from injury, players performing rehabilitation sessions, or players who participated partially in training sessions were excluded. Additionally, goalkeepers were not held in contention for external load comparisons due to their distinct role and movement profile (Di Salvo et al., 2007). These criteria ensured comparability of physical exposure and reduced measurement noise (Halson, 2014). Across the observation period, over 140 individual players contributed data, with repeated observations across multiple seasons and competitive phases, resulting in >4,000 individual first-team observations and >800 academy / reserve-team observations.

2.5 Measurements

2.5.1 Anthropometrics and Body Composition

Anthropometric assessments included the measurement of body height, body mass and levels of adiposity. While Dual-energy X-ray absorptiometry (DXA) represents a gold-standard method for body composition assessment, providing excellent precision and high-accuracy analyses, its use is uncommon and rarely feasible due to costs and logistical constraints within a professional club environment - factors that are incompatible with frequent, season-long monitoring in applied settings - and deemed undesirable because of radiation exposure (Ackland et al., 2012).

Measurements of body height and body mass were carried out using calibrated stadiometer and scales following standardised procedures. Adiposity was estimated using skinfold thickness measurements at multiple anatomical sites, performed by an experienced assessor, with assessor reliability of measurements reported in the individual studies, but of note, all were within acceptable limits.

Skinfold assessment is a widely accepted and accessible low-cost method for estimating body composition in athletes and demonstrates acceptable reliability when performed consistently by trained practitioners (Reilly et al., 2009b; Ackland et al., 2012). While DXA would have been preferable, for the aims of the thesis,

skinfolds were deemed appropriate and serve as a pragmatic compromise when performed to high standards.

2.5.2 Aerobic Fitness Testing

Laboratory-based maximal oxygen uptake testing using gas analysis and indirect calorimetry is the gold standard for assessing aerobic capacity (Bassett & Howley, 2000). However, in an applied sports environment, direct gas analysis is impractical since it is time-consuming when analysing large groups and bound to logistical constraints. Consequently, aerobic capacity and match-relevant intermittent endurance were assessed with the 30:15 Intermittent Fitness Test (30:15 IFT), providing estimated VO_2max values derived using established predictive equations (Buchheit, 2008).

Despite VO_2max estimates being indirect and influenced by motivation and pacing strategies, the 30:15 IFT is specifically designed for intermittent team-sports and has been validated against laboratory-based maximal oxygen uptake assessments, demonstrating strong correlations with match running performance (Buchheit & Rabbani, 2014). This test has been shown to possess high test-retest reliability for assessing maximal velocity and maximal heart rate (HRmax), and consequently overall physical fitness, across various team sport populations. Reported intraclass correlation coefficients (ICC) range from 0.80 to 0.99 (with most values between 0.90 and 0.99), while coefficients of variation fall between 1.5% and 6.0% (Grgic et al., 2021). In addition, the test has been validated as an indicator of cardiorespiratory fitness (Buchheit et al., 2011). Other practical advantages include superior ecological validity since the test is field-based and mimics intermittent exercise patterns similar to soccer and allows high feasibility for groups.

2.5.3 External Load and Performance

2.5.3.1 Global Positioning System (GPS) Technology

Given the central role of external (locomotor) load in the thesis, wearable global satellite navigation system (GNSS)/ global positioning system (GPS) units with integrated micro-electro-mechanical systems (MEMS) accelerometers were the primary tool for field monitoring across Studies 2–4.

Optical tracking systems and motion-capture technologies represent the gold standard to establish superior positional accuracy. However, these systems are limited to fixed venues and are not feasible for daily training or academy environments (Linke et al., 2018). Over the past decade, GPS technology has been considered standard practice in applied research and elite soccer to quantify movement demands and external load during training and match play (Cummins et al., 2013; Akenhead & Nassis, 2016). Levels of accuracy are prone to decrease during rapid changes of direction and short, high-intensity movements, and accelerometer-derived metrics may be sensitive to noise causing high-intensity and neuromuscular demands to be underestimated (Hennessy & Jeffreys, 2018). Despite these limitations, validation studies have demonstrated acceptable accuracy for distance, speed, and high-speed running metrics at sampling frequencies ≥10 Hz, particularly in open-field sports such as soccer (Johnston et al., 2014; Scott et al., 2016). Reliability is enhanced when players are assigned the same unit consistently, minimising inter-unit error (Buchheit et al., 2014).

Additionally, GPS technology offers great feasibility and ecological value since it can be used in training and match contexts, is non-intrusive, and produces time-aligned locomotor metrics (Cummins et al., 2013; Benson et al., 2020). Therefore, GPS represented a pragmatic compromise, offering sufficient accuracy with high ecological validity. Logistically, for the purpose of consecutive season-long monitoring in a professional club, the trade-off of slightly lower precision for far greater availability was intentionally accepted.

During studies 2, 3 and 4, external load during training and matches was monitored using wearable GPS devices sampling at 10 Hz with integrated 100-Hz triaxial accelerometers. To minimise inter-unit variability, each player was assigned a consistent device across sessions, as recommended in the literature (Buchheit et al., 2014). Sessions with device malfunction (poor satellite signal quality, low satellite counts, low horizontal dilution of precision (HDOP)) or obvious recording errors were excluded. Where necessary, match observations with playing time <60 min were excluded from some match analyses (Study 3) or normalized to full-match durations when appropriate and justified. These pre-analysis decisions were registered in lab logs and applied consistently. Where multiple tracking systems were used across seasons (e.g. Catapult and FieldWiz for historical profiles), cross-system comparability checks and calibration steps were performed where possible. For example, when comparing current academy players with former successful graduates measured on different devices, comparisons were limited to relative variables and conservative inferential thresholds were applied.

2.5.3.2 External Load Metrics

The following variables were analysed across studies 2, 3 and 4 during training sessions and games: session duration (minutes), total distance covered (TD; meters), total high-speed distance covered (THSD; >19.8 $km.h^{-1}$), high-speed distance covered (HSD; 19.8 - 25.2 $km.h^{-1}$) sprint distance covered (SpD; >25.2 $km.h^{-1}$), number of sprints (efforts >25.2 $km.h^{-1}$), number of high-speed efforts (efforts >19.8 $km.h^{-1}$), metres per minute ($m.min^{-1}$) and total high-speed metres per minute (HS $m.min^{-1}$) covered. Velocity thresholds were applied using absolute values derived from established soccer literature (Di Salvo et al., 2007; Malone et al., 2017). Individualised speed thresholds have been proposed to better reflect relative effort (Buchheit & Simpson, 2017). However, absolute thresholds remain common practice in professional environments due to ease of implementation, historical benchmarking, and comparability across cohorts.

2.5.3.3 Peak Metabolic Power

Metabolic power provides insight into high-intensity activity beyond distance metrics, particularly in intermittent sports such as soccer (Osgnach et al., 2010; Gaudino et al., 2013). To estimate energetic demands in study 3, peak metabolic power was derived from GPS-based acceleration and speed data by equating accelerated running on flat terrain to uphill locomotion (di Prampero et al., 2005), with a detailed description of the methodology and calculation in study 3. Estimates do not represent direct measurements of physiological energy expenditure, are sensitive to GPS noise and subject to modelling assumptions (Varley et al., 2017).

However, while direct calorimetry or portable gas analysis would represent gold standards, such measures are impractical during training sessions and competitive match play. The thesis therefore used metabolic power as an additional, interpretive metric rather than as definitive evidence of absolute metabolic expenditure.

2.5.3.4 Internal Load and Subjective Measures

Internal load and subjective measures (e.g. rating of perceived exertion (RPE), heart-rate training impulse, biochemical markers) can enrich interpretation of external exposure by indexing physiological and perceptual response (Impellizzeri et al., 2019). In this thesis, heart-rate data were recorded where available for fitness profiling but were inconsistently available across match datasets. Consequently, internal load metrics were not systematically integrated into every analysis.

Session-RPE was also not captured consistently across the full multi-season datasets. While it is commonly used to estimate internal load (Foster et al., 2001), its omission followed the studies' focus on externally observable demands and objective exposure patterns, which aligned with the thesis aim of examining structural and environmental constraints on development. Internal load considerations are acknowledged as important but were beyond the scope of the present analyses.

2.6 Statistical Analyses

All statistics were carried out using R (3.6.1) and SPSS (27.0) software. Descriptive statistics were used to summarise trends and variability (e.g. to characterise player profiles, training loads, and match performance) and are presented as means ± standard deviations (SD) within 95% confidence intervals.

In studies 2-4, normality of data was assessed using Shapiro-Wilk tests in addition to a visual inspection of Q-Q plots when necessary. Parametric tests were used where the assumptions of a normal distribution of data were met. Parametric tests included independent samples t-tests (study 2 and 3), linear mixed models with Sidak post-hoc comparisons (study 2), one-way analysis of variance (ANOVA; studies 3 and 4) and repeated-measures ANOVA (study 4), with Bonferroni (study 3) or Tukey (study 4) post-hoc comparisons as appropriate for multiple comparisons. For non-normal distributions or comparisons between small samples (e.g., retro-profiled former academy graduates) the non-parametric Mann–Whitney U test (study 2) was used. To determine meaningful differences, effect sizes were calculated using Hedges' *g* (study 2) and Cohen's *d* (study 3 and 4). Classification followed applied sports science conventions (i.e. trivial/small/moderate/large/very large). Heteroscedasticity was examined using Box's M and Levene's tests (study 4).

Correlation analyses were used to investigate the relation between the match involvement of CTP and club league ranking (using non-parametric Spearman's ρ, study 1) and to analyse match outcomes (using parametric Pearson's χ^2, study 3). Throughout this thesis, statistical significance has been accepted at $p<0.05$.
The combined emphasis on p-values and effect size is consistent with current best practices in sports-science reporting (Hopkins et al., 2009).

Pre-analysis sample size calculations were carried out based on previous studies with similar designs (with α=0.05 and ß=0.2, study 2-4) (Batterham & Hopkins, 2006). Where relevant, post-hoc power calculations (with α=0.05) were calculated and reported when significant differences were observed (study 2-4). Despite longitudinal large-sample datasets increasing statistical power, these analyses were

limited to a single-club dataset and observational designs reducing causal inference. These limitations are inherent to elite sport research and are consistent with contemporary applied literature (Carling et al., 2012a).

2.7 Summary

This chapter outlined the comprehensive methodological framework, detailing the study designs, participant characteristics, measurement techniques, and analytical approaches used to investigate post-formation talent development in elite soccer. By integrating longitudinal demographic analysis with physical profiling and applied performance monitoring, the thesis employed methods that balanced scientific rigour with applied feasibility and allowed for relevant and meaningful interpretation within the context of professional football. The following chapters build upon this methodological foundation to examine how structural opportunity, physical readiness, match utilisation, and training exposure collectively shape progression to senior elite football.

Chapter 3

Study 1: Youth-to-Senior Transition in Elite European Club Soccer

3.1 Abstract

The priority for soccer academies is to develop youth players that graduate and transfer directly to their senior squads. The aim of this study was to assess the retention rate of this direct youth-to-senior pathway by examining the extent to which club-trained players (CTPs) are currently involved in elite male European soccer. Relevant demographic longitudinal studies between 2009 and 2020 conducted by the International Centre for Sports Studies Football Observatory were analysed. The main findings were that the proportion of CTPs in senior squads has decreased from 23% to 17% over this time period, while the proportion of expatriates (EXPs) has increased from 35% to 42%. Moreover, clubs resorted more frequently to making new signings (NS, i.e. association-trained players (ATPs) and/or EXPs), with squad proportion increasing from 37% to 44%, while only launching one debutant (DBT, i.e. CTP with no previous senior experience) on average per season. Similar trends are observed in the evolution of playing time: while the fielding of CTPs remained constant (15%), EXPs and NS are fielded increasingly more (49% and 36%, respectively), despite a positive relationship between CTP match fielding and league ranking, with a Spearman Rank correlation r=0.712 (95% confidence interval [0.381-0.881]), p<0.01. In conclusion, young talents are still provided opportunities; however, these are limited and increasingly less frequent at their parent clubs. This potentially suggests a dysfunctional direct youth-to-senior development pathway.

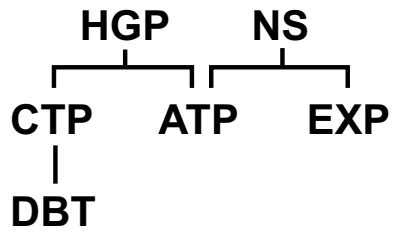
3.2 Introduction

Association football or soccer is arguably the most popular sport in the world. There are ~21.5 million registered youth players under the age of 18 worldwide; however, only ~113,000 (0.5%) are listed as professional players (Kunz, 2007); i.e. have signed a ratified professional contract or agreement with a professional soccer club. This means the outcome for the vast majority of youth players in the development and beginning stages of their active soccer careers is subject to extreme competition and remains largely unknown and uncharacterized.

A characteristic of elite sports, including soccer, is low retention due to drop-out or deselection in the transition from elite youth to elite adult levels (Barreiros & Fonseca, 2012; Barreiros et al., 2014). The main factors that explain this include player-specific deficiencies related to body size and somatotype, functional capacity and performance, and sport-specific, technical and tactical skills (Figueiredo et al., 2009; Huijgen et al., 2014), whereas misjudged talent identification or under-performing development efforts by the club do not appear to explain it (Vaeyens et al., 2006; Vaeyens et al, 2008). The Wylleman's development model on such transitions identify 4 holistics sub-areas (athletic, individual/psychological, psychosocial and academic/vocational) where young athletes need to develop sufficiently to make a successful transition (Wylleman & Lavallee, 2004), whereas others have also indicated that a successful youth-to-senior transition depends on factors beyond athletic development, such as social, personal and cognitive functioning (Bruner et al., 2008; Burgess et al., 2012; Finn & McKenna, 2010; Morris et al., 2016; Stambulova, 2003; Stambulova et al., 2021). Consequently, those unable to meet the expected standard of the higher competitive environment are either transferred to other clubs or released as "free agents" (Brown & Potrac, 2009).

Thus, the youth-to-senior transition in soccer is demanding for both players and clubs, especially at elite top-division level where demands are exaggerated. Within professional soccer clubs, academies are charged with overseeing this, including the selection and subsequent development of those players (Larkin & O'Connor, 2017;

Martindale et al., 2005; Unnithan et al., 2012; Vaeyens et al., 2008; Williams & Reilly, 2000), with the primary aim being to deliver high-quality players to their senior squads (European Club Association, 2012). Within this framework, the ideal scenario for both club and player would thus be graduation from academy with direct transfer to senior squad within the same club. Such academy graduates can most accurately be indicated by so-called club-trained players (CTPs) in senior squads, referring to those registered for minimum 3 seasons with the employer club between the ages of 15-21 (Union of European Football Associations (UEFA), 2005) and therefore suggesting the player has been developed at the current club prior to inclusion in the senior squad (Figure 1).



Home-grown player (HGP): A player who has been registered for a minimum of 3 seasons between the ages of 15 and 21 at the current club of employment or at any different club affiliated to the same association
New signing (NS): ATPs or EXPs who were signed during the course of the current season
Club-trained player (CTP): A player who has been registered for a minimum of 3 seasons between the ages of 15 and 21 at the current club of employment
Association-trained player (ATP): A player who has been registered for a minimum of 3 seasons between the ages of 15 and 21 at a club, other than the current club of employment, affiliated to the same association
Expatriate (EXP): A player who has not been developed at the current club of employment or at any other club affiliated to the same association
Debutant (DBT): A player who make senior debut at the current club of employment without any previous senior experience

Figure 1. Definitions and relations of the terminology on the categorization of senior players.

However, the success rate from academy to first team transition in elite club soccer remains unknown. Therefore, the aim of this study was to examine the retention rate of the youth academy-to-senior first team transition within elite top-division European soccer clubs, by quantifying the CTP squad and match involvement in those clubs.

3.3 Methods

3.3.1 Protocol

The independent and publicly available online repository of the International Center for Sports Studies (https://football-observatory.com) Football Observatory was accessed, completed in May 2021. This repository reports on player transitions and movements across European club soccer. 19 reports were identified as potentially relevant and following a full-text review, 9 longitudinal demographic reports (Monthly Reports 9,13,24,29,33,39,45,49,59; Poli et al., 2015; Poli et al., 2016; Poli et al., 2017a; Poli et al., 2017b; Poli et al., 2018a; Poli et al., 2018b; Poli et al., 2019a; Poli et al., 2019b; Poli et al., 2020) containing relevant quantitative data were selected for inclusion, which included squad and match involvement of the relevant player categories in European elite club soccer 2009-2020, with definitions of those provided in Figure 1. Where overt overlaps of data between different reports were identified, the replicates were excluded from our analysis. These studies involved 31 European top division leagues, comprising ~470 teams/year and ~12,000 first-team players/year. From these, we also extracted data from Europe's 5 highest rated leagues (English Premier League, French Ligue 1, Italian Serie A, German Bundesliga, Spanish La Liga) to enhance the focus on the highest elite level.

This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (Navalta et al., 2020).

3.3.2 Analysis

We analyzed i) proportions of player categories in squads and ii) match involvement of those players, across Europe in the years 2009-2020. The relationship between CTP match involvement and club league ranking was statistically assessed by Spearman Rank non-parametric correlation, due to the monotonic and rank order nature of the data and no assumption of a distribution, with statistical significance $p<0.05$ (SPSS version 27, IBM, Armonk, NY).

3.4 Results

3.4.1 Demography of Players

From 2009 to 2020, CTPs have consistently been outnumbered by players of other origin in senior squads in Europe's 31 top division leagues, and there has been a continuous decrease in the proportion of CTPs, from 23% to 17% (Figure 2). Conversely, the number of expatriates (EXPs) has increased from 35% to 42%, while the number of association-trained players (ATPs) has remained constant at 41-42%. This trend of an increased proportion of non-CTPs was also supported by assessing the number of new signings (NS), showing an increase from 37% to 44% during the same period. On average, clubs launched 1 debutant (DBT) each year.

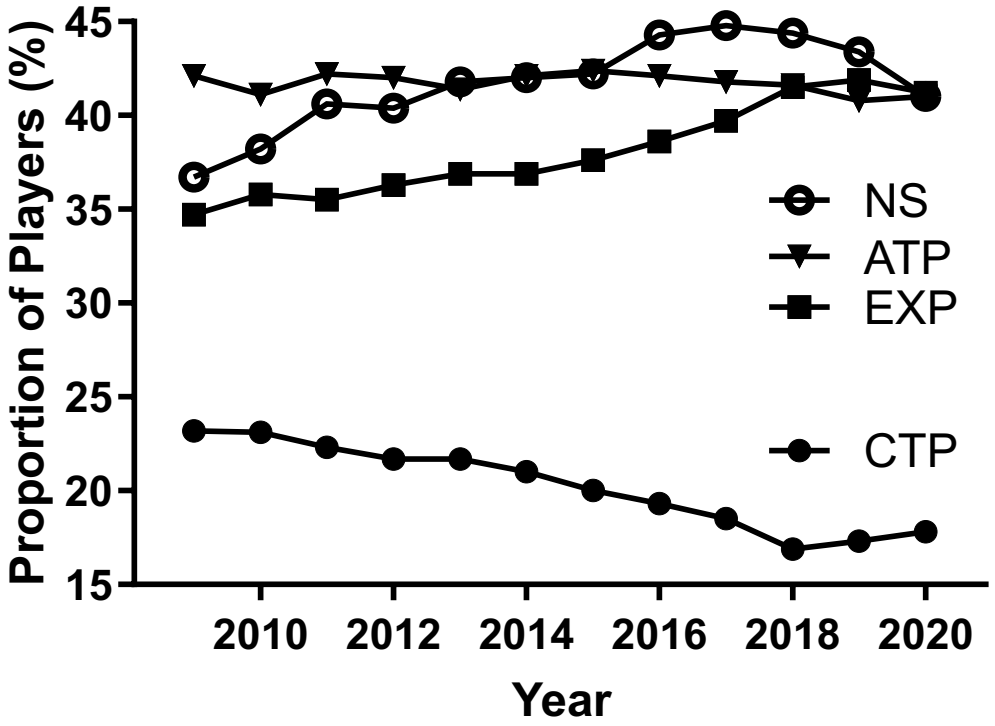


Figure 2. Proportion (%) of senior players per calendar year according to their categorization. Data includes all team squads from 31 European top division leagues between 2009-2020; NS: new signings; ATP: association-trained players; EXP: expatriates; CTP: club-trained players.

3.4.2 Match Time

The extent of CTP opportunities may also be measured by their match involvement; therefore, we assessed playing time. Fielding of CTPs remained constant at ~15% (range 12-19%) of the overall available playing time between 2009 and 2017, which corresponds to 513 minutes over a typical 38-match season or 13.5 mins/match. Fielding of EXPs increased from 44% to 49%, resulting in 1648 min/season over the course of a 38-match season or 44 mins/match at the end of the period, whereas fielding of NS increased from 31% to 36%, resulting in 1194 mins/season or 32 mins/match.

Match time for players under the age of 21 (Under-21) remained at 10-11%; the equivalent of ~10 mins/match. Match time for players under the age of 22 (Under-22) showed slightly higher participation, on average 15% of the overall match time, resulting in 13 mins/match, whereas match time for Under-22 ATPs remained 11-12%, corresponding to 10-11 mins/match. In contrast, there was an increase in match time from 19% to 26% for Under-22 EXPs, resulting in 23 mins/match at the end of the period.

3.4.3 Match Day Squad

Converting the involvement of CTPs to a match day scenario results in 3 CTPs making a typical match day squad of 18, of which 2 CTPs make the team of 11, playing on average 14 of the 90 minutes (Figure 3). The remainder of the match day squad consists of 7 EXPs and 8 ATPs, of which 4 EXPs and 5 ATPS make the starting 11. Similar to ATPs, 8 NS would make the match day squad, with 5 in the starting 11.

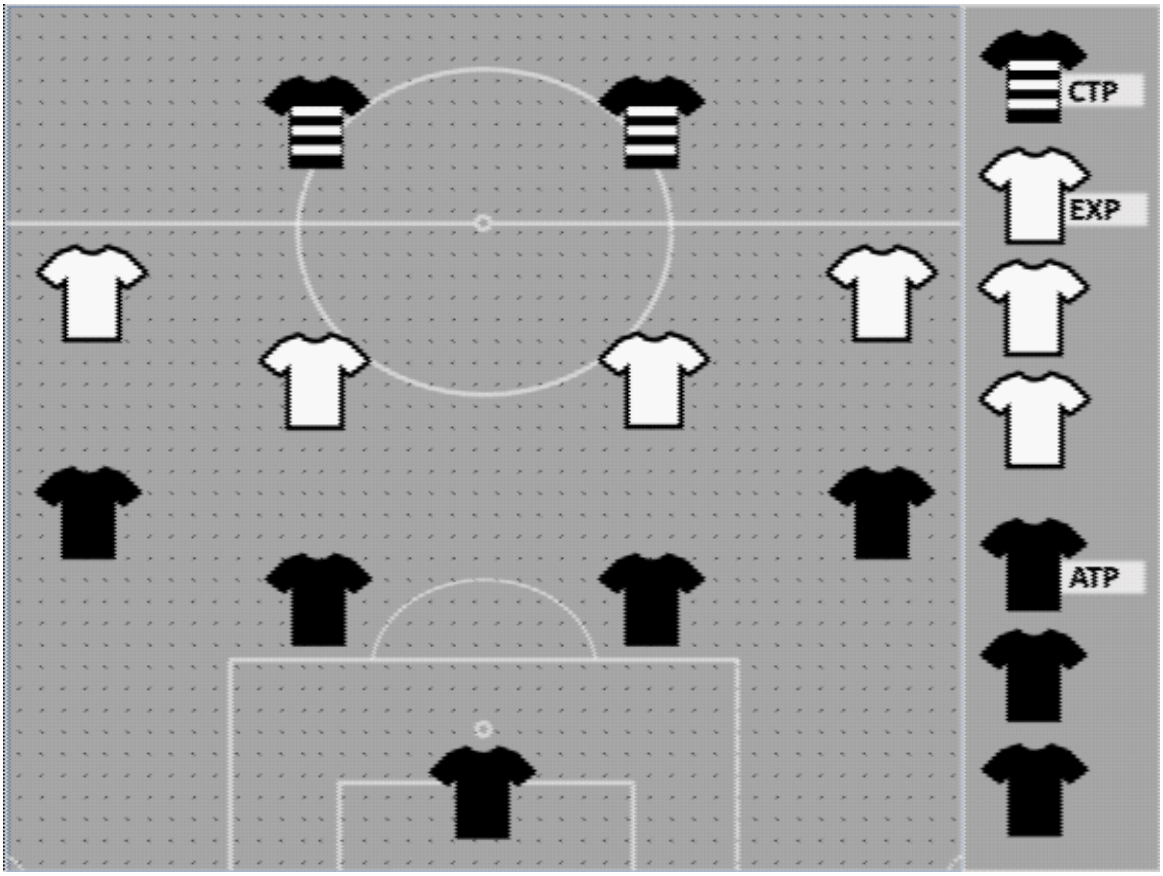


Figure 3. Graphic representation of the average proportions of senior players during a typical match day squad in elite European soccer, with representative starting 11 and substitute players on the pitch and sideline, respectively. CTP: club-trained players (striped shirts); EXP: expatriates (white shirts); ATP: association-trained players (black shirts).

3.4.4 Regional Differences

Regional differences regarding origin of players exist in Europe's 31 national top divisions. For CTPs, the highest proportion was found in Israel, with 104 CTPs of 317 players (33%) in 2020, whereas the lowest proportion was found in Portugal, with 33 of 474 players (7%). Conversely, for EXPs, the highest proportion was found in Cyprus, with 234 of 345 players (68%), whereas the lowest proportion was found in Serbia, with 76 of 513 players (15%). For NS, the highest proportion was found in Serbia, with 274 of 513 players (54%), whereas the lowest proportion was found in England, with 144 of 509 players (28%). The highest number of DBTs was recorded in Ukraine in 2015, with 2.29/team.

3.4.5 Top 5 Leagues

We assessed Europe's 5 highest rated leagues (England, France, Germany, Italy, Spain). First, the proportion of CTPs (9-20%) relative to all senior players was throughout below proportions of ATPs (29-46%), EXPs (35-58%), and NS (30-41%) in 2020 (Figure 4) and essentially similar in previous years. Secondly, match involvement reported between 2010 and 2017 (not reported subsequently) ranged for CTPs 5-23 mins/match, while EXPs and NS accrued 22-58 and 21-40 mins/match, respectively (Table 1).

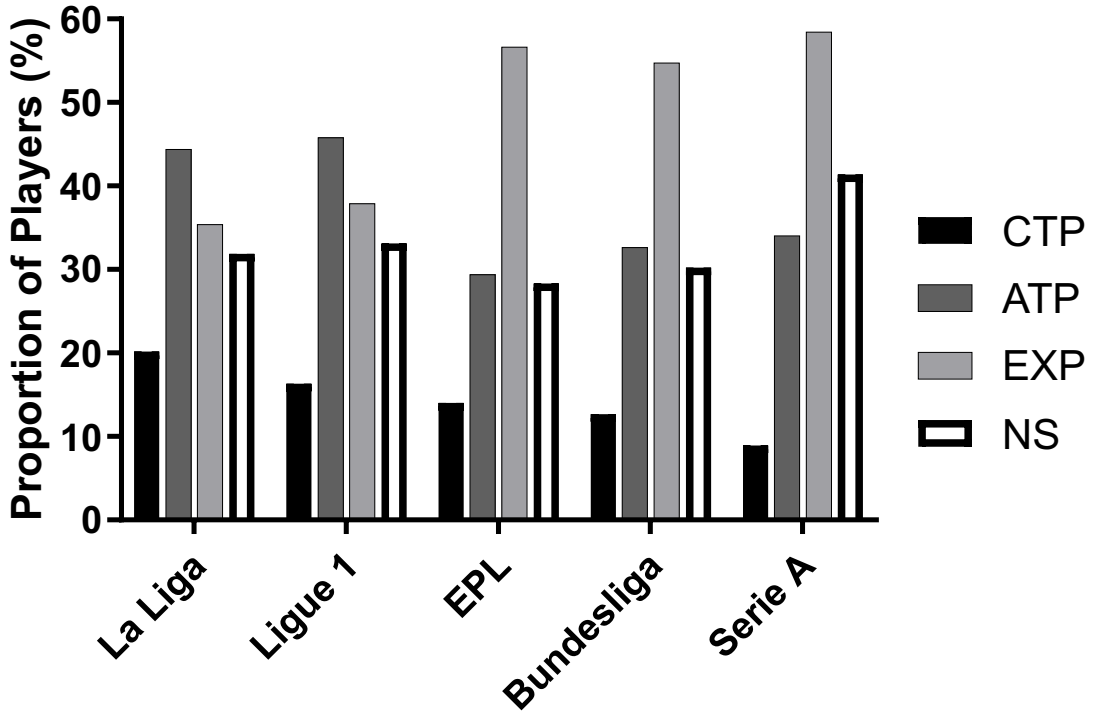


Figure 4. Proportion of senior players in Europe's 5 highest rated leagues in 2020. CTP: club-trained players; ATP: association-trained players; EXP: Expatriates; NS: new signings; EPL: English premier league.

Table 1: Minimum (Min)-maximum (Max) range of match fielding of club-trained players (CTP), expatriates (EXP), and new signings (NS) in Europe's 5 highest rated leagues between 2010-2017.

	CTP Range Min-Max		EXP Range Min-Max		NS Range Min-Max	
	Mins/Match	% of Match	Mins/Match	% of Match	Mins/Match	% of Match
Spanish La Liga	16-23	17.6-25.7	32-38	35.2-42.0	26-37	29.2-41.1
French Ligue 1	13-20	14.9-22.6	22-30	24.8-32.8	24-35	26.5-39.3
German Bundesliga	10-16	11.3-17.9	36-47	40.1-52.4	24-31	26.5-34.8
English Premier League	5-12	6.1-13.6	48-58	53.3-64.4	21-32	23.2-35.3
Italian Serie A	5-8	5.4-9.3	37-53	40.8-58.9	28-40	30.9-44.6

Data is based on 6-month period averages, normalized to 90-minutes (Mins) match time.

With exception for the minimum fielding of NS in the English Premier League, the minimum amount of match time for EXPs and NS exceeded the maximum amount for CTPs in all 5 leagues. The Spanish La Liga featured the highest CTP player proportion and match involvement, whereas the Italian Serie A and English Premier League featured the lowest CTP proportion and involvement. This was further supported by examining how much individual clubs fielded CTPs during matches. The top 10 clubs permitted CTPs 48-75% match time, and of these, Spanish La Liga clubs were over-represented with 3 (Real Sociedad, Athletic Bilbao, Barcelona) of top 10 places and all those within top 4. In contrast, the bottom 10 clubs permitted CTPs 0-1% match time, with English Premier League teams over-represented with 7 (Bolton Wanderers, Fulham, Burnley, Birmingham City, Watford, Blackpool, Bournemouth) of bottom 10 places (Figure 5). This also revealed a positive relationship between CTP match involvement and respective national league ranking, showing a clear tendency towards high CTP match involvement associating with greater league success (Figure 5).

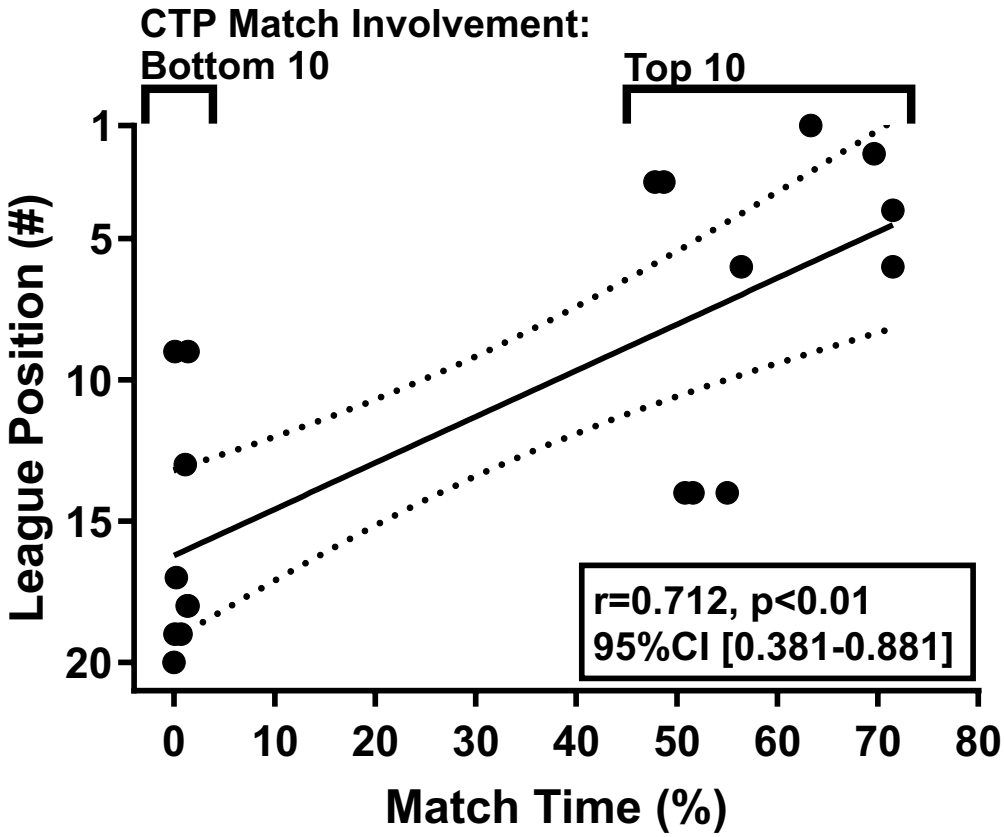


Figure 5. Relationship and Spearman Rank correlation between club-trained player (CTP) match involvement and club performance in national league. Match time is averaged over 6-month periods, while league position is at end of season.

3.5 Discussion

We assessed the retention rate of youth-to-senior transition in elite European soccer, by examining the extent to which CTPs were involved in elite top-division European club soccer, with data made available 2009-2020. This showed that the annual proportion and involvement of CTPs in elite clubs have been limited and consistently decreasing, whereas in contrast, EXPs, ATPs and NS have enjoyed a proportionally larger and increasing involvement in the same clubs. This tendency has been observed among all European leagues, including the 5 highest rated leagues, which is somewhat surprising given that there is simultaneously a tendency toward CTP fielding breeding success.

The above therefore indicates that clubs rely more on ATPs and EXPs for bringing in new players. This coincides with the general globalization of sport including soccer (Waalkes, 2017), whereby the increased mobility of players and internationalization of club squads, including players under the age of 22 (Stambulova, 2003), allows clubs to recruit players globally, which may bring specific qualities the club wants while at the same time expanding its fanbase. The negative outcome of this is however the fewer opportunities afforded young players to gain success in their development clubs, illustrated by the low number of DBTs launched each year. Below, we discuss potential motivations and explanations for these trends.

3.5.1 Financial Power

'Money talks.' Clubs that can afford it may sign top-level ready-to-perform players, whether domestic or foreign, to reinforce their teams; a strategy shown to ensure success (Pawlowski et al., 2010), despite the positive relationship we show between the CTP usage and club success. This comes at the cost of promoting academy graduates. However, and while no correlation has yet been established between financial power and player recruitment within clubs, a noticeable trend suggests that financial inferiority may link to increased success of academy graduates: of those clubs launching a minimum of 4 DBTs per year (Poli et al., 2015), none ranked among the wealthiest clubs in Europe (Brand Finance, 2020). A different view is however that CTPs may also provide a significant return to the club that invests in them either through generating income as a player and/or by a future sale, and as such CTPs also provide a route to club success and income on and off the pitch.

3.5.2 Strategies to Protect and Promote Young Players

These findings raise questions about effectiveness in CTP promotion in clubs. The Union of European Football Associations have introduced the "financial fair play" and the "home-grown player" (HGP; Figure 1) rules, which require clubs name a minimum of 8 HGPs in their 25-player senior squads. However, the rules apply only to Union of European Football Associations competitions or those national leagues that have chosen to adopt them, and moreover, clubs are not required to include HGPs in

match day squads or field them on the pitch, and therefore they have failed to substantially improve youth development (Dalziel et al., 2013). Instead, short-term loans of young players out to lower-level clubs and introduction of elite club B-squads in lower-level leagues or specific Under-21 competitions have been designed to develop and promote young players.

Another suggestion under consideration has been to reduce the HGP maximum age limit from 21 to 18 and thus require the player to be registered with the current club from the age of 15 to satisfy the 3-season requirement (Figure 1) that qualifies the player as HGP. This would force clubs to invest in and facilitate young player development, but since European Union legislation only allows free movement for work purposes across borders from the age of 16, it follows that it would reduce international mobility of young players, and as a consequence support local talented players. It is also conceivable this will be compounded in the United Kingdom by its leaving the European Union ("BREXIT"), and in Europe as well as globally by the Coronavirus-19 disease epidemic, for which effects cannot yet be fully appreciated, albeit the early trend is a greater reliance on CTPs and less on EXPs (Poli et al., 2020).

Despite strategies to protect and promote young players, given that first teams employ 25 and academies employ typically >200 players; given each first team playing career extends ~10 years, and given the overall high number of players (15), it should be acknowledged that the realistic chances of successful transition to an elite-level first team are minimal for young players, with some suggesting a 0.012% success rate (Calvin, 2007).

3.5.3 Player Quality

It has anecdotally been suggested that the low proportion of CTPs in soccer may be due to actual or perceived inferior quality. Likewise, it has been suggested non-local young players excel versus local, despite refusal of this myth (Ankersen, 2012). It should however be recognized that players in this category undergo constant development and maturation commensurate to their age and thus clubs should

exercise patience in handling CTPs. This call for patience can be further supported by our analysis which indicates that increasing involvement of CTPs in matches does not deter success for the club, though a causal relationship between a club's competitive success and the fielding of CTPs is yet to be established.

3.5.4 Limitations

Ambiguous terminology in this field may cause confusion. CTP- and HGP-terms are often mistakenly used to describe the same players, even though they differ (Figure 1). While CTP refers to development in a player's current club, HGP refers to development in current club or a club associated with the same national football association, which therefore encompasses both CTPs and ATPs. From the current datasets, we have assessed true player status as much as possible rather than make potentially unfounded assumptions.

Notwithstanding the above, a measure of CTPs may not be a true reflection of the effectiveness of the youth-to-senior transition in a club or indeed of a club's academy. A better indicator would be the proportion of academy graduates playing in professional senior squads and hence also include ATPs and EXPs regardless of origin, as this would be a measure of successful academy production. However, this metric is not available, and hence CTPs are recorded as surrogate measures of youth-to-senior transition success.

The relationship we show between CTP match involvement and respective club league ranking (Figure 5) is due to data availability constructed from only the top and bottom 10 clubs with respect to CTP match time and thus lacks data from the majority of clubs. It nonetheless indicates a positive relationship that we consider important, but we acknowledge it is incomplete. It should also be acknowledged that a universal and optimum value of CTPs in club football may not exist; it may be fluid, vary, and depend on other circumstances, but it also seems CTPs may be under-valued, to the detriment of both players and clubs.

3.5.5 Conclusions

We aimed to assess the retention rate of the direct youth-to-senior pathway in soccer by examining whether and the extent to which CTPs were involved in elite-level European soccer between 2009-2020. We found the annual proportion of CTPs in elite professional soccer has been limited and decreasing, with CTPs playing a minimum amount of overall match time compared to ATPs, EXPs and NSs. These trends indicate that clubs are less inclined to employ academy products and resort progressively more to external transfers of incoming players to supplement and reinforce their squads.

3.5.6 Conflicts of Interest

The authors declare that no conflicts of interest exist regarding this manuscript.

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Chapter 4

Study 2: Physical Profiling in Elite Professional Men's Soccer: Academy, Reserve and First Team Variations in Fitness and Performance

Study 1 demonstrated a declining contribution of club-trained players to senior squads within elite European football, highlighting the structural challenges associated with progression from academy to senior football. These findings raised the question of whether limitations in physical readiness may contribute to this reduced progression. Therefore, Study 2 examined the physical characteristics and training and match demands of academy, reserve, and first-team players within the same elite football environment.

4.1 Abstract

We profiled physical fitness and training and match performance of elite academy (under-18 (U18, n=23), reserve (RES, n=15)), and first teams (FT, n=25) to assess physical readiness for academy-FT progression. Further, we segregated into player positions, age, and current versus former academy players that had successfully progressed to FT. Aerobic capacity, anthropometry, and global positioning system- and heart rate-derived performance profiles in training and matches quantified external and internal loads. FT demonstrated 10% more body mass ($p<0.01$) with similar adiposity versus U18, and ~10% higher aerobic capacity ($p<0.01$) versus RES. In training, U18 covered more distances: 727m (16%) total distance, 115m (48%) high-speed, and 65m (79%) sprint distance, and generated 0.63m/s (8%) higher peak speeds versus FT (all $p<0.01$), while FT displayed higher mean speeds: 8m/min (11%) and 18m/min (24%) versus U18 and RES (all $p<0.05$). In matches, U18 and RES covered more distance: total 539m (5%) and 567m (6%) and high-speed distance: 111m (18%) and 121m (20%), and displayed higher mean speeds: 13m/min (11%) and 14m/min (12%), versus FT (all $p<0.05$). Thus, in this club, FT players demonstrated higher aerobic capacity, but not physical performance in training or matchplay. Academy players were not inferior, but displayed different performance behaviours.

4.2 Introduction

Football places extensive physical demands on players, making physical fitness a key determinant of performance (Bangsbo et al., 2006; Sporis et al., 2009; Waldron & Murphy, 2013). Higher levels of physical fitness associate with higher matchplay performance (Koudellis et al., 2024), team success (Apor 1988), and increased capacity to sustain high intensity in training and match, regardless of development and competition level (Barnes et al., 2014; Bradley et al., 2009; Bush et al., 2015; Carpels et al., 2021; Dugdale et al., 2021; Helgerud et al., 2001; Houtmeyers et al., 2021). The focus on physical fitness has further become increasingly important because of fixture-congestions and elevated match demands following increased intensity of play (Clemente et al., 2021; Dellal et al., 2015; Malone et al., 2015; Nassis et al., 2020); including in academy football (Burgess et al., 2012).

Despite a structured development and progression pathway from academy to reserve to first team, only a small proportion of players achieve this (Carpels et al., 2021; Dugdale et al,. 2021). A major cause of this is systemic and individual constraints. At the systemic level, discrepancies in training and match demands between academy, reserve and first teams lead to different microcycles, even in the same club (e.g. first team playing 2 games per week versus academy or reserve teams playing one game per week), which result in mismatched load profiles that may inadequately prepare players for first team transition (Carpels et al., 2024; Swallow et al., 2021). At the individual level, players may lack anthropometric characteristics, physical capacity, or performance outputs required at first team level, including the ability to consistently perform high-intensity actions and sustain high-intensity workloads (Milsom et al., 2015; Veale et al., 2010), especially in selected player positions where specific physical demands may dictate player selection (Bloomfield et al., 2007; Bush et al., 2015; Di Salvo et al., 2007; Martin-Garcia et al., 2018).

These differences highlight the importance of physical profiling. Characterization of anthropometric and external and internal load parameters provides a robust framework for identifying developmental gaps and benchmarking progression toward elite performance standards (Houtmeyers et al., 2021). While previous studies have examined differences across competition levels and training contexts (Carpels et al., 2024; Koudellis et al., 2024; Martin-Garcia et al., 2018; Swallow et al., 2021), no study has yet systematically compared these physical profiles across academy, reserve and first teams within the same professional elite environment, including after segregation for player positions, age groups and players that did or did not achieve success.

Player development and progression is multifactorial (Morgans et al., 2023), but the above indicates a substantial physical dimension. We propose that comparing physical player profiles across the different cohorts establishes benchmarks for physical standards that academy and reserve players must meet in order to compete at the higher level (Sporis et al., 2009; Cone, 2012). The aim of this study was therefore to compare anthropometric characteristics, physical fitness, and external and internal load parameters between academy, reserve and first-team players within the same elite professional environment. Analyses were further stratified by player positions, age groups, and success in transitioning to first team, by comparing current academy and reserve players to players who had previously achieved this progression.

4.3 Materials and Methods

4.3.1 Participants

Full-time professional elite academy consisting of under-18 and reserve teams and senior first team football players in a male Scottish Premier League club during the 2018-2019 season were included, covering all on-field playing position, with player positions and player numbers and characteristics shown in Figure 6 and Table 2. Player assignment was decided by club. All academy players had a minimum of 1-year employment history within the club and therefore were following club health screening and physical conditioning and training protocols. All teams competed in premier domestic (Scottish Football Association league and cup) and international competitions (UEFA Europa League). The study conformed to the Declaration of Helsinki, all procedures were approved by the Institutional Review Board (College of Medical, Veterinary and Life Sciences Ethics Committee, University of Glasgow, FBLS1006), and all players including parents/guardians for under-18 players provided written informed consent.

4.3.2 Study Design

The study included cross-sectional comparisons using data collected prospectively across one season, with longitudinal capture of training and match performances. Training data were recorded throughout the competitive season, while match data were recorded during a 2-month competitive period where academy, reserve and first team fixtures and results were comparable and thus had equal opposition effects and result influences. Anthropometry and physical fitness were measured at end of pre-season due to availability for simultaneous testing across teams and because physical performance tends to peak at or around this time (Meckel et al., 2018) (Figure 6). Deconditioned or injured players were excluded, while GK data were included for player characteristics, but excluded from training and match physical performances due to different training and match requirements. Individual outfield player sessions were also excluded where club management dictated a departure from normal training schedule. Number of observations are provided in Tables 3 and

4. Prior to each test, training session or match, players warmed-up following club protocol.

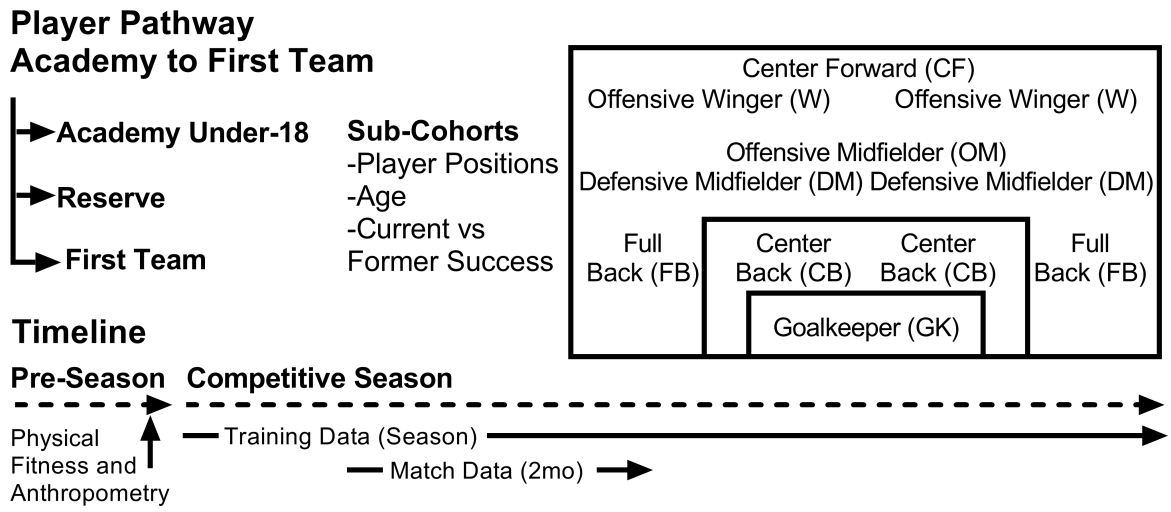


Figure 6: Study design with teams and sub-cohort analyses including player positions, and timings of data capture periods. mo = months.

4.3.3 Anthropometry and Physical Fitness

Age and body height and mass were recorded and adiposity assessed from subcutaneous fat skinfold recordings (Harpenden Skinfold Caliper, HaB Direct, Warwickshire, UK) by averaging minimum 2 recordings each of triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf sites, by the same experienced observer; as validated in football (Reilly et al., 2009a). Calculation of intra-observer technical error of measurements (TEM; Ulijaszek & Kerr, 1999), showed high precision, with relative TEM ranging 2.1-5.4%.

The 30:15 Intermittent Fitness Test (IFT) assessed football-specific aerobic and anaerobic endurance capacity and 180° change of direction ability. This test has previously demonstrated excellent test-retest reliability for measuring both maximal aerobic velocity and maximal heart rate (HR_{max}) and thus determining aerobic fitness, in a variety of comparable team sports study groups, with intraclass correlation coefficients (ICC) ranging 0.80-0.99 (with majority of comparisons

ranging 0.90-0.99), and coefficients of variation ranging 1.5-6.0% (Grgic et al., 2021), and has been found valid for estimating cardiorespiratory fitness (Buchheit et al., 2011).

Maximal performance was defined when players failed to reach the required zone 3 consecutive times, whereupon the velocity of the last completed stage (V_{IFT}) was recorded, while maximal oxygen uptake ($\dot{V}O_{2max}$) was estimated as: $\dot{V}O_{2max}$=28.3-(2.15xG)-(0.741xA)-(0.0357xW)+(0.0586xAxV_{IFT})+(1.03xvIFT), with G=gender (male: 1), A=age (years), W=body mass (kg), and V_{IFT}=maximal velocity of IFT (km/h) (Buchheit, 2008). $\dot{V}O_{2max}$ was allometrically scaled to body mass (mL/kg$^{0.75}$/min) to appropriately compare players with different body masses (Helgerud et al., 2001). Heart rate (HR) was continuously measured using Polar Team Pro heart rate monitors with chest straps positioned according to manufacturer specifications (Polar Electro, Kempele, Finland), with 1Hz data logging following 1000Hz capture, previously validated and used in Football (Dalen & Loras, 2019; Gilgen-Ammann et al., 2019). Highest recording was defined as HR_{max}.

4.3.4 Training

On-pitch physical conditioning match preparation and recovery sessions were analyzed, whereas technical/tactical drills and indoor gym-based strength and conditioning sessions were excluded. For most of the season, microcycles consisted of the first team playing 2 matches/week whereas both academy teams played 1 match/week, which resulted in different load profiles, which are common (Carpels et al., 2024; Martin-Garcia et al., 2018; Swallow et al., 2021) but understudied and unexplored, and which lead to the rationale of the study of comparing physical profiles between them. This affects also training schedules and regimens, with the first team experiencing fewer and/or shorter training sessions versus academy teams. As a result, typical weeks included 3-4 analyzed training sessions from first team and 4 from academy teams (with training structures outlined in chapter 2), which were longer than first team sessions. All training was on grass pitches and measured by Catapult OptimEye X4 Athlete Monitoring System (Catapult Sports, Melbourne, Australia) global positioning system (GPS, 10Hz) and triaxial

accelerometry (100Hz), previously reported valid and reliable for this purpose, with ICC ranging 0.51-0.99 (with majority of comparisons in 0.80-0.99 range), %-age typical error ranging 0.8-4.8, and no difference from higher-frequency sampling (Johnston et al., 2014). To avoid interunit errors, typically the major source of error (Theodoropoulos et al., 2020), each player was assigned their own specific device. Mean number of connected satellites during recordings was 14±1 and the horizontal dilution of precision (HDOP) was 0.73±0.04. Devices were activated ~10mins prior to each session and worn according to the manufacturer's instructions in purpose-designed vests. Individual rehabilitation or gym sessions, and players involved in sessions outside their team designation were excluded. Measurements included total distance (m), high-speed distance (5.5-7m/s; m), sprint distance (>7m/s; m), peak speed (m/s), and relative effort exerted measured as mean speed (m/min) and time spent >85% of HR_{max} (min:sec). Time spent >85% of HR_{max} was analyzed as exercise above this threshold represents high-intensity cardiovascular load in youth football (Tounsi et al., 2024).

4.3.5 Match

Matches were analyzed from a 2-month period in the first half of the season (mid-October to mid-December) where all teams experienced 2-matches/week microcycles. 16 matches from all teams were analysed including domestic (11 league, 1 cup) and international (5 Europa League) matches, with academy teams following first team schedule. Measurements replicate those described above, except HR -was not measured during matches. Player data with <60mins/match were excluded, and player data from >60-<90mins/match were normalized to full length of that specific match.

4.3.6 Age-Dependent Effects

We extracted match physical performance data from defined age-groups within the different teams. This allowed us to examine age-dependent effects by comparing ≤16years versus >16years in under-18 team players, and ≥18years reserve players

versus ≤23years first-team players, with cut-points informed by documented maturational transitions in elite youth football (Tounsi et al., 2024).

4.3.7 Analysis of Successful Former Academy Players

Finally, we compared current to former academy players who progressed to first team contracts and subsequently featured regularly in first team matches. Inclusion required the availability of comparable measurements in terms of duration and seasonal timing, collected during their academy phase. Players whose development occurred under substantial different academy training or physical profiling frameworks were excluded to ensure contextual consistency. This approach yielded a sample of 4 successfully transitioned players and included data on player characteristics as well as training (24 sessions) and match (34 matches) performances. Contemporary data were collected as described above, but historical data were supplemented with measurements captured with FieldWiz (ASI, Lausanne, Switzerland) and PlayerTek (Catapult Sports, Melbourne, Australia), which were in use at that time. The inclusion of these data was considered necessary to enable a rare and practically valuable longitudinal comparison of current versus former successful academy players within the same club environment.

4.3.8 Statistical Analysis

Training and match data were analysed with the OpenField Console Software (version 1.14, Catapult Sports, Melbourne, Australia), while statistical analysis was by R (version 3.6.1, R Core Team). Sample size determination was deemed impractical since player logistics were managed by club, but sample size calculation for necessary number of players to identify expected differences between teams, based upon expected minimal team differences and standard deviation (SD) of measurements of total, high-speed and sprint distances, mean speed, V_{IFT} and $\dot{V}O_{2max}$, from our own previous experience (Carpels et al., 2024) and published studies with similar designs (e.g. Houtmeyers et al., 2021), with α=0.05 and ß=0.2 (80% power), indicated that each team required 10-12 players. This allowed us to divide the elite academy into under-18 and reserve teams. Furthermore, sample size calculation for

numbers of observations/team based upon the same criteria as above suggested ~20 observations/team. Normal distribution of data was confirmed by Shapiro Wilk test $p>0.05$ (observed range $p=0.11$-0.64) and by observing diagonal data distribution in Q-Q plots.

Comparisons between 2 cohorts were conducted using 2-tailed unpaired t-tests with unequal variances. Comparisons across 3 cohorts were conducted using linear mixed models with teams (under-18, reserve, first team) and player positions as fixed factors and individual player identity included as a random factor to account for repeated observations within individuals across training sessions and matches. Estimation method was restricted maximum likelihood and degrees of freedom were calculated by Satterthwaite approximation. Where significant main effects occurred, pairwise Sidak post-hoc comparisons were conducted to identify those effects. Current and former academy players were compared by non-parametric Mann-Whitney U tests due to the small sample size. Statistical significance was set at $p<0.05$.

To control for multiplicity, we corrected for 5% false discovery rate (FDR) across all comparisons via the Benjamini-Hochberg procedure, whereby FDR-confirmed statistical significances appear in results presentation. Effect size (ES) was measured by Hedges' *g* due to different sample sizes, with effects classified as trivial (<0.2), small (≥0.2), moderate (≥0.6), large (≥1.2) and very large (≥2.0). Statistical power of the observations was calculated post-hoc with $\alpha=0.05$ when significant differences occurred and found to be in the range 90%-100%. For non-significant comparisons, observed power ranged 4-60%, indicating risk of type II errors in some position-specific analyses with very small sample sizes (e.g. GK n=2-3). Mean±SD are reported and 95% confidence interval (CI) of the mean differences are reported for key comparisons.

4.4 Results

4.4.1 Player Characteristics

First-team players were naturally older (ES 2.60-very large, p<0.001), but also taller (ES 0.58-small, p=0.031) and heavier (ES 1.11-moderate) versus academy under-18 (p=0.008) and reserve players (p=0.040) (Table 2). Subgroup analysis showed this was particularly pronounced in Ws and FBs, whereas other player positions showed similar, but not statistically significant, trends. In contrast, subcutaneous fat and adiposity did not differ between teams, including after sub-division into player positions, which suggests the higher body mass in first-team players was due to higher lean mass.

IFT performance did not differ between teams, indicating comparable aerobic and anaerobic endurance and change of direction capacities, but calculated $\dot{V}O_{2max}$ was ~7% (ES 1.09-moderate higher in first team versus both under-18 and reserve, p=0.009 and p=0.007 respectively) higher in first-team players, and ~10% (ES 1.55-large, p=0.008 and p=0.010 versus under-18 and reserve, respectively) higher after allometric scaling. Subgroup analysis showed this was especially pronounced in FBs, but a tendency for this effect was also observed in other player positions.

Table 2. Player characteristics of elite academy under-18 (U18) and reserve (RES) teams and first team (FT).

	GK			FB			CB			DM			OM			W			CF			TEAM		
Number of players	U18 (3)	RES (2)	FT (3)	U18 (5)	RES (3)	FT (5)	U18 (4)	RES (4)	FT (4)	U18 (3)	RES (2)	FT (4)	U18 (3)	RES (1)	FT (2)	U18 (3)	RES (2)	FT (5)	U18 (2)	RES (1)	FT (2)	U18 (23)	RES (15)	FT (25)
Age (years)	16.7 ±0.6 *#	19.0 ±0.0 *	26.3 ±4.0	16.6 ±0.5 *#	18.0 ±0.0 *	23.8 ±4.7	16.0 ±1.4 *#	18.5 ±0.6 *	28.8 ±8.7	16.0 ±1.0 *#	18.0 ±0.0 *	24.0 ±3.8	16.7 ±0.6 *	18.0 /	26.5 ±4.9	16.7 ±0.6 *#	19.0 ±0.0 *	27.2 ±5.3	16.0 ±0.0 *	19.0 /	26.5 ±6.4	16.4 ±0.8 **##	18.5 ±0.5 **	26.0 ±5.2
Height (cm)	190.2 ±9.2 *	186.7 ±0.6 *	177.8 ±4.7	176.3 ±5.2	178.0 ±5.3	186.2 ±5.8	182.5 ±3.0	188.6 ±2.7	182.4 ±7.2	178.7 ±3.8	182.1 ±2.6	184.2 ±6.3	174.8 ±2.3	175.8 /	180.1 ±4.0	167.7 ±2.0 *	169.7 ±0.8 *	184.6 ±5.7	175.3 ±2.9	179.7 /	186.8 ±9.0	178.1 ±7.6 *	181.4 ±4.0	183.4 ±6.0
Body Mass (kg)	75.6 ±9.8	79.9 ±4.7	72.2 ±4.6	64.6 ±5.1 *	70.4 ±4.9 *	81.3 ±5.5	73.2 ±5.6 #	82.0 ±4.1	79.0 ±4.3	66.5 ±5.5	74.4 ±3.8	76.0 ±8.1	68.7 ±3.0	66.4 /	78.3 ±1.0	64.7 ±7.5 *	62.5 ±7.8 *	81.6 ±5.5	71.8 ±8.6	78.0 /	84.1 ±5.2	69.0 ±6.9 **	74.5 ±8.0 *	79.0 ±5.9
Skinfolds (mm)	59.8 ±16.6	78.7 ±11.5	48.6 ±3.6	47.7 ±4.8	53.3 ±13.5	52.3 ±5.8	58.3 ±2.7	61.5 ±10.9	50.0 ±10.4	60.6 ±12.7	42.8 ±5.9	60.0 ±17.9	56.4 ±12.8	62.6 /	42.9 ±0.4	45.5 ±5.3	46.6 ±0.9	51.5 ±22.2	70.2 ±3.0	49.6 /	47.9 ±5.9	55.6 ±10.8	56.9 ±13.8	51.4 ±12.8
vIFT (km/h)	20.0 ±0.0	19.5 /	18.8 ±1.3	21.5 ±0.5	21.5 ±0.0	21.3 ±0.6	20.3 ±1.2	20.5 ±0.5	21.0 ±1.4	20.8 ±0.8	20.8 ±0.4	21.8 ±0.4	21.0 /	/ /	22.0 /	21.2 ±0.8	14.0 /	20.8 ±1.0	20.3 ±0.4	/ /	18.0 /	20.8 ±0.8	19.9 ±2.3	20.6 ±1.5
VO_{2max} (mL/kg/min)	51.2 ±0.2	50.9 /	52.3 ±0.8	54.6 ±1.2 *	55.0 ±0.1 *	58.5 ±1.4	51.6 ±1.2	52.7 ±0.8	56.1 ±2.4	52.9 ±1.7	53.4 ±0.6	58.2 ±3.1	53.8 /	/ /	62.6 /	53.9 ±1.5	40.0 /	57.0 ±1.1	51.6 ±0.4	/ /	48.5 /	53.0 ±1.9 **	51.8 ±4.6 **	56.3 ±3.6
VO_{2max} ($mL/kg^{0.75}$/min)	150.7 ±6.4	153.7 /	156.5 ±1.2	154.8 ±5.0 *	160.9 ±0.7 *	173.5 ±4.0	150.9 ±10.2	159.5 ±2.9	170.9 ±5.0	151.1±6.5	156.9 ±3.8	171.4 ±6.7	152.9 /	/ /	184.4 /	152.8 ±4.2	110.0 /	167.7 ±1.4	150.0 ±5.6	/ /	147.6 /	152.2 ±5.8 **	153.1 ±16.4**	167.7 ±9.5
HR_{max} (bpm)	/ /	193 ±1	/ /	200 ±3	197 ±5	188 ±11	200 ±3	197 ±5	193 ±12	203 ±10	201 ±13	202 ±8	196 ±3	204 /	197 ±8	195 /	203 ±9	194 ±9	203 ±4	194 /	180 ±4	200 ±5*	198 ±7*	193 ±10

GK = goalkeeper, FB = full back, CB = center back, DM = defensive midfielder, OM = offensive midfielder, W = offensive winger, CF = center forward, vIFT = maximal speed at 30:15 intermittent fitness test, VO_{2max} = maximal oxygen uptake, HR_{max} = maximal heart rate, bpm = beats per minute. Data are mean ± standard deviation. Statistical difference after Benjamini-Hochberg correction: * = $p<0.05$, ** = $p<0.01$ versus FT; # = <0.05, ## = $p<0.01$ versus RES.

Table 3. Physical performance during training in elite academy under-18 (U18) and reserve (RES) teams and first team (FT).

	FB			CB			DM			OM			W			CF			TEAM		
Number of observations	**U18** *(26)*	**RES** *(13)*	**FT** *(36)*	**U18** *(19)*	**RES** *(16)*	**FT** *(32)*	**U18** *(11)*	**RES** *(6)*	**FT** *(30)*	**U18** *(26)*	**RES** *(7)*	**FT** *(15)*	**U18** *(7)*	**RES** *(9)*	**FT** *(27)*	**U18** *(16)*	**RES** *(2)*	**FT** *(19)*	**U18** *(105)*	**RES** *(53)*	**FT** *(159)*
Total Distance (m)	3027 ±697 ##	4335 ±669 **	3346 ±1068	5313 ±824 *#	4339 ±1154	4441 ±1144	5039 ±694 **#	3675 ±733	2748 ±1112	5854 ±1278	5255 ±706	4766 ±1026	6644 ±616 ##	4794 ±1465	5758 ±1038	3737 ±1388	3118 ±423	3155 ±1307	4701 ±1576 **	4415 ±1087	3974 ±1518
High-Speed Distance (5.5-7m/s, m)	51 ±44	104 ±160	92 ±106	339 ±178 **##	152 ±102	153 ±114	291 ±169 **	155 ±292	72 ±67	322 ±167 **	213 ±67	168 ±103	510 ±154 **##	145 ±56	179 ±74	134 ±226	42 ±9	102 ±153	239 ±209 **##	143 ±140	124 ±110
Sprint Distance (>7m/s, m)	7 ±13	6 ±9	15 ±29	131 ±160 **	31 ±53	31 ±32	64 ±133 *	7 ±16	1 ±4	129 ±99 **##	14 ±38	31 ±37	134 ±104 **	71 ±67	22 ±24	55 ±116	0 /	5 ±15	82 ±118 **##	25 ±48	17 ±28
Peak Speed (m/s)	6.75 ±0.73	6.95 ±0.57	5.80 ±1.99	7.68 ±0.66	7.20 ±0.94	7.43 ±0.63	7.36 ±0.63 *#	6.62 ±0.61	6.59 ±0.49	7.95 ±0.65 #	6.80 ±0.64	7.50 ±0.61	7.92 ±0.62	7.93 ±1.30	7.55 ±0.59	7.51 ±1.77	6.08 ±0.09	6.71 ±0.66	7.47 ±1.01 **	7.10 ±0.94	6.84 ±1.26
Mean Speed (m/min)	58 ±7 **	64 ±16 *	89 ±23	69 ±14 #	51 ±12 **	75 ±11	66 ±11 ##	47 ±7	61 ±11	73 ±10 #	59 ±10 *	75 ±7	78 ±10	67 ±8 *	82 ±10	66 ±13 #	43 ±6	63 ±11	67 ±12 *#	57 ±14 *	75 ±17
Time >85% HR_{max} (min:sec)	3:59 ±4:19 *	10:09 ±8:50	9:28 ±10:57	9:43 ±6:54	6:50 ±9:21	9:03 ±6:27	10:19 ±5:28	4:36 ±4:48	7:33 ±8:49	14:18 ±10:45 #	4:16 ±6:30	11:05 ±7:27	18:26 ±6:08	14:51 ±11:02	18:38 ±10:20	8:23 ±10:15	5:10 ±2:49	9:04 ±10:00	9:53 ±8:55	8:21 ±9:04	10:41 ±9:50

FB = full back, CB = center back, DM = defensive midfielder, OM = offensive midfielder, W = offensive winger, CF = center forward, HR_{max} = maximal heart rate. Data are mean ± standard deviation. Statistical difference after Benjamini-Hochberg correction: * = $p<0.05$, ** = $p<0.01$ versus FT; # = $p<0.05$, ## = $p<0.01$ versus RES.

Table 4. Physical performance during match in elite academy under-18 (U18) and reserve (RES) teams and first team (FT).

	FB			CB			DM			OM			W			CF			TEAM		
Number of observations	**U18** *(6)*	**RES** *(7)*	**FT** *(15)*	**U18** *(5)*	**RES** *(2)*	**FT** *(15)*	**U18** *(4)*	**RES** *(4)*	**FT** *(8)*	**U18** *(4)*	**RES** *(7)*	**FT** *(13)*	**U18** *(4)*	**RES** *(8)*	**FT** *(15)*	**U18** *(4)*	**RES** *(5)*	**FT** *(7)*	**U18** *(27)*	**RES** *(33)*	**FT** *(73)*
Total Distance (m)	10711 ±773	10974 ±877	10179 ±592	9851 ±710	10449 ±167	9317 ±876	11140 ±409	11210 ±372	11261 ±462	10381 ±1268	10969 ±1392	10956 ±750	10778 ±976	10641 ±909	10525 ±660	10444 ±1019	10579 ±942	8778 ±1533	10734 ±1007 *	10762 ±987 *	10195 ±1105
High-Speed Distance (5.5-7m/s, m)	751 ±137 **	718 ±154 **	516 ±125	395 ±121	446 ±144	357 ±94	552 ±151	537 ±132	421 ±95	592 ±137	603 ±121	599 ±159	699 ±117	708 ±117	603 ±110	671 ±82	658 ±80	468 ±193	612 ±155 **	622 ±159 **	501 ±156
Sprint Distance (>7m/s, m)	245 ±86	208 ±88	162 ±52	85 ±33	83 ±50	72 ±36	93 ±55	94 ±46	66 ±40	116 ±63	101 ±58	140 ±60	216 ±90	260 ±116	249 ±81	144 ±90	159 ±92	180 ±92	148 ±91	157 ±99	149 ±88
Peak Speed (m/s)	8.73 ±0.59	8.58 ±0.54	8.71 ±0.35	8.32 ±0.54	8.50 ±0.80	8.32 ±0.48	8.00 ±0.31	8.11 ±0.28	8.19 ±0.41	8.14 ±0.42	8.22 ±0.55	8.35 ±0.40	8.76 ±0.64	8.86 ±0.56	8.82 ±0.23	8.17 ±0.51	8.46 ±0.68	8.60 ±0.40	8.41 ±0.58	8.42 ±0.56	8.51 ±0.44
Mean Speed (m/min)	119 ±9 *	122 ±10 *	106 ±6	109 ±8	116 ±2 *	97 ±9	124 ±5	125 ±4	118 ±5	115 ±14	122 ±15	114 ±9	120 ±11	118 ±10	110 ±7	116 ±11 *	118 ±10 *	91 ±16	119 ±11 *	120 ±11 *	106 ±12

FB = full back, CB = center back, DM = defensive midfielder, OM = offensive midfielder, W = offensive winger, CF = center forward, HR_{max} = maximal heart rate. Data are mean ± standard deviation. Statistical difference after Benjamini-Hochberg correction: * = $p<0.05$, ** = $p<0.01$ versus FT.

4.4.2 Physical Performance: Training

4.4.2.1 Distance

In a regular training session, under-18 players covered 727m, 95% CI [345-1109] (ES 0.47-small, $F(2,314)=5.20$, $p=0.006$) more total distance than first-team players, whereas reserve players showed a similar, but not statistically significant trend (Table 3). This effect was also observed within some player positions. Of the total distance, 2-6% of this was in high-speed or sprint zones across the teams and player positions. Within these zones, under-18 players covered more high-speed distance than first-team players (ES 0.73-moderate, $F(2,314)=4.78$, $p=0.009$) and reserve players (ES 0.58-small, $F(2,314)=5.05$, $p=0.007$), as well as more sprint distance than first-team players (ES 0.84-moderate, $F(2,314)=12.24$, $p<0.001$) and reserve players (ES 0.57-small, $F(2,314)=9.64$, $p<0.001$), whereas no differences occurred between reserve and first-team players. This effect was also observed within some player positions.

4.4.2.2 Speed

Under-18 players achieved 0.63m/s [0.34-0.92] (ES 0.54-small, $F(2,314)=4.88$, $p=0.009$) higher peak speeds than first-team players, but not reserve players, whereas reserve players also tended to reach higher peak speeds than first-team players, but this did not reach statistical significance (Table 3). Within specific player positions, this finding was however less consistent.

We also calculated mean speed of training sessions, as an estimate of relative effort. For this, the situation was opposite to the above, as first-team players achieved 8m/min [4-12] (ES 0.52-small, $F(2,314)=3.79$, $p=0.024$) and 18m/min [13-23] (ES 1.10-moderate, $F(2,314)=4.19$, $p=0.016$) higher values than under-18 and reserve players, respectively. Some player position variability was observed, but reserve players in most positions achieved lowest mean speeds.

4.4.2.3 HR

No significant differences were observed between teams regarding time spent >85% of HR_{max}, but subgroup analysis indicated some player positions in under-18 and reserve teams to under-perform (Table 3).

4.4.3 Physical Performance: Match

4.4.3.1 Distance

In matches, academy players covered 5-6% more distance than first-team players: under-18 539m [56-1022] (ES 0.50-small, F(2,130)=3.51, p=0.034) and reserve 567m [122-1012] (ES 0.53-small, F(2,130)=3.49, p=0.034) versus first-team players (Table 4). Of the total distance, 6-10% of this was high-speed or sprint across the teams, with both under-18 (ES 0.71-moderate, F(2,130)=4.88, p=0.009) and reserve (ES 0.77-moderate, F(2,130)=4.96, p=0.008) players covering 18-20% more high-speed distance than first-team players, but not more sprint distance. These effects were not attributed to specific player positions.

4.4.3.2 Speed

In line with sprint distance, no peak speed differences were observed. For mean speed, the situation differed from training, as both academy teams played matches with higher mean speed than the first team: under-18 ES 1.11-moderate (F(2,130)=3.33, p=0.039) and reserve ES 1.20-large (F(2,130)=4.04, p=0.020) (Table 4). This was attributed to FB, CF and partly CB.

4.4.4 Physical Performance: Training versus Match

All teams covered >100% (all p<0.001) more distances in matches than in training (Figure 7: comparison of data in Tables 3 and 4), but training and match durations were not equalized so this may not solely reflect effort.

However, all teams also achieved >15% higher peak and >40% higher mean speeds in matches than in training, though ES of training-match differences indicate that academy and especially under-18 players were closer to reaching match requirements in training versus first-team players in terms of high-intensity efforts (high-speed and sprint distances and peak speed), but first-team players were closer to reaching match requirements for relative effort (mean speed). Subgroup analyses showed that team findings were replicated across player positions.

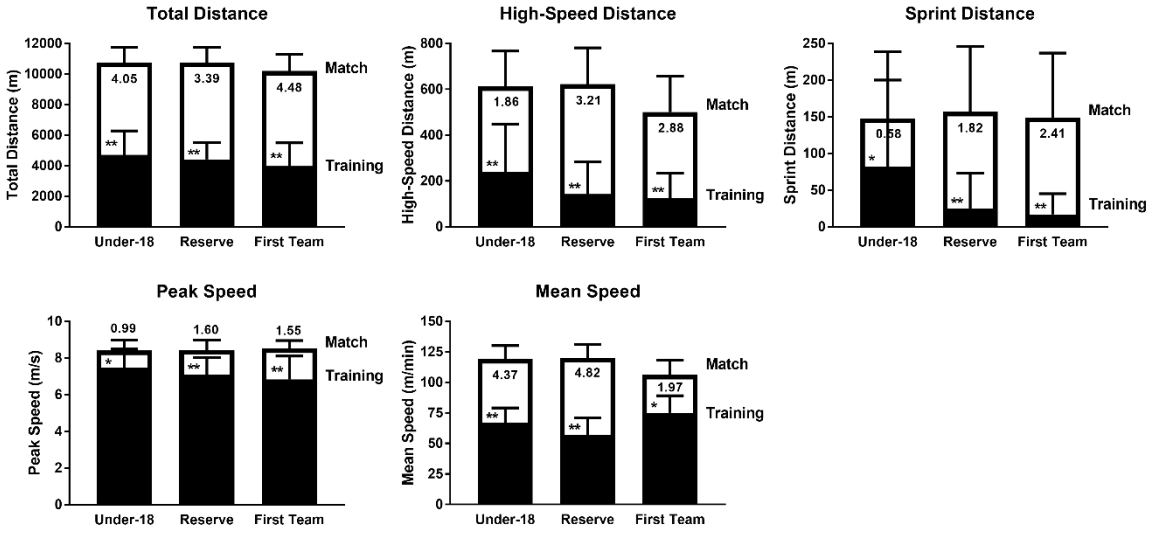


Figure 7: Physical performance in match versus training following comparison of training data in Table 3 (black bars) versus match data in Table 4 (white bars). Effect size (ES) of difference between match and training for the individual team is numerically indicated on the bars. Statistical difference match versus training * = $p<0.05$, ** = $p<0.01$.

4.4.5 Age-Dependent Effects

Since the variances within each team are not evenly distributed (e.g. first team has a wider range in player age, experience and history of training and competitions versus academy teams), we extracted sub-category data from defined age-groups within the different teams, with cut-points informed by maturational transitions (Table 5). Albeit a trend commensurate with maturation was observed in youth

players, no statistically significant differences occurred between the youngest and oldest under-18 team players.

However, in the comparison between the oldest (≥18years) reserve players versus youngest (≤23years) first-team players, an age-dependent effect occurred. The oldest reserve players covered more total (ES 0.92-moderate, p=0.008) and high-speed distances (ES 1.13-moderate, p=0.010) and achieved higher (ES 1.45-large, p=0.004) mean speeds versus the youngest first-team players.

Table 5. Age-specific physical performance during match in elite academy under-18 (U18) and reserve (RES) teams and first team (FT).

	U18		**RES versus FT**	
Number of players	**≤ 16 yo** (16)	**> 16 yo** (10)	**≥ 18 yo RES** (23)	**≤ 23 yo FT** (16)
Total Distance (m)	10129±715	10702±866	11287±1037**	10248±1253
95% CI	*[-72, 1218]*		*[293, 1784]*	
High-Speed Distance (5.5-7m/s, m)	599±175	673±174	642±142**	489±126
95% CI	*[-72, 219]*		*[63, 243]*	
Sprint Distance (>7m/s, m)	133±58	164±104	164±107	154±80
95% CI	*[-34, 96]*		*[-54, 74]*	
Peak Speed (m/s)	8.21±0.34	8.24±0.41	8.61±0.71	8.51±0.50
95% CI	*[-0.28, 0.34]*		*[-0.32, 0.52]*	
Mean Speed (m/min)	113±8	119±10	125±12**	107±13
95% CI	*[-1, 13]*		*[10, 26]*	

yo = years old, CI = confidence interval of the mean difference. Data are mean ± standard deviation. Statistical difference: ** = p<0.01.

4.4.6 Current versus Former Academy Players

Finally, we investigated if current academy players are on trajectory to reach first team standard, compared to previous academy-first team transitioners at comparable stages of development. For this, we identified 4 previous academy players that successfully transitioned to the first team and for whom we could retrieve comparable data (Table 6). This showed that current under-18 players in

most parameters were comparable to former under-18 players, but also that current under-18 players had deficits in aerobic capacity (21% lower $\dot{V}O_{2max}$, ES 2.81-very large, p=0.031) and relative effort exerted in training (109% lower mean speed, ES 6.15-very large, p=0.016), whereas at reserve team level, no differences occurred between current and former successful players.

Table 6. Former elite academy players that transitioned to first team (n=4) versus current academy players (U18 n=23, RES n=15).

	Former Academy - First Team Transition Players			
	Former U18 Mean±SD	**Δ versus Current U18** 95% CI	**Former RES** Mean±SD	**Δ versus Current RES** 95% CI
Player Characteristics				
Height (cm)	168.7±8.8	-9.4 [-34.8, 16.0]]	184.2±3.0	2.8 [-42.6, 48.2]
Body Mass (kg)	59.2±7.3	-9.8 [-33.8, 14.2]	72.2±3.0	-2.3 [-50.4, 45.8]
Skinfolds (mm)	50.3±0.6	-5.3 [-184.0, 173.4]	46.4±4.5	-10.5 [-92.8, 71.8]
$\dot{V}O_{2max}$ (mL/kg/min)	63.9±4.7 *	10.9 [4.5, 17.3]	56.8±5.1	5.0 [-1.4, 11.4]
Training Performance				
Total Distance (m)	3716±1879	-985 [-2143, 173]	5035±1231	620 [-2262, 3502]
High-Speed Distance (5.5-7m/s, m)	238±302	-1 [-154, 152]	338±206	195 [-783, 1173]
Sprint Distance (>7m/s, m)	44±62	-38 [-134, 58]	137±166	112 [-341, 565]
Peak Speed (m/s)	6.75±1.06	-0.72 [-1.50, 0.00]	7.98±0.79	0.88 [-7.70, 9.40]
Mean Speed (m/min)	140±5 *	73 [62, 83]	88±21	31 [-67, 129]
Match Performance				
Total Distance (m)	10721±909	-13 [-2243, 2217]	10768±717	6 [-12770, 12782]
High-Speed Distance (5.5-7m/s, m)	545±278	-67 [-369, 235]	519±179	-103 [-2587, 2381]
Sprint Distance (>7m/s, m)	84±67	-64 [-294, 166]	149±119	-8 [-1565, 1549]
Peak Speed (m/s)	7.60±0.24	-0.81 [-3.70, 2.00]	8.36±0.54	-0.06 [-8.50, 8.40]
Mean Speed (m/min)	114±13	-5 [-27, 17]	119±14	-1 [-175, 173]

U18 = under-18 team, RES, Reserve team, CI = confidence interval of the mean difference, $\dot{V}O_{2max}$ = maximal oxygen uptake. Data are mean ± standard deviation (SD). Statistical difference: * = $p<0.05$ versus current players.

4.5 Discussion

Several systemic factors explain low academy-to-first team transition in professional top-level football (Carpels et al., 2021; Dugdale et al., 2021). However, the notion here was that factors related to physical fitness and performances in training and match may also contribute, and therefore to suggest an approach whereby individual academy players are assessed for physical readiness for academy-to-first team transfer in an objective and evidence-based manner. For this, we compared physical fitness and performance profiles in training and matches between players of the respective teams, including after sub-division to player positions and age-groups and after comparison to previous successful academy-to-first team-transitioners. This generated benchmark requirements for individual players to meet in order to achieve upward transfer. These may be specific to the current club and context, but the approach will be transferable to other environments.

We found that academy under-18 and reserve players have not yet reached first team level physical fitness and stature, but are largely able to produce comparable physical performance outputs in training and matches. We also identified performance behaviours that misaligned academy to first-team players, which may raise the possibility that academy players can be sub-optimally prepared for first team transition. As such, this approach identifies specific deficits that may render current academy players less likely to achieve first team transition, but that may be overcome with appropriate training and conditioning. These development needs may vary between clubs and environments, but physical profiling will identify those and create local benchmarks that may inform and leverage local practice.

4.5.1 Physical Profiling

Previous studies have described similar benchmarking (Cone et al., 2012; Sporis et al., 2009) and examined physical characteristics and position-specific match demands (Bangsbo et al., 2006; Barnes et al., 2017; Bloomfield et al., 2007; Rampinini et al., 2007). However, these have not stratified into different development stages or across academy-reserve-first team environments. We show

for the first time that academy players have not yet developed comparable physical capacity to fully compete for first team transition, and nor have they fully developed body and lean mass, though the latter is not surprising (Milsom et al., 2015; Veale et al., 2010). Despite this, they show comparable physical performances in both training and match, although some performance behaviors differ between teams, e.g. high-intensity and average effort parameters. Such behavior differences may however also be linked to contexts and different tactical objectives. Nonetheless, capacity differences between academy and first teams may warrant rectification in academy players intending to progress to first team.

4.5.2 Physical Performance in Training and Match

First, it adds external validity that training and match performances in the present study were comparable to European elite football reported previously, though below the very high high-speed and sprint distances observed in English Premier League (Barnes et al., 2014; Rampinini et al., 2007; Di Salvo et al., 2007; Lago-Penas et al., 2009). Academy players performing at comparable or higher physical levels in training and matches than first-team players could be explained by several factors. Fixture frequencies and congestions vary, with first team typically experiencing 2-matches/week and academy teams 1-match/week microcycles, resulting in different load profiles (Carpels et al., 2024; Martin-Garcia et al., 2018; Swallow et al., 2021). Although we identified a 2-month period in the season with comparable fixture frequencies between teams for the match performance analysis, the different microcycles that dominate the season will likely also have affected training performances and accrued to spill-over affect match performances, despite the latter being recorded at a time with comparable microcycles. As a result of the different microcycles across the season, the first team trained fewer sessions, but to compensate, they trained at higher mean speed and relative effort (normalized to duration) and thus higher intensity, in line with previous reports (Carpels et al., 2024; Houtmeyers et al., 2021). This ultimately suggests that scheduling constraints also may dictate for between-team differences, which in first-team players results in a higher level of alertness and engagement with training; a trait which academy players may still need to fully develop.

Match physical performance may also be influenced by variable contextual and opposition effects (Rampinini et al., 2007). As such, it is possible that academy players exhibit end-to-end action with more high-intensity movements throughout the full match because they prioritize individual education and development objectives, and because they have less match management experience. In contrast, first-team players tend to be governed by the collective objective of securing a good result while minimizing physical effort (Kolodziejczyk et al., 2023). This was largely prevalent in this study, as the first team during the study period dominated and won the majority of matches and ended #2 in the domestic league. Although the academy teams also won the majority of their matches, match states and further contextual factors such as coaching priorities and tactics may ultimately still have contrasted player loads and match physical performances between teams.

4.5.3 Subgroups

The observed differences in physical profiles and performances appeared as systematic trends within teams that were not explained by distinct player positions, albeit some position-specific differences were noted. In contrast, an expected maturation effect occurred across the academy, where older players demonstrated higher physical performances than younger counterparts. Interestingly though, the oldest reserve players also out-performed age-matched first-team players, presumably because they were competing for individual first team transitions, whereas the youngest first-team players already had achieved this. Overall, the subgroup analyses, and especially the comparison between current and former retro-profiled successful academy players indicated the current players to be close to trajectory to reach benchmark standards, but also highlighted areas for continued development. However, the above may reflect the composition of the current teams this season. As such, indicators like these may identify interesting player prospects rather than systemic biases, although the latter possibility should not be excluded if trends continue over several cohorts of players.

4.5.4 Limitations

Interpretation of the current findings should be considered in light of key limitations, mainly single-club generalizability, unequal training and match contexts between teams, and analytical constraints.

We report a single-club study, single-season study. As such, the specific quantitative findings should only be generalized to other clubs, leagues or developmental systems with caution. , but the approach of applying comparative physical profiling to identify trends and development needs is generalizable. Additionally, subgroup analyses involved relatively small sample sizes due to player availability, which is inherently controlled by club operations and therefore difficult to control. While the primary conclusions derive from team-level data with adequate statistical power, subgroup results should be interpreted as indicative rather than definitive. Nevertheless, the broader approach of comparative physical profiling to identify developmental trends is transferable across performance environments.

Important contextual differences between teams with respect to training and matches limit comparisons. Different microcycles between first and academy teams (Carpels et al., 2024) means that between-team comparisons should be interpreted with caution. Practitioners should therefore incorporate contextual information when evaluating outcomes and making decisions. Furthermore, training sessions included exercises that may mask positional specificity, meaning that observed physical outputs may partly reflect individual behaviors rather than true position-specific demands. Also, training sessions were neither designed to fully replicate match conditions nor normalized to match durations. Consequently, the observation that training outputs do not reach match levels should not be interpreted as evidence of insufficient training per se, but rather as a reflection of different contextual constraints. This discrepancy is particularly relevant in academy settings, where reduced match loads create capacity for increased training loads.

Several analytical constraints also introduce additional uncertainty. Firstly, the use of historical data for retrospectively profiling previous academy players means that an unavoidable inter-device variability between systems (OptimEye X4 versus FieldWiz versus PlayerTek) may introduce systematic bias. While GPS technologies at these sampling frequencies have demonstrated acceptable validity (Johnston et al., 2014), we acknowledge that this comparison provides indicative benchmarks and contextual insight rather than absolute equivalence. Secondly, match data for players completing >60-<90mins were normalized to full match duration without adjustment for fatigue-related substitution effects, as substitutions may also have occurred due to tactical or injury-related factors (Rampinini et al., 2007). Thirdly, physical fitness was assessed using the 30:15 IFT. It provides an indirect estimate of cardiorespiratory fitness and VO2max, but is widely accepted in team sports for this purpose (Buchheit et al., 2011). Although test-retest reliability was not established in this cohort, others have reported high reliability in comparable cohorts (see Materials and Methods for detail). Finally, the study focuses exclusively on physical performance metrics; however, match outcomes and ultimately player development are also influenced by technical, tactical, and psychological factors (Morgans et al., 2023), but these were beyond the scope of this study.

4.5.5 Practical Applications

The described analytic approach can inform short- and long-term decision-making within a club, helping it to identify players or cohorts who may require targeted support during their development pathway. This includes players who may benefit from adjustment in areas such as body composition, aerobic capacity and training or match performance behaviors. Importantly, the first team data presented here should not be interpreted as universal performance thresholds, but rather as club-specific reference values that can inform individualized development decisions within this particular performance environment.

These reference values are inherently shaped by contextual factors, including playing style, coaching philosophy and training structure. E.g. clubs employing counter-attack or high-press strategies may demonstrate different physical profiles compared to more position-oriented clubs. Accordingly, practitioners are encouraged to interpret and develop such reference values within their own club context, using them as a guide rather than as fixed standards. When applied appropriately, club-specific profiling may identify interesting academy prospects as well as areas of concerns, enabling more informed and targeted follow-up interventions.

Although academy and first team players in the present study demonstrated broadly comparable physical performance profiles in both training and match, it would be incorrect to state that academy players have no development requirements. Rather, the findings highlight the importance of individualized follow-up and development pathways, as performance gaps and strengths may vary between players. In practical terms, transitions from academy to first team environments may be facilitated through progressive exposure to first team requirements, allowing players time to adapt to higher or differently structured loads before full integration.

The observation that academy players can achieve comparable or, in some cases, higher training and match external performance outputs than first-team players despite lower physical capacities further underscores the need for careful monitoring of internal load and recovery statuses. This suggests that practitioners should consider individualized recovery strategies and load management approaches across teams to support fatigue resistance, performance in high-intensity match actions, and injury risk (Andrade et al., 2020; Martins et al., 2021). Finally, where academy players compare favorably to first-team players, communicating this achievement may have positive motivational benefits that boost confidence.

4.6 Conclusions

Analytical physical profiling provides practical reference values from the first team that may be used to guide academy player development and assess and support transition readiness from a physical fitness and performance perspective. To optimize training and match practices, coaching staff should use these to target specific gaps in academy players while maintaining those aspects that already meet first-team standards. This ultimately allows for data-driven decision-making in clubs with regard to player logistics. Since these reference values are club- and context-specific, it is essential that each club establishes its own bespoke profiling frameworks.

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Chapter 5

Study 3: Substitutions in Professional Elite Soccer Increase Distance and High-Intensity Efforts

Study 2 demonstrated that differences in physical capacity between academy and senior players do not necessarily translate into proportionally different match performance demands, suggesting that physical readiness alone may not explain progression into senior football. This raised the question of whether opportunities to gain exposure to senior match demands may represent an important component of the post-formation process. Therefore, Study 3 examined the use and performance implications of player substitutions as a potential mechanism for managing match demands and providing exposure to senior-level competition.

5.1 Abstract

Physical performance in intense domains including distance covered and high-intensity actions are central for success in soccer. During a match, players need to appropriately distribute their capacity for intense match-play to last the full match. Substitutions may mitigate performance losses. Here, we investigated physical performance via global positioning system-tracked total distance, repeated high-intensity efforts (RHIE) and peak metabolic power, and result score impact, of substitutions in top division male professional elite soccer players (n=48) in 95 competitive matches over 3 seasons, featuring 253 substitutions. We found that full match-players showed 4% higher maximal oxygen uptake ($p<0.05$) versus substitution players. Relative distance covered in match was 50-74% higher ($p<0.01$) in players that substituted into the match versus players that played the full match or were replaced during the match. RHIE in match was 61-93% higher ($p<0.01$) in players that substituted into the match versus those that played the full match or were replaced during the match. These effects occurred in all player positions, and no home and away match differences occurred. Peak metabolic power did not differ between full-match or substitute players. Finally, we found that substitutions were 3-4 times more likely to improve match score than worsen it ($p<0.01$), especially substitutions between 60-80 minutes of the match. In conclusion, substitutions permit a team to maintain or increase physical performance, including high-intensity actions, during the course of a match.

5.2 Introduction

Soccer is an intermittent high-intensity sport with high physical demands (Bangsbo et a., 2006; Koudellis et al., 2025; Sporis et al., 2009), where as a result, physical fitness and the ability to generate high physical performances such as high-speed and sprint movements, accelerations, decelerations, and change of directions in short bursts during match-play becomes important for success (Helgerud et al., 2001; Reilly et al., 2000; Stolen et al., 2005; Wisloff et al., 1998). A high level of physical fitness allows players and teams to rapidly move across the field of play, cover high distances and engage in high numbers of high-intensity efforts, while also recover faster during periods of lower intensity play (Barnes et al., 2014; Bradley et al., 2009), with this trend observed across player positions (Bloomfield et al., 2007; Bush et al., 2015; Lago-Penas et al., 2009) and predicted to continue (Nassis et al., 2020).

Since matches last 90 minutes or more, with average physical output of a match already being high (Bangsbo et al., 2006; Stolen et al., 2005), but also with relatively low numbers of goals scored, it results in high-intensity actions characterized by high physical performance outputs in short burst high-pressure situations often becoming match-defining (Bortnik et al., 2024; Lobo-Trivino et al., 2025). Interestingly, high-intensity actions, as well as general physical performance, tend to reach higher levels in home matches (Barrera et al., 2021; Morgans et al., 2024). These actions associate with both a high demand for muscle energy availability and expenditure (Bangsbo, 1994a; Di Prampero et al., 2015), as well as muscle fatigue (Bangsbo et al., 2007; Gualtieri et al., 2023), so to sustain match physical performance, adequate energy supply and avoidance of fatigue in muscle becomes important, especially towards the end of matches and perhaps especially in home matches due to the above-described contextual observations. The consequence of inadequate energy and development of fatigue is reduced ability to generate force, which leads to inevitable declines in work-rate and deterioration of physical performance, as the match progresses (Castillo-Rodriguez et al., 2023; Harper et al., 2016). Muscle fatigue is difficult to measure directly during a match (Cosio et al., 2025), but indirectly and on the field, this has effectively been quantified as progressive and

substantial decreases in total distance and high-intensity efforts as matches progress (Padron-Cabo et al., 2018), and with only 3% of players displaying their most active period in the final 15-minute epoch (Mohr et al., 2003). Likewise, energy expenditure is also difficult to directly measure during a match, but measuring peak metabolic power, derived from global positioning system (GPS) time-motion data, provides an integrated metric for energy cost of accelerations, decelerations and sprint runs that thus evaluates metabolic demand and energetics of high-intensity actions in match-play (Di Prampero et al., 2015, Manzi et al., 2015), and where use of this approach has indicated that players spend a majority of their available energy on high-intensity actions (Osgnach et al., 2010). Hence, bursts of high-intensity actions are important for match outcome, but prone to decline in matches due to physiologic and metabolic state disturbances.

One strategy to mitigate physical performance declines in matches is by appropriate physical exercise training and conditioning in advance of matches (Helgerud et al., 2011), tailored to match-loads (Carpels et al., 2024), but another strategy is the use of substitutions during matches (Lorenzo-Martinez et al., 2022). Currently, most associations and competitions permit 5 substitutions/team/match, though in circumstances such as play-off extra-time, additional substitutions are permitted. Teams apply these variably depending on tactics, injuries, need to introduce new players, and need to replace under-performing or fatigued players (Hills et al., 2018; Reilly et al., 2008). A substitute as such is a player brought into the game during a stoppage in play, in exchange for a player being replaced and who may not take any further part in the match. However, the impact of substitutions on physical performance parameters remains unclear. While some studies have reported a moderately positive effect, especially in terms of high-speed, sprint and high-intensity efforts (Hills et al., 2018; Janusiak et al., 2024) and especially by midfielders or attackers being brought into the match (Bradley et al., 2014; Padron-Cabo et al., 2018; Russell et al., 2016), others have reported no change (Castillo-Rodriguez et al., 2023) or even detrimental effects (Sydney et al., 2023) on team physical performance when comparing performance parameters before and after substitutions. In addition, where changes following substitutions have been reported,

it remains unclear whether this has been due to superior performance in substitutes or inferior performance in those players being replaced and whether player position or home-away contextual circumstances affect the outcome.

The aim of this study was therefore to investigate physical performance outputs total distance, repeated high-intensity efforts (RHIE) and peak metabolic power, as well as impact, in competitive matches, in players who are substituded into the match (sub-in), players that are replaced (sub-out), and those that play the full duration of the match (full) in professional elite first-team soccer, including stratification into player positions and home or away matches. We hypothesized that sub-ins would display higher physical performance in comparison to players whom they replaced (sub-outs) and those who played the full match (full).

5.3 Materials and Methods

5.3.1 Experimental Approach to the Problem

Study design was observational, cross-sectional, longitudinal, with recordings from 95 competitive domestic and international matches, of which 46 were home and 49 away matches. Physical fitness measurements to characterize players were recorded at end of pre-season (August), and where individual players were recorded over several seasons, the average of measurements were calculated. Prior to physical fitness testing and matches, players warmed-up following club protocol.

5.3.2 Subjects

Subjects were 48 full-time male professional elite first-team soccer players from a Scottish Premier League club between 2017-18 and 2019-20 seasons competing in premier domestic (Scottish Premiership, Scottish Cup, Scottish League Cup) and international (UEFA Europa League) competitions; this included 5 full backs, 7 center backs, 18 center midfielders, 10 offensive wingers, and 8 forwards, with positions assigned by club (see Table 7 for player characteristics). Injured or post-injury

deconditioned players were excluded, while goalkeepers were excluded because of infrequency of substitutions and match physical performance requirements that substantially differ from outfield players. The study conformed to the Declaration of Helsinki, all procedures were approved by the Institutional Review Board (University of Glasgow), and all players provided written informed consent.

Table 7. Player characteristics.

	Team	FB	CB	CM	W	CF
Number of players	48	5	7	18	10	8
Age (years)	26.4±5.0 [23.9-28.9]	24.5±4.9 [18.2-30-6]	27.6±7.9 [20.3-34.9]	26.3±5.8 [23.4-29.2]	27.2±5.6 [23.1-31.2]	28.1±7.0 [22.2-33.9]
Height (cm)	183.8±5.5 [179.2-188.4]	179.6±6.2 [171.9-187.3]	183.5±6.9 [177.1-189.9]	181.2±7.2 [177.6-184.8]	181.9±5.5 [178.0-185.3]	186.0±8.8 [178.6-193.4]
Body Mass (kg)	79.1±5.1 [75.5-81.6]	77.5±5.0 [71.3-83-7]	79.7±4.5 [75.5-83.8]	78.8±6.2 [75.7-81.9]	79.1±4.9 [75.5-82.6]	85.5±5.9 [80.6-90.4]
vIFT (km/h)	21.3±1.9 [20.6-22.9]	21.3±0.9 [20.1-22.4]	20.6±1.3 [19.4-21.8]	21.9±1.8 [21.0-22.8]	21.0±1.6 [19.8-22.1]	19.6±1.8 [18.1-21.1]
VO_{2max} (mL/kg/min)	58.2±3.0 [57.0-59.4]	58.5±1.9 [56.1-60.9]	56.8±2.7 [54.3-59.3]	61.4±3.0* [59.9-62.9]	59.8±1.8 [58.5-61.1]	56.0±2.6 [53.8-58.2]
HR_{max} (bpm)	194±6 [192-196]	194±3 [190-197]	193±4 [189-197]	201±7 [197-204]	196±5 [192-200]	190±7 [184-196]

FB = full back, CB = center back, CM = center midfielder, W = offensive winger, CF = center forward, vIFT = maximal speed at 30:15 intermittent fitness test, VO2max = maximal oxygen uptake, HRmax = maximal heart rate, bpm = beats per minute. Data are mean±standard deviation and [95% confidence intervals]. Statistical difference: * = $p<0.05$ versus other player positions.

5.3.3 Procedures

5.3.3.1 Player Characteristics and Fitness

Age and body height and mass were recorded, and soccer-specific aerobic and anaerobic exercise capacity and change of direction ability was assessed by the 30:15 on-field Intermittent Fitness Test (IFT). Following progressively increasing running velocity and thus intensity, the test ceased when players consecutively 3 times failed to reach the required zone, whereupon the velocity of the last completed stage (VIFT) was recorded and taken as maximal performance. Maximal oxygen uptake (VO2max) was calculated: VO2max=28.3-(2.15xG)-(0.741xA)-(0.0357xW)+(0.0586xAxVIFT)+(1.03xvIFT), with G=gender (male: 1), A=age (years),

W=body mass (kg), and VIFT=maximal velocity of IFT (km/h) (Buchheit, 2008). Heart rate (HR) was also recorded, with highest recording taken as maximal HR (HRmax).

5.3.3.2 Match Observations

Grass pitch match physical performance data were collected by a wearable GPS tracking system (Catapult OptimEye S5 version 5.1.7, firmware version 7.18, Capapult Sports, Melbourne, Australia), with each device sampling GPS time-motion at 10Hz and triaxial accelerometry at 100Hz, which previously has been found to report valid and reliable metrics for locomotor activity, with intraclass variability ranging 0.88-0.99, error ranging 0.8-4.8%, and with no difference from higher-frequency sampling (Johnston et al., 2014; Theodoropoulos et al., 2020). To further avoid interunit errors, each player was assigned the same specific device. Devices were activated ~10mins prior to recordings started and worn according to manufacturer instructions in purpose-built vests. Mean number of connected satellites during recordings was 14±1 and the horizontal dilution of precision (HDOP) was 0.73±0.04; this is well within industry standards to accept signal quality (Malone et al., 2017). Measurements included total distance covered (m), RHIE, classed as a minimum of 3 consecutive high-intensity movements (defined as high-acceleration >2.78m/s2 or high-speed >19.8km/h) with a mean recovery time equal to or less than 20secs between each effort (Gabbett et al., 2013), and peak metabolic power, which utilizes the fact that acceleration and deceleration events on a flat surface are energetically equivalent to running at a constant speed on a slope, and if the acceleration is known from the GPS tracking system, it allows equivalent slope and equivalent mass to be calculated from the angle between the accelerating player and the ground, and the force the player is exerting on the ground. The metabolic energy cost of accelerating (in J/Kg) may then be calculated as:

$$\text{Energy Cost} = \text{Equivalent Slope} \times \text{Equivalent Mass} \times KT$$

where KT is a constant of 1.29 to account for extra energy needed to run on a grass pitch surface (Pinnington & Dawson, 2001) as opposed to running on a treadmill, from

which the original calculations were derived. Metabolic power (in W/Kg) may then be calculated as:

Metabolic Power = Energy Cost x Running Velocity

as previously established (Osgnach et al., 2010) and found reliable with coefficients of variation ranging 2.2-26.2% (Hoppe et al., 2017). From this, we identified peak metabolic power displayed during match-play in order to evaluate the metabolic requirement of high-intensity efforts.

5.3.3.3 Data Analysis

Data were processed and analyzed by OpenField Console software version 1.14 (Catapult Sports, Melbourne, Australia). Player characterization was by team and positional roles (Table 7) and by match roles (Table 8): those who played the full duration of the match (full), those substituted out of the match (sub-out) and those substituted into the match (sub-in). For Table 8, since players invariably rotated between playing full matches, featuring as sub-outs or sub-ins, or did not play at all, we did not designate specific players to match roles; instead, we characterized match roles by those players that in any match participated as full, sub-out or sub-in players; i.e. a match may include e.g. 7 full, 3 sub-outs and 3 sub-ins from 10 out-field players, with goalkeepers being excluded, and consequently individual player data contributed with a log as either full, sub-out, or sub-in player following each match participation, or none at all if they did not actively play. Data for substitutions occurring <10mins of match end were excluded from analysis of player physical performance as short substitutions were deemed insufficient to ascertain accurate performances. Total distance and RHIE were normalized to time to enable comparisons between players that played different match durations, whereas peak metabolic power was normalized to body mass to enable comparisons between players of different sizes. Finally, matches were also divided into home and away, and impact of substitutions was assessed by whether final match score improved, worsened, or remained unchanged after a substitute was introduced.

5.3.4 Statistical Analysis

Calculation of sample size of players was impractical since the club managed players, but calculation of sample size of substitutions based upon expected minimal differences and standard deviation (SD) of observed parameters from previous experience (Carpels et al., 2024), with α=0.05 and ß=0.2 (80% power), indicated that 16 substitutions would be required for analysis of discrepancies between players that played full match durations or were substituted into or out of the match, allowing us to segregate team observations into player positions. The Shapiro-Wilk test confirmed normal distribution of data (observed range p=0.34-0.86) and by observing data distribution in Q-Q plots. Intergroup differences were established by 1-way analysis of variance (ANOVA) and Bonferroni post-hoc tests, differences between 2 groups were established by independent samples t-tests, and categorical match outcomes were analyzed by Pearson's χ^2 test, with statistical significance level $p<0.05$ (SPSS version 27, IBM, Chicago, IL). Effect size (ES) was analyzed using Cohen`s d, with interpretations as trivial (<0.2), small (>0.2), moderate (>0.6), large (>1.2) and very large (>2.0) (Hopkins et al., 2009). Retrospective post-hoc statistical power of observations was calculated, with α=0.05. Data are presented as means±SD and 95% confidence intervals.

5.4 Results

In total, 253 substitutions fulfilling the entry-criterium of not occurring in the last 10mins of match were observed; i.e. ~2.7 substitutions/match. The sub-ins included 27 full backs, 20 center backs, 64 center midfielders, 67 offensive wingers, and 75 center forwards, whereas the sub-outs included 22 full backs, 11 center backs, 98 center midfielders, 74 offensive wingers, and 48 center forwards; hence, 80% of substitutions involved attacking players, but sub-ins did not mirror sub-outs. Most of the substitutions occurred in the second half and especially within the 60-90mins period (Figure 8).

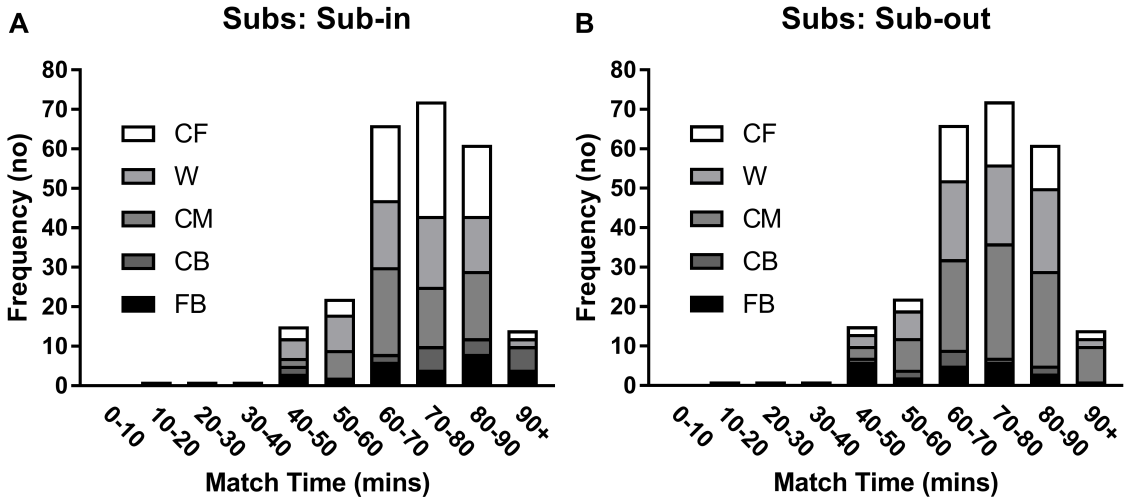


Figure 8: Substitution frequencies according to player position and time of substitution; A: substitutions into match (Sub-in); B: substitutions out of match (Sub-out, replaced players). FB (full back), CB (center back), CM (center midfielder), W (offensive winger), and CF (center forward)

Table 7 shows characteristics of the team and player positions. IFT performance did not differ between positions, indicating inseparable aerobic and anaerobic endurance and change of direction capacities, but calculated VO2max was 5% (ES 0.8-moderate) higher in center midfielders. Table 8 shows that player characteristics age and HRmax segregated between match roles, and that those who played full matches presented with 4% (ES 0.7-moderate) higher calculated VO2max than those who were substituted out of or into the match.

Relative distance covered in match was highest in players who were substituted into the match (sub-ins) versus those who played the full match (ES 1.5-large, 74%) or were replaced during the match (sub-outs; ES 1.4-large, 50%). This was observed in all player positions (ES range 0.8-moderate-1.6-large) (Figure 9A). No differences occurred between full and sub-out players, and no differences occurred between home and away matches (Figure 9B).

Table 8. Player characteristics of those that play full matches and appear in substitutions.

	Full	Sub-Out	Sub-In
Counts	697	253	253
Age (years)	28.1±3.9* [27.5-28.7]	26.0±5.2* [24.9-27.1]	23.4±5.7* [22.4-24.4]
Height (cm)	183.9±4.8 [182.5-185.3]	182.8±5.9 [181.1-184.5]	182.1±5.0 [180.6-183.6]
Body Mass (kg)	79.3±5.4 [77.7-80.9]	78.6±6.2 [76.8-80.4]	76.7±7.3 [74.5-78.9]
vIFT (km/h)	22.2±1.5 [21.6-22.6]	21.4±1.5 [20.7-22.0]	21.5±1.9 [20.9-22.0]
VO_{2max} (mL/kg/min)	59.0±2.7* [58.2-59.8]	57.5±2.4 [56.8-58.1]	56.9±2.8 [56.1-57.7]
HR_{max} (bpm)	191±4* [189-193]	195±3* [193-197]	198±5* [196-200]

Full = full match, Sub-Out = substituted out of match, Sub-In = substituted into match, vIFT = maximal speed at 30:15 intermittent fitness test, VO2max = maximal oxygen uptake, HRmax = maximal heart rate, bpm = beats per minute. Data are mean±standard deviation and [95% confidence intervals]. Statistical difference: * = p<0.05 versus other player positions.

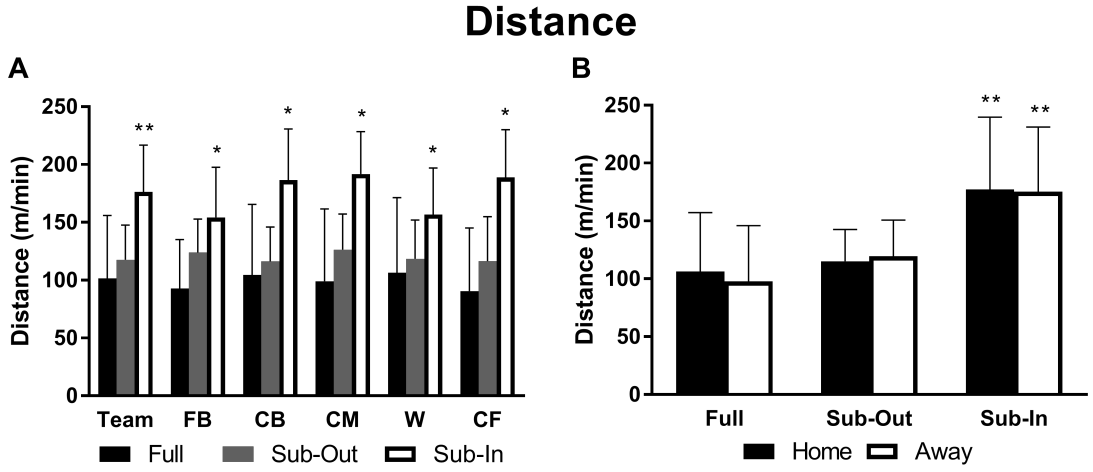


Figure 9: Relative distance in match; A: comparison between players that played full duration of match (Full), players that were substituted out of match (Sub-Out, replaced) and players that were substituted into match (Sub-In) in team and player positions FB (full back), CB (center back), CM (center midfielder), W (offensive winger), and CF (center forward); B: comparison between Full, Sub-Out and Sub-In players in home and away matches. Substitutions occurring in last 10mins of match were excluded. Statistical difference Sub-In versus Full and Sub-Out **=p<0.01, *=p<0.05.

RHIE in match was highest in players who were substituted into the match (sub-ins) versus those who played the full match (ES 1.8-large, 93%) or were replaced during the match (sub-outs; ES 1.4-large, 61%), and this was observed in all player positions (ES range 0.9-moderate-1.3-large) (Figure 10A). No differences occurred between full and sub-out players, and no differences occurred between home and away matches (Figure 10B).

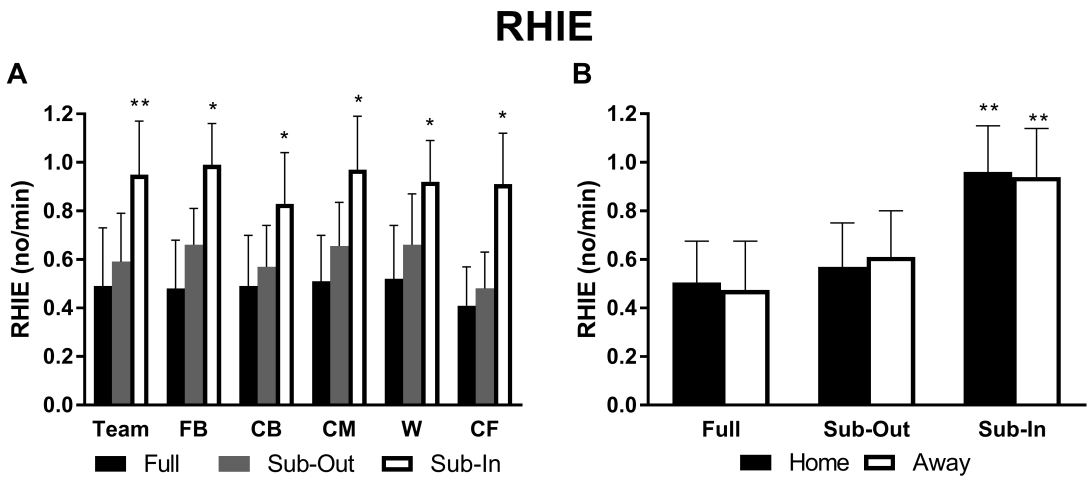


Figure 10: Repeated high-intensity efforts in match; A: comparison between players that played full duration of match (Full), players that were substituted out of match (Sub-Out, replaced) and players that were substituted into match (Sub-In) in team and player positions FB (full back), CB (center back), CM (center midfielder), W (offensive winger), and CF (center forward); B: comparison between Full, Sub-Out and Sub-In players in home and away matches. Substitutions occurring in last 10mins of match were excluded. Statistical difference Sub-In versus Full and Sub-Out **=p<0.01, *=p<0.05.

Peak metabolic power in match did not differ between those who played full matces or were substituted out of or into matches (Figure 11A), but it reached higher values in home versus away matches for all of full (ES 1.6-large, 95%), sub-out (ES 1.1-moderate, 46%) and sub-in (ES 1.3-large, 59%) players (Figure 11B).

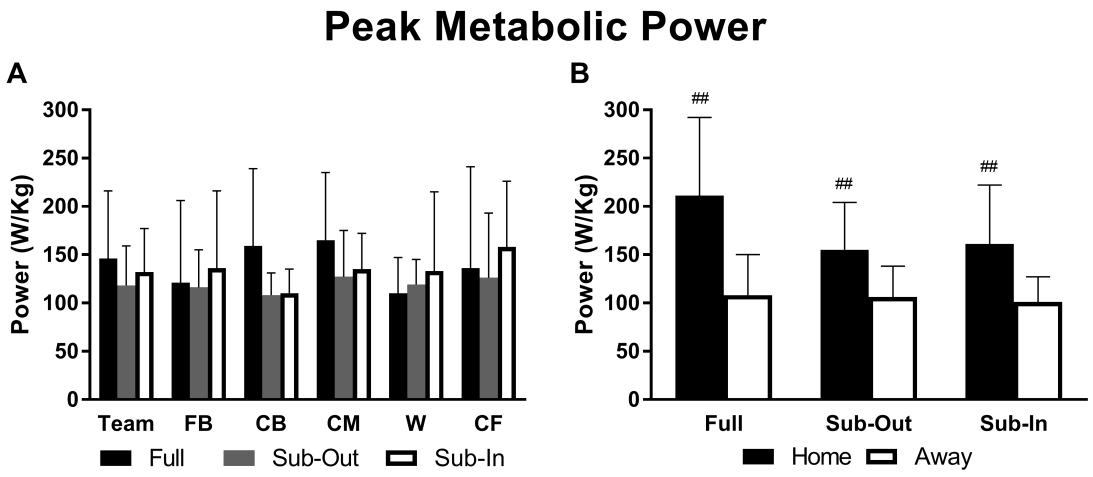


Figure 11: Peak metabolic power in match; A: comparison between players that played full duration of match (Full), players that were substituted out of match (Sub-Out, replaced) and players that were substituted into match (Sub-In) in team and player positions FB (full back), CB (center back), CM (center midfielder), W (offensive winger), and CF (center forward); B: comparison between Full, Sub-Out and Sub-In players in home and away matches. Substitutions occurring in last 10mins of match were excluded. Statistical difference home versus away ##=$p<0.01$.

Finally, we assessed the impact of substitutions on match outcomes. There was a clear statistically significant association between substitutions and match result, as introduction of sub-ins was 3-4 times more likely to improve match score than worsen it, regardless of whether this was quantified per match (Figure 12A) or per individual substitution (Figure 12B). When impact of individual substitutions was displayed relative to the match epoch they occurred in, it appeared that sub-ins introduced between the 60th and 70th minutes, and to a lesser extent between 70th and 80th minutes of the match, had the highest likelihood of improving match score (Figure 12C).

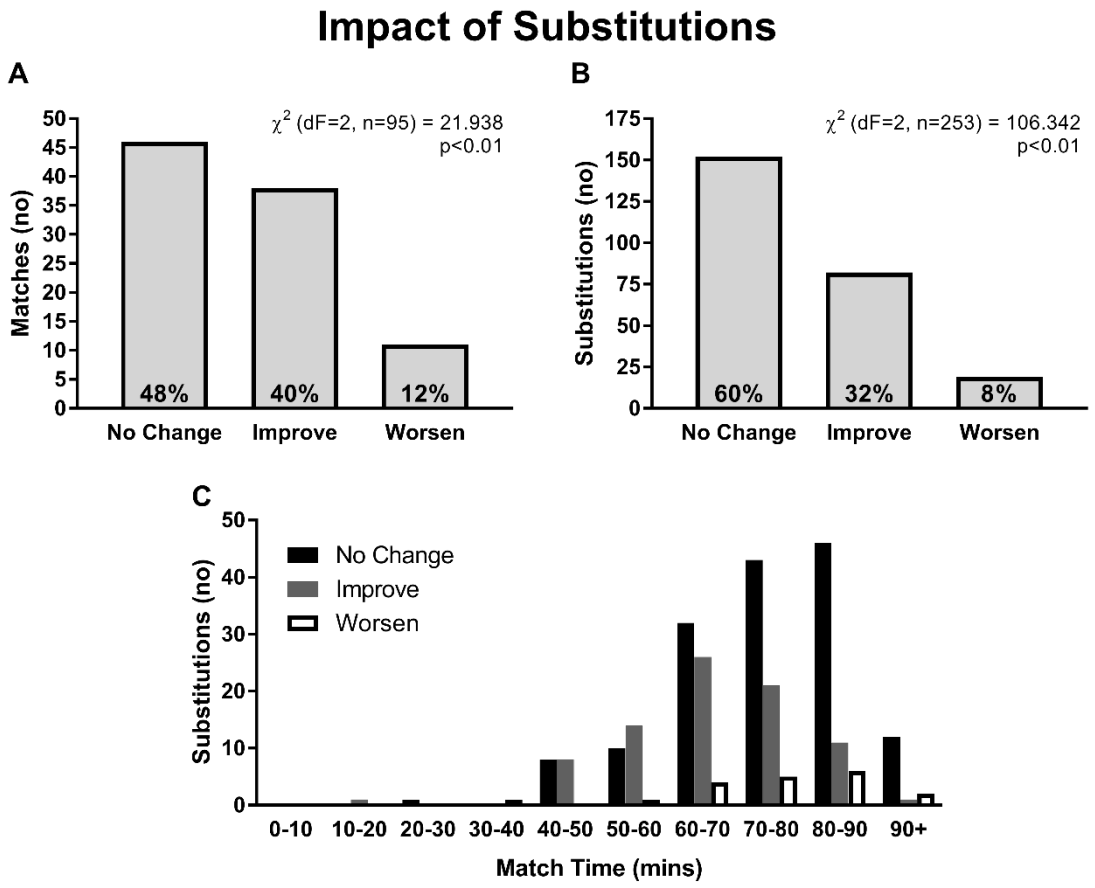


Figure 12: Impact of substitutions on match score; A: per match; B: per individual substitution; C: per individual substitution in different epochs of match. Categorical match outcomes were analyzed by Pearson's x^2 test.

5.5 Discussion

Several lines of evidence have suggested that high-intensity actions may increase the chance of a positive outcome in soccer matches, as reviewed in the introduction. The present study was therefore assessing the potential that introducing substitutions into the match may effectively permit more of those high-intensity actions, since starting players in most cases need to extend their performance to a longer period of the match and at the time of the substitution may already be experiencing fatigue, and consequently introduction of substitute players may positively affect team performance and consequently match outcome. Our observations confirmed this hypothesis, as we found that both relative distance covered and RHIE were highest

in sub-ins and that sub-ins more often than not improved the match result, even if sub-ins may have lower physical fitness than players that start and play full matches. Thus, from the time of a substitution, team work rate and high-intensity actions increased when comparing relative distance covered and repeated high-intensity efforts in sub-ins versus sub-outs and those that played the full match.

Substitution-induced increases in work rate and high-intensity actions were not explained by peak metabolic power; a soccer-specific measure of energy demands derived from high-intensity actions (Di Prampero et al., 2015; Manzi et al., 2014; Osgnach et al., 2010), although we did observe that players were capable of generating higher peak powers in home matches, possibly contributing to home advantage (Pollard & Gomez, 2009). The observed association was also not caused by any specific player positions outperforming others, meaning that at least in our study, coaches need not consider whether substitutions in specific player positions may systematically be more advantageous or disadvantageous than others with respect to generating a physical performance impact, although they may of course consider specific match scenarios and individual players with regard to other metrics they may have but are not on display in this study, e.g. specific match demands, injuries, player performances in other metrics, available player strengths and weaknesses, and opposition strengths or weaknesses.

There are many reasons to substitute players during the course of a match: fatigue, injury, changing match demands, opposition effects, the need to introduce new, development, or returning-from-injury players into the match, and to rotate match-time between available players in the squad (Hills et al., 2018; Reilly et al., 2008). This study showed that physical under-performance in a player is however rarely a reason for replacing players during a match; under-performance may have been perceived by coaches and this may have instigated a substitution, but objectively measured performance may not support this. However, and importantly, physical performance of the team, at least with respect to high-intensity actions and distance covered on the pitch, noticeably increases with each substitution, in a manner that is more likely than not to positively affect the match outcome, such that substitutions are still warranted. This is in line with previous studies also showing a

positive impact of substitutions, albeit via different parameters (Bradley et al., 2014; Hills et al., 2018; Janusiak et al., 2024; Padron-Cabo et al., 2018; Russell et al., 2016), but the findings that enhanced physical performance closely associates with improved match score outcomes and that match home or away locations or specific player positions do not affect substitution effects on high-intensity and distance performance parameters, are novel. While it has previously been shown that match locations (Chaize et al., 2024; Lago-Penas & Lago-Ballesteros, 2011) and player positions (Bangsbo et al., 2006; Barnes et al., 2014; Bloomfield et al., 2007; Bush et al., 2015) contribute to team performance in distinct proportions, these have not previously been linked to substitutions in the manner we show in the current study.

Matches account for ~25% of total weekly internal and external loads in teams playing 1 match/week (Impellizzeri et al., 2005) or more when they play 2 matches/week (Carpels et al., 2024), and this is true also in teams at lower or junior levels (Dalen & Loras, 2019). As a result, this may partly explain why those who play full matches present with higher aerobic fitness versus those that do not, but more important in this context is that the fatigue widely reported in soccer players (Bangsbo et al., 2007; Castillo-Rodriguez et al., 2023; Gualtieri et al., 2023; Harper et al., 2016; Mohr et al., 2003; Reilly et al., 2008) is also largely attributable to matches, which substitutions may mitigate. Our observation that substitutions largely do not decrease team physical performance – in fact have the opposite effect – suggests that effectively and strategically utilizing substitutions could disperse high weekly loads across a larger base of players. With the recent regulations change to allow 5 substitutions per match, this allows teams to disperse high weekly loads to an even larger base of players.

We acknowledge several limitations. First, we observed that many players across the analyzed matches appear in all categories of full, sub-out, and sub-in players over the study period, and therefore we cannot categorically characterize a player as a substitute player or as a player that started and played full matches; but we can count each occurence a player made in the various categories of full, sub-out, and sub-in roles. Hence, the profiles or full, sub-out, and sub-in players in Table 8 may

be prone to some stochasticity, but a comparison between them still had sensitivity to indicate that more mature and more fit players tended to be selected to start and complete matches, in line with previous studies (Bangsbo et al., 2006; Filho & Butterworth, 2021; Stolen et al., 2005).

Secondly, we did not include substitutions from the last 10 minutes of matches in the analysis of physical performance as they were deemed insufficient to ascertain accurate performances; however, we ackowledge that very late substitutions may still affect match outcome and therefore were included in the match outcome analysis, for example if defensive players are brought in to secure a match result, which in Figure 12C may appear as a "No Change" but effectively may be a positive contribution.

Thirdly, we also note that the current team was very successful during the period of study, with national top league top-3 placements and European competition participation in each season. This specific context may have resulted in opposing teams adjusting their match tactics (Rampinini et al., 2007), as well as resulting in match requirements changing during the course of matches, e.g. from a match starting with a draw result to a lead result at the time of substitutions, which may have affected starting and sub-in players differently. Our observations may have been influenced by this scenario; nonetheless, the impact of substitutions on physical performance was clear and likely also applies to teams at different levels of competition, even if the match score outcome may not compare to the current study. This supposition is supported by other studies indicating that match performance in general is facilitated by high physical capacity and high physical performance (Helgerud et al., 2001; Reilly et al., 200; Stolen et al., 2005; Wisloff et al., 1998), and by studies of lower-level and youth players indicating a comparable effect (Sydney et al., 2023).

Finally, our observations being of a single team may reduce the external validity, but the 3-year period of observation and the extensive number of observations adds strength. To quantify this, we calculated statistical power of the observations. This showed that for within-team comparisons between sub-ins and full and between sub-

ins and sub-outs where significant differences occurred, that the observed power was high: for VO2max it was 78.5%, and for distance covered and RHIE it was 90-100%. For comparisons within player positions, it ranged 75-95%. Hence, the observed statistical power gives reason to assume a high confidence in our results. This is also supported by the fact that our results are comparable to previous results, where similar parameters have been measured in comparable studies (Bradley et al., 2014; Castillo-Rodriguez et al., 2023; Hoppe et al., 2017; Janusiak et al., 2024; Mohr et al., 2003; Padron-Cabo et al., 2018). This therefore adds external validity.

In conclusion, we note that high physical capacity and performance in players will facilitate match performance and that good strength and conditioning strategies in the club will increase physical capacity in a manner that permits players to display higher physical performances in matches and thereby positively influence match performance, but this may not be enough. Our study however complements this by showing that good match management by coaches, whereby substitutions are used strategically, may also permit a team to further increase physical performance, including high-intensity actions, during the course of a match, in a manner that further and positively influenced match performance. We found that introduction of sub-ins increased relative distance covered and RHIE in a match, even when the sub-out players that were being replaced were not under-performing and even when sub-ins present with lower physical fitness than those who play full matches, and that this improved the match result. Hence, each substitution is likely to increase work rate and high-intensity actions in a team.

5.6 Practical Applications

The current observations inform decision-making and practice regarding substitutions in a manner that directly and immediately benefits soccer teams and which coaches may use to their advantage. First, coaches should note the positive impact substitutions may have to a match, even when starting players are not under-performing and there may not as such be a perceived need to replace any player. Secondly, coaches should note that since there is no evidence to suggest that

substitutions to specific player positions or in specific home/away scenarios affect physical performance more than others, it opens up the possibility that substitutions may evenly rotate across the team in order to equalize match loads between the nominal starting players in the team, independent of match location, which may have long-term benefits for avoiding injuries and managing fatigue (Garcia-Aliaga et al., 2023). At least from a high-intensity physical performance perspective, there is no need for the majority of substitutions being limited to attacking players, as we and others (Bradley et al., 2014; Padron-Cabo et al., 2018) have observed, and moreover, there is no reason to not utilize all available substitutes in a given match, including after regulations changed to allow 5 substitutions. Thirdly, our data suggest that substitutions are more beneficial if they occur relatively early in the second half, such as the 60-70 and 70-80mins epochs, which is a period of the match where fatigue may start to compromise starting players (Bradley et al., 2014; Padron-Cabo et al., 2018), and there is still adequate time for sub-ins to affect the match. Finally, a different factor that may counter the above suggestions is that substitute players often present with a lower level of fitness, as observed in the current and previous (Filho & Butterworth, 2021) studies, but when this is uncovered by fitness testing, it could be mitigated by delaying the introduction of less-fit substitutions towards the end of matches, or prospectively by appropriate strength and conditioning interventions to create fitness equity within the squad, including for high-intensity effort capacity, such as e.g. soccer-specific speed- and high-intensity training drills (Bangsbo et al., 2025; Hoff et al., 2002) and small-sided match-play (Savoia et al., 2021) protocols that enhance soccer-specific capacity. Applied systematically, these practices are likely to improve match physical performance and thereby match results.

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Chapter 6

Study 4: Mind The Gap: Comparison of External Load and Load Variation Between a Reserve Team in a One-Game Week Microcycle and its First Team in a Two-Game Week Microcycle within an Elite Professional Soccer Club

Study 3 highlighted the importance of exposure to senior match demands during the post-formation phase and demonstrated that opportunities to experience these demands may be influenced by how players are utilised in competition. This raised a further question regarding whether the training environments provided to developing players adequately prepare them for the demands of senior football. Therefore, Study 4 compared the physical characteristics and training and match demands of academy, reserve, and first-team players to examine how training exposure aligns with the requirements of senior competition.

6.1 Abstract

The aim of this study was to quantify and compare weekly external load and within-week load variation of reserve-team players (RES) in a one-game week microcycle to first-team players (FT) in a two-game week microcycle within the same professional soccer club. External load data were collected between 2017 and 2020 for the following parameters: duration, total distance (TD), total high-speed distance (THSD; >19.8 km·h^{-1}), high-speed distance (HSD; 19.8-25.2 km·h^{-1}), sprint distance (SpD; >25.2 km·h^{-1}), number of sprints (number of efforts >25.2 km·h^{-1}), number of high-speed efforts (number of HS efforts >19.8 km·h^{-1}), meters/minute and high-speed meters/minute. FT were subcategorized into starters (ST) and non-starters (NST). Inter-group differences in cumulative weekly load and weekly load patterns were statistically analyzed, while training monotony (TM) was quantified to assess intra-group within-week load variation. RES showed similar cumulative weekly loads to ST, apart from significant differences ($p<0.005$) in duration (8%), TD (21%) and HS efforts (16%). Like ST, RES showed greater values than NST ($p<0.0005$) for duration (18% and 10% compared to ST and RES respectively), TD (28% and 9% respectively), THSD (36% and 30% respectively), HSD (34% and 26% respectively), SpD (46% and 45% respectively), sprints (40% and 40% respectively) and HS efforts (33% and 22% respectively). Weekly patterns in RES were different from ST and NST ($p<0.05$). TM was highest for NST for all parameters, apart from number of sprints. RES need to be prepared to cope with cumulative weekly loads and recovery patterns between games that ST face. However, when RES become NST, effective loading strategies need to be designed within the limits of two-game week microcycles to ensure continuous development.

6.2 Introduction

The transition from academy to senior level is an important developmental stage for soccer players as it often represents a key breakthrough that largely defines a player's future career trajectory, but it is also one of the most challenging barriers players face, because in any given European top-level club, each year only one or very few club-trained players with no previous senior experience will on average appear in competitive first team games (Carpels et al., 2021). This is further illustrated by the limited amount of game time players under the ages of 21 and 22 are granted at senior level (~10 and 13 minutes, respectively) (Carpels et al., 2021). To successfully progress from late-stage academy (i.e. ≥U18s), players need to meet first team technical, tactical, mental, and physical requirements in both training and games in order to competitively perform with the first team and in the first team environment. This remains challenging, as physical match demands increase from academy to first team levels and have gradually diverged to widen the gap between those levels, in particular with respect to high-intensity actions (Barnes et al., 2014; Bradley et al., 2009; Buchheit et al., 2010; Bush et al., 2015; Coppalle et al., 2021). In addition, physical and physiological capacities display age-dependency and exerted training loads display age-specificity, which further compounds the issue (Barnes et al., 2014; Buchheit et al., 2010; Coppalle et al., 2021; Houtmeyers et al., 2021).

To maintain or improve physical capacity in-season, periodization blocks as part of a considered, systematic training plan have become common. The intention is to maximize adaptation by appropriately balancing functional overload with adequate recovery (Bompa & Buzzichelli, 2019; Casamichana et al., 2013; Impellizzeri et al., 2004; Kelly & Couts, 2007). Several layers exist, but a microcycle structure (i.e. one week duration/cycle) is the shortest but in practice the most detailed structure (Kelly & Couts, 2007; Martin-Garcia et al., 2018). This fills consecutive training and recovery days with focus and content and is organized around at least one competitive game, usually played during the weekend. Each day within the microcycle is labelled according to its proximity to the previous and/or following

match (i.e. match day (MD) +/- days to/from match) (Martin-Garcia et al., 2018). Depending on a team's game schedule, microcycles include recovery, loading, preparation and performance phases, and are generally well applied to teams that play one competitive game/week, as this allows for acquisition training sessions where strength and conditioning loading may enhance physical preparedness. Academy and reserve teams commonly adopt such one-game week microcycles. In contrast, competitive senior first teams regularly face congested fixture periods with games every 3-4 days, due to specific seasonal phases and/or involvement in multiple concurrent competitions (domestic league, cup, international tournament). Such two-game week microcycles are significantly more challenging as players accumulate fatigue due to incomplete recovery (Carling et al., 2012b; Dellal et al., 2015; Rollo et al., 2014). As a result, fitness and performance may drop significantly and players may be exposed to increased injury risks, and therefore, the main focus during two-game week microcycles shifts to optimizing recovery and maximizing player availability (Dupont et al., 2010).

It is reasonable to suggest that the one- vs two-game week microcycle difference between academy and reserve teams vs first teams adds further challenge to the academy-to-senior transition and may even slow individual development of late-stage academy players if they participate in two-game week microcycles. However, to the authors' knowledge, differences in weekly external loads incurred by one- vs two-game week microcycles in a late-stage academy team and a first team, respectively, have yet to be investigated. The present study therefore aimed to compare and contrast the weekly external load of an academy/reserve team in a one-game week microcycle with that of a first team in a two-game week microcycle within the same professional soccer club. We hypothesized that significant microcycle-associated variation exists between teams and therefore that academy and reserve players may be underprepared to compete in the first team environment.

6.3 Methods

6.3.1 Experimental Approach to the Problem

The aim of this study was to quantify and compare weekly external loads of a reserve team that also included late-stage academy players in a one-game week microcycle to a first team in a two-game week microcycle within the same professional soccer club. Using global positioning systems (GPS), data were collected over 3 seasons (2017-2018 to 2019-2020); the latter cut short by the COVID-pandemic. Microcycles were recording throughout regular match-seasons, but not pre- and post-seasons. A total of 50 two-game week microcycles with 260 training sessions and 100 competitive games were analyzed for first-team players (4649 individual observations), while 31 one-game week microcycles with 111 training sessions and 31 competitive games were analyzed for reserve-team players (867 individual observations). No individual or rehabilitation sessions were included, or gym or other indoor sessions. Training sessions and games were performed on natural grass pitches exclusively, within pitch dimensions of 105x68m. Data for training sessions were only considered for players who took part in entire sessions. Skewed data following malfunctioning equipment or incorrect recording were excluded (<1% of total data).

6.3.2 Subjects

Data from 91 first-team players (age: 26.0±5.2 years, range 19-35 years; height: 183.4±6.0 cm; body mass: 79.0±5.9 kg) and 55 reserve-team players (age: 17.2±1.2 years, range 16-19 years; height: 179.4±7.5 cm; body mass: 71.1±7.7 kg) were included. First-team players averaged 212 senior club appearances and 24 international team appearances per player. Both first-team players and reserve-team players were registered at the same professional soccer club that competed in the Scottish Premier League and the Union of European Football Associations (UEFA) Europa League. For the purposes of this study, any player was deemed a first-team player or a reserve-team player according to which team they trained with, and when transfers between teams occurred, their team designation also changed; if a transfer

occurred mid-microcycle week, recording in that week would stop and a new recording re-start at start of next full week, and hence only complete weeks were used for analysis to preserve the integrity of microcycles. All positions of outfield players were included (29 center backs (CB), 26 full backs (FB), 41 center midfielders (CM), 24 offensive wingers (W) and 26 center forwards (CF) within a 4-3-3 formation), except goalkeepers (GK) as they represent a specific activity profile that was deemed irrelevant for inclusion. This study was carried out in accordance with the Declaration of Helsinki. Data collection and management of both training sessions and games is part of the club's daily operations and while players' consent for monitoring was assumed to be part of their contractual conditions, all players or in the case of under-18 players, all players and parents/guardians also provided additional written informed consent as study participants. This study was approved by the institutional review board (University of Glasgow).

6.3.3 Procedures

6.3.3.1 External Load

External load measures were captured using a micro-electrical mechanical system (MEMS) device (Catapult OptimEye S5, 52x96 mm, version 7.18, Catapult Sports, Melbourne, Australia). Each device contained a global positioning system (GPS) component and tri-axial accelerometer, sampling at frequencies 10Hz and 100Hz, respectively. This has been reported to provide valid and reliable estimates of locomotor activity, with intraclass variability typically ranging 0.88-0.99, error typically ranging 0.8-4.8%, and with no difference from higher-frequency recordings (Johnston et al., 2014; Theodoropoulos et al., 2020). Each individual player was consistently assigned their own specific device in order to avoid interunit error. Devices were activated ~10 min prior to each session and were worn using a specifically designed vest provided by the manufacturer that held the device firmly between the player's scapulae. The mean number of satellites connected during data collection was 14±1 and the horizontal dilution of precision (HDOP) was 0.73±0.04, in line with previous recommendations suggesting a minimum of 6 satellites required

for an acceptable quality of signal (Malone et al., 2017). After each session, data was processed and analyzed using the OpenField Console Software (version 1.14, Catapult Sports, Melbourne, Australia). Time on pitch duration (min), total distance (TD; m), total high-speed distance (THSD; >19.8 km·h^{-1}; m), high-speed distance (HSD; 19.8-25.2 km·h^{-1}; m), sprint distance (SpD; >25.2 km·h^{-1}; m), number of sprints (number of efforts >25.2 km·h^{-1}, dwell time ≥0.1 sec), number of high-speed efforts (number of HS efforts >19.8 km·h^{-1}, dwell time ≥0.1 sec), meters per minute (m·min^{-1}) and high-speed meters per minute (HS m·min^{-1}) covered during training sessions and games were selected and included for analysis. Specific velocity thresholds were applied based on previous research (Owen et al., 2017; Tierney et al., 2016).

6.3.3.2 First Team Microcycle

For both the first team and the reserve team, a typical recurrent weekly microcycle structure was identified (Table 9). As the first team engaged in competitive match play in four different competitions (Scottish Premiership, Scottish Cup, Scottish League Cup and UEFA Europa League) for the majority of each season throughout the study, two-game week microcycles were considered where two consecutive games were played no more than 3 days apart within the same calendar week (Monday-Sunday). Weeks without two-games/week were excluded. Games were commonly played on Thursdays and Sundays, interspersed by recovery and match preparation training sessions after and before each game, respectively. Training sessions were categorized relative to the previous and upcoming game (i.e. MD+ or MD-) (Malone et al., 2015; Martin-Garcia et al., 2018; Swallow et al., 2021). As a significant variability in game load was expected between individual players based on their squad status (i.e. starting or substitute), game data were considered separately according to squad status and number of minutes played on a game-per-game basis. Players who started the game and performed ≥90 minutes were considered starters (ST), players who did not start the game and played ≤45 minutes were considered non-starters (NST). Players who started the game but were replaced before end-of-game were excluded, and players who did not start the game and played ≥45 minutes did not appear in the dataset. The day after competition (MD+1), players were

divided into two training groups based on the number of minutes played the day before: ST completed a recovery session focused on regeneration (MD+1R), while NST completed a compensatory session to simulate match demands (MD+1C). All players then completed the remaining training sessions similarly. Sessions performed two days (MD-2) and one day (MD-1) before competition typically consisted of low-load physical re-activation and priming drills with an increased technical-tactical focus.

Table 9: Typical weekly microcycles for first-team starters, first-team non-starters and reserve-team players.

	First-Team Starters (ST)	First-Team Non-Starters (NST)	Reserve-Team Players (RES)
Monday	MD+1: Recovery	MD+1: Compensatory	MD-1: Match Prep
Tuesday	MD-2: Technical-Tactical	MD-2: Technical-Tactical	MD: Game (≥90 minutes)
Wednesday	MD-1: Match Prep	MD-1: Match Prep	MD+1: Off
Thursday	MD: Game (≥90 minutes)	MD: Game (≤45 minutes)	MD+2: Regeneration
Friday	MD+1: Recovery	MD+1: Compensatory	MD+3: Endurance
Saturday	MD-1: Match Prep	MD-1: Match Prep	MD-3: Strength
Sunday	MD: Game (≥90 minutes)	MD: Game (≤45 minutes)	MD-2: Off

First-team players (both ST and NST) are on a two-game week microcycle, RES are on a one-game week microcycle; MD = match day.

6.3.3.3 Reserve Team Microcycle

A typical one-game week microcycle was established for reserve-team players (RES) where only one game was played within the same calendar week and a minimum of 4 training sessions were completed. Game data were exclusively considered for players performing ≥90 minutes, in order to assess player demands between two-game week microcycle first-team players and one-game week microcycle academy and reserve players competing for upward transfer. Following a rest day after competition (MD+1), MD+2 focused on regeneration from previous game and MD+3 and MD-3 focused on acquisition training sessions for strength and conditioning utilizing large- and small-sided games as well as soccer-specific drills, respectively. To optimally recover from acquisition training sessions, a second rest day was scheduled two days prior to the following game (MD-2), before a match preparation session was completed the day before competition (MD-1). Data from first-team

players attending reserve team sessions or games and/or vice versa were excluded when these occurred individually, while microcycle-length transitions were included after team re-designation.

6.3.4 Statistical Analysis

External loads were reported as a cumulative training week and per individual training or match day, while training monotony (TM) was calculated by dividing mean daily external load by standard deviation of external load over a microcycle (Comyns & Flanagan, 2013; Foster, 1998). All data are presented as means±standard deviation (SD) and 95% confidence intervals (CI). Normality of data was confirmed using the Shapiro-Wilk test, while heteroscedasticity was tested and refuted by Box's M and Levene's tests. Inter-group differences were identified by One-Way Analysis of Variance (ANOVA) with Tukey's post hoc test, while intra-group day-to-day variations within microcycles were identified by Repeated Measures ANOVA with Tukey's post hoc test. Significance level was $p<0.05$. Effect sizes (ES) were calculated using Cohen's *d* to determine meaningful differences and classified as: trivial (<0.2), small (≥0.2), moderate (≥0.6), large (≥1.2) and very large (≥2.0) (Hopkins et al., 2009). Pre-measurement calculation for sample size of players was inappropriate as this was managed by club, but calculation for sample size of observations based upon expected minimal group differences and SD of measurements of external load parameters from previous experience, with α 0.05 and β 0.2 (power 80%), indicated that 40-80 observations/team/MD would be required. Finally, retrospective post-hoc statistical power of the observations was calculated, with α 0.05.

6.4 Results

Table 10 shows the weekly cumulative external loads (training and games included) for ST, NST and RES. Compared to ST in a two-game week microcycle, RES spent 8% less time on pitch (duration, $p<0.0001$, ES=1.12, moderate), covered 21% less TD ($p<0.0001$, ES=2.76, very large) and performed 16% less HS efforts ($p<0.005$, ES=0.71, moderate). In contrast, RES showed significantly greater values than NST in a two-

game week microcycle in most parameters observed. Apart from spending 10% more time on pitch ($p<0.0001$, ES=1.13, moderate), RES covered 9% more TD ($p<0.0005$, ES=0.89, moderate), 30% more THSD ($p<0.0001$, ES=1.09, moderate), 26% more HSD ($p<0.0005$, ES=0.90, moderate) and 45% more SpD ($p<0.0001$, ES=1.17, moderate) while also performing 40% more sprints ($p<0.0001$, ES=1.27, large) and 22% more HS efforts ($p<0.0005$, ES=0.91, moderate). During a typical two-game week microcycle, ST reported significantly higher values than NST in every parameter observed. Most notably, ST spent 18% more time on pitch ($p<0.0001$, ES=1.93, large) and covered 28% more TD ($p<0.0001$, ES=3.13, very large), 36% more THSD ($p<0.0001$, ES=1.40, large), 34% more HSD ($p<0.0001$, ES=1.30, large) and 46% more SpD ($p<0.0001$, ES=1.21, large) while also performing 40% more sprints ($p<0.0001$, ES=1.19, moderate) and 34% more HS efforts ($p<0.0001$, ES=1.62, large), vs NST.

Table 10: Weekly cumulative external training load for first-team starters, first-team non-starters and reserve-team players.

	First-Team Starters (1)	First-Team Non-Starters (2)	Reserve-Team Players (3)	Effect Sizes (Cohen's d)			95% Confidence Intervals		
Number of Weeks	64	64	36	Group 1 v 2	Group 1 v 3	Group 2 v 3	Group 1 v 2	Group 1 v 3	Group 2 v 3
Duration (min)	417 ± 36 [a,b]	344 ± 39 [a,c]	382 ± 19 [b,c]	1.93	1.12	1.13	[1.52-2.36]	[0.69-1.56]	[0.70-1.58]
Total distance (m)	37000 ± 3089 [a,b]	26575 ± 3528 [a,c]	29340 ± 2004 [b,c]	3.13	2.76	0.89	[2.62-3.66]	[2.22-3.34]	[0.47-1.33]
Total high-speed distance (m)	1692 ± 466 [a]	1084 ± 393 [a,c]	1554 ± 483 [c]	1.40		1.09	[1.02-1.80]		[0.66-1.53]
High-speed distance (m)	1387 ± 376 [a]	920 ± 335 [a,c]	1248 ± 403 [c]	1.30		0.90	[0.93-1.69]		[0.48-1.33]
Sprint distance (m)	308 ± 136 [a]	167 ± 91 [a,c]	306 ± 155 [c]	1.21		1.17	[0.84-1.59]		[0.73-1.62]
Number of sprints	20 ± 8 [a,b]	12 ± 5 [a]	20 ± 8 [b]	1.19		1.27	[0.82-1.57]		[0.83-1.73]
Number of high-speed efforts	132 ± 30 [a]	87 ± 25 [a,c]	111 ± 28 [c]	1.62	0.71	0.91	[1.23-2.03]	[0.29-1.14]	[0.49-1.35]
Meters per minute	89 ± 11 [a]	77 ± 14 [a,c]	77 ± 6 [c]	0.94	1.25		[0.59-1.32]	[0.81-1.70]	
High-speed meters per minute	4 ± 1 [a,b]	3 ± 1 [a,c]	4 ± 1 [b,c]	0.99		0.99	[0.63-1.37]		[0.57-1.43]

Data are presented as mean values ± standard deviation. Total high-speed distance = distance covered above 19.8 $km \cdot h^{-1}$, high-speed distance = distance covered between 19.8 and 25.2 $km \cdot h^{-1}$, sprint distance = distance covered above 25.2 $km \cdot h^{-1}$. Effect sizes (Cohen's d) and effect size estimates (±95 confidence intervals) indicate significant intergroup differences. a = significant difference between groups 1 and 2 ($p<0.05$), b = significant difference between groups 1 and 3 ($p<0.05$), c = significant difference between groups 2 and 3 ($p<0.05$).

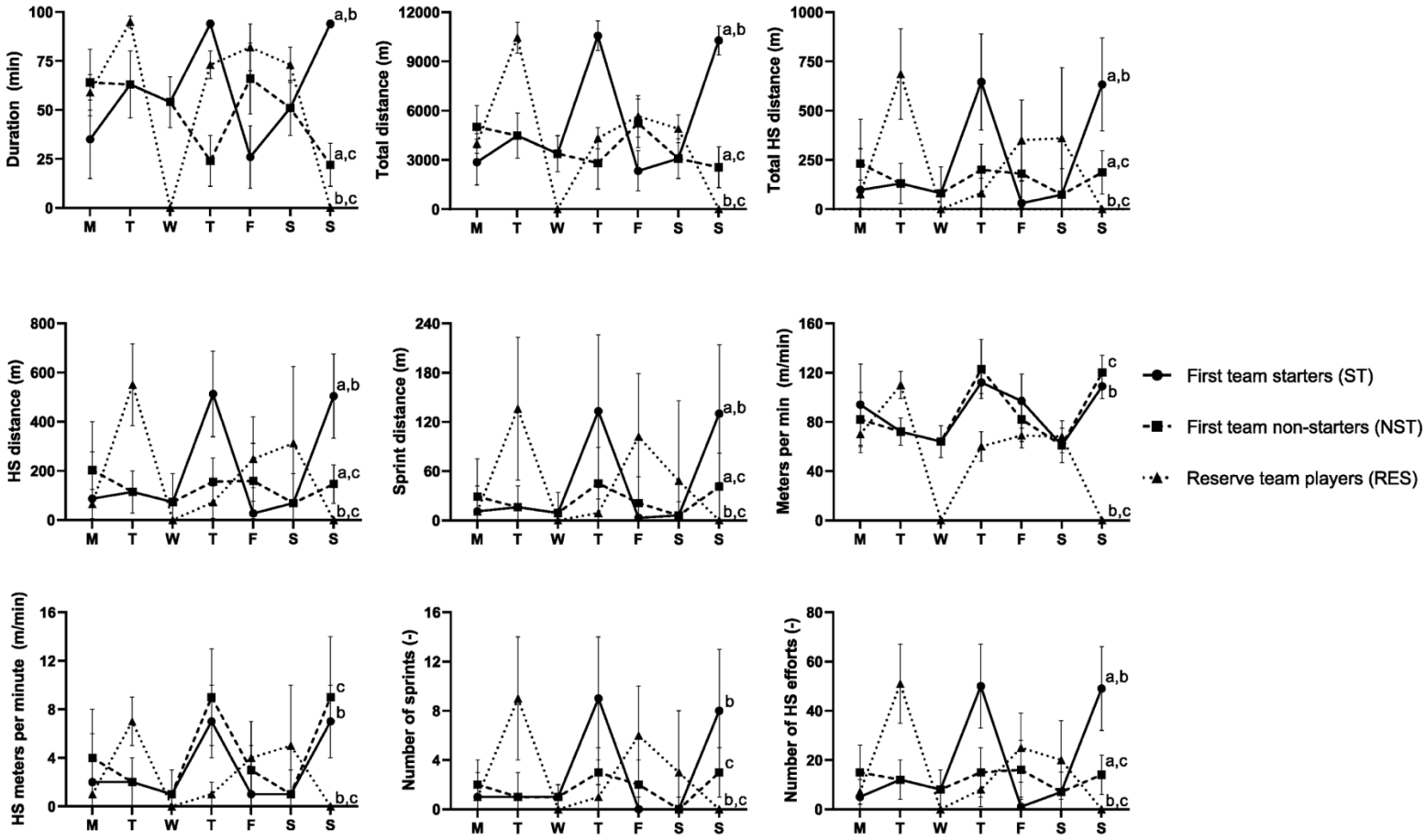


Figure 13: Daily external TL plotted as weekly external TL trend lines for first-team starters (●), first-team non-starters (■) and reserve-team players (▲) within their respective weekly microcycles. a = significant different weekly trends between first-team starters and first-team non-starters ($p<0.05$), b = significant different weekly trends between first-team starters and reserve-team players ($p<0.05$), c = significant different weekly trends between groups first team substitutes and reserve team ($p<0.05$).

To illustrate weekly load variation, daily external loads were plotted as weekly trend lines for ST, NST and RES over the course of their respective microcycles (Figure 13). RES show significantly different trend lines to ST for all parameters: duration ($p<0.05$), TD ($p<0.05$), THSD ($p<0.005$), HSD ($p<0.001$), SpD ($p<0.005$), number of sprints ($p<0.005$), number of HS efforts ($p<0.001$), $m \cdot min^{-1}$ ($p<0.05$) and HS $m \cdot min^{-1}$ ($p<0.005$). Similarly, differences in trend lines between RES and NST were significant for all parameters: duration ($p<0.005$), TD ($p<0.05$), THSD ($p<0.005$), HSD ($p<0.005$), SpD ($p<0.01$), number of sprints ($p<0.005$), number of HS efforts ($p<0.005$), $m \cdot min^{-1}$ ($p<0.05$) and HS $m \cdot min^{-1}$ ($p<0.005$). Trend lines between ST and NST were significantly different for duration ($p<0.005$), TD ($p<0.005$), THSD ($p<0.05$), HSD ($p<0.005$), SpD ($p<0.05$) and number of HS efforts ($p<0.05$).

Absolute daily external loads for ST, NST and RES in their respective microcycles is presented in Table 11. Daily changes in external load were significant throughout the week within each group for all parameters observed ($p<0.0001$). TM scores from most parameters showed significant differences between the groups, except for SpD ($p=0.0817$) (Table 12). Specifically, NST showed higher TM scores compared to RES for TD ($p<0.0001$, ES=0.94, moderate), THSD ($p<0.0001$, ES=0.84, moderate), HSD ($p<0.0001$, ES=1.28, large) and number of HS efforts ($p<0.0001$, ES=1.14, moderate), as well as higher scores compared to ST for duration ($p<0.05$, ES=0.43, small), TD ($p<0.0001$, ES=1.57, large), THSD ($p<0.0001$, ES=1.18, moderate), HSD ($p<0.0001$, ES=1.55, large), number of sprints ($p<0.05$, ES=0.48, small) and number of HS efforts ($p<0.0001$, ES=1.50, large). Finally, we calculated statistical power of the observations. This showed that when significant differences occurred, observed power was high: for external load it was 93.9%-100% (RES vs ST), 98.6%-100% (RES vs NST) and 100% (ST vs NST), while for TM it was 94.2% (RES vs ST), 69.4%-100% (RES vs NST) and 76.6%-100% (ST vs NST); thus yielding $\beta=0.00$ (range 0.31-0.00) for the majority of observations with significant differences.

Table 11: Daily external training load for first-team starters, first-team non-starters and reserve-team players.

		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	p	F
FIRST-TEAM STARTERS	MD +/-	**MD+1**	**MD-2**	**MD-1**	**MD**	**MD+1**	**MD-1**	**MD**		
	Number of observations	155	749	932	373	241	949	329		
	Duration (min)	35 ± 20	63 ± 17	54 ± 13	94 ± 2	26 ± 16	51 ± 14	94 ± 2	p < 0.0001	1180.4355
	Total distance (m)	2868 ± 1391	4486 ± 1368	3382 ± 1102	10563 ± 897	2337 ± 1215	3084 ± 1209	10280 ± 883	p < 0.0001	3515.9745
	Total high-speed distance (m)	98 ± 209	130 ± 102	81 ± 134	646 ± 244	30 ± 112	74 ± 131	633 ± 236	p < 0.0001	1201.4121
	High-speed distance (m)	87 ± 190	114 ± 85	73 ± 115	513 ± 174	27 ± 104	69 ± 120	504 ± 172	p < 0.0001	1068.6722
	Sprint distance (m)	11 ± 31	16 ± 26	9 ± 25	133 ± 93	3 ± 14	6 ± 17	130 ± 84	p < 0.0001	749.0439
	Number of sprints	1 ± 2	1 ± 2	1 ± 1	9 ± 5	0 ± 1	0 ± 1	8 ± 5	p < 0.0001	979.3778
	Number of high-speed efforts	5 ± 10	12 ± 8	8 ± 8	50 ± 17	1 ± 4	7 ± 8	49 ± 17	p < 0.0001	1608.6972
	Meters per minute	94 ± 33	72 ± 11	64 ± 13	112 ± 9	97 ± 22	61 ± 14	109 ± 10	p < 0.0001	1076.0742
	High-speed meters per minute	2 ± 4	2 ± 2	1 ± 2	7 ± 3	1 ± 4	1 ± 2	7 ± 3	p < 0.0001	513.9941
FIRST-TEAM NON-STARTERS	MD +/-	**MD+1**	**MD-2**	**MD-1**	**MD**	**MD+1**	**MD-1**	**MD**		
	Number of observations	159	749	932	140	478	949	329		
	Duration (min)	64 ± 17	63 ± 17	54 ± 13	24 ± 13	66 ± 18	51 ± 14	22 ± 11	p < 0.0001	314.2257
	Total distance (m)	5023 ± 1284	4486 ± 1368	3382 ± 1102	2813 ± 1583	5233 ± 1483	3084 ± 1209	2554 ± 1242	p < 0.0001	263.1088
	Total high-speed distance (m)	232 ± 225	130 ± 102	81 ± 134	200 ± 130	180 ± 171	74 ± 131	187 ± 110	p < 0.0001	77.3836
	High-speed distance (m)	203 ± 197	114 ± 85	73 ± 115	156 ± 96	159 ± 153	69 ± 120	146 ± 79	p < 0.0001	67.0353
	Sprint distance (m)	29 ± 46	16 ± 26	9 ± 25	45 ± 44	21 ± 32	6 ± 17	41 ± 41	p < 0.0001	83.9489
	Number of sprints	2 ± 2	1 ± 2	1 ± 1	3 ± 2	2 ± 2	0 ± 1	3 ± 2	p < 0.0001	187.0118
	Number of high-speed efforts	15 ± 11	12 ± 8	8 ± 8	15 ± 10	16 ± 12	7 ± 8	14 ± 8	p < 0.0001	87.6794
	Meters per minute	82 ± 22	72 ± 11	64 ± 13	123 ± 24	82 ± 18	61 ± 14	120 ± 14	p < 0.0001	712.6021
	High-speed meters per minute	4 ± 4	2 ± 2	1 ± 2	9 ± 4	3 ± 4	1 ± 2	9 ± 5	p < 0.0001	372.2798
RESERVE-TEAM PLAYERS	MD +/-	**MD-1**	**MD**	**MD+1**	**MD+2**	**MD+3**	**MD-3**	**MD-2**		
	Number of observations	229	184	-	156	116	182	-		
	Duration (min)	59 ± 9	95 ± 3	-	73 ± 7	82 ± 12	73 ± 9	-	p < 0.0001	509.1512
	Total distance (m)	3998 ± 597	10452 ± 947	-	4324 ± 655	5660 ± 1268	4096 ± 852	-	p < 0.0001	1787.9837
	Total high-speed distance (m)	76 ± 72	686 ± 229	-	82 ± 76	350 ± 205	360 ± 358	-	p < 0.0001	256.4955
	High-speed distance (m)	65 ± 60	550 ± 166	-	73 ± 66	248 ± 172	312 ± 312	-	p < 0.0001	234.3348
	Sprint distance (m)	11 ± 22	136 ± 87	-	9 ± 17	102 ± 77	48 ± 98	-	p < 0.0001	121.9925
	Number of sprints	1 ± 1	9 ± 5	-	1 ± 1	6 ± 4	3 ± 5	-	p < 0.0001	165.0370
	Number of high-speed efforts	7 ± 5	51 ± 16	-	8 ± 7	25 ± 14	20 ± 16	-	p < 0.0001	398.3889
	Meters per minute	70 ± 15	110 ± 11	-	60 ± 12	69 ± 10	68 ± 13	-	p < 0.0001	434.9018
	High-speed meters per minute	1 ± 1	7 ± 2	-	1 ± 1	4 ± 3	5 ± 5	-	p < 0.0001	164.6055

Data are presented as mean values ± standard deviation. Total high-speed distance = distance covered above 19.8 km·h^{-1}, high-speed distance = distance covered between 19.8 and 25.2 km·h^{-1}, sprint distance = distance covered above 25.2 km·h^{-1}.

Table 12: Training monotony for first-team starters, first-team non-starters and reserve-team players.

	First-Team Starters (1)	First-Team Non-Starters (2)	Reserve-Team Players (3)	Effect Sizes (Cohen's d)			95% Confidence Intervals		
Number of Weeks	64	64	36	Group 1 v 2	Group 1 v 3	Group 2 v 3	Group 1 v 2	Group 1 v 3	Group 2 v 3
Duration (AU)	2.15 ± 0.48 [a]	2.92 ± 2.45 [a]	2.75 ± 1.75	0.43			[0.08-0.79]		
Total distance (AU)	1.44 ± 0.18 [a,b]	2.74 ± 1.15 [a,c]	1.80 ± 0.60 [b,c]	1.57		0.94	[1.18-1.97]		[0.52-1.38]
Total high-speed distance (AU)	0.77 ± 0.09 [a]	1.26 ± 0.68 [a,c]	0.79 ± 0.16 [c]	1.18		0.84	[0.74-1.63]		[0.42-1.27]
High-speed distance (AU)	0.80 ± 0.10 [a]	1.30 ± 0.52 [a,c]	0.75 ± 0.16 [c]	1.55		1.28	[1.09-2.02]		[0.84-1.73]
Sprint distance (AU)	0.61 ± 0.08 [b]	0.67 ± 0.31	0.71 ± 0.21 [b]						
Number of sprints (AU)	0.65 ± 0.09 [a,b]	0.75 ± 0.28 [a]	0.75 ± 0.21 [b]	0.48			[0.13-0.83]		
Number of high-speed efforts (AU)	0.84 ± 0.11 [a]	1.48 ± 0.59 [a,c]	0.93 ± 0.13 [c]	1.50		1.14	[1.11-1.90]		[0.71-1.58]
Meters per minute (AU)	3.28 ± 0.60 [b]	3.57 ± 1.61 [c]	2.38 ± 1.46 [b,c]		0.89	0.76		[0.47-1.33]	[0.34-1.18]
High-speed meters per minute (AU)	0.86 ± 0.13	0.93 ± 0.35 [c]	0.79 ± 0.17 [c]			0.47			[0.05-0.88]

Data are presented as mean values ± standard deviation, in AU (arbitrary units). Total high-speed distance = distance covered above 19.8 km·h^{-1}, high-speed distance = distance covered between 19.8 and 25.2 km·h^{-1}, sprint distance = distance covered above 25.2 km·h^{-1}. Effect sizes (Cohen's d) and effect size estimates (±95 confidence intervals) indicate significant intergroup differences. a = significant difference between groups 1 and 2 ($p<0.05$), b = significant difference between groups 1 and 3 ($p<0.05$), c = significant difference between groups 2 and 3 ($p<0.05$).

6.5 Discussion

The aim of the present study was to quantify and compare the weekly external loads of a reserve team following a one-game week microcycle on a non-congested fixture schedule to that of a first team following a two-game week microcycle with a congested fixture schedule, both within the same professional soccer club. As starting and non-starting players differ, we considered playing status (ST vs NST) of first-team players as part of our analysis with which to compare reserve-team players. Additionally, we examined within-week load variation within both types of microcycles. To the author's knowledge, no other studies have previously investigated these characteristics, despite the different fixture schedules, microcycle structures, and training and game schedules between academy/reserve teams and first teams across football associations. This ensures a high external validity to our analysis. The results thus provide insight into the physical regimens young players need to depart *from* and adapt *to* in order to progress to a first team that competes twice per week.

6.5.1 Weekly External Load

Reserve-team players experienced less overall external load from training and matches over the microcycle week than first team starting players, but more than first-team non-starters, while simultaneously, non-starters did not achieve the load of starters. The main explanation for this is that first team starting players were involved in congested fixture periods with two 90-minute games and additional daily training sessions, leading to the highest loads, whereas non-starting first-team players largely followed the same schedule but without accruing comparable game times, leading to the lowest loads, while reserve-team players fail to replace load lost from playing less games with comparable training. The result is that neither reserve team nor non-starting first-team players accrue the weekly external loads of first-team starting players and therefore may be under- or sub-optimally prepared to compete in games.

These results contradict those where U19 players showed greater weekly external loads than first-team players (Coppalle et al., 2021; Houtmeyers et al., 2021), due to an increased focus on physical development during academy training sessions as well as an inferior technical-tactical awareness during games that overall lead to higher workloads. However, in these cases, both U19/academy players and first-team players were on one-game week microcycles, whereas we show that when microcycles were not comparable (one- vs two-game week), weekly external loads differed, to the detriment of those players trying to establish themselves as first team starting players. This is supported by previous reports of higher absolute values for duration and total distance for players in two-game weeks (Anderson et al., 2016; Clemente et al., 2021). Although the additional acquisition training sessions during one-game weeks may compensate for some of the drop in weekly external load, it did not equalize it. In contrast, non-starting first-team players showing significantly lower weekly external loads compared to starting players is not surprising (Fields et al., 2021; Nobari et al., 2020; Nobari et al., 2021). This is because their game time was limited to a maximum of 45 minutes and because the majority of first team training sessions aimed to promote recovery and maximize game readiness through low-load exercises, and where non-starting players received additional compensatory sessions, these were restricted by the limited number of available players. Thus, non-starting first-team players are in line with reserve-team players also under-prepared for first team game time.

6.5.2 Within-Week Load Variation

The overall weekly external load indicates the amount of work carried out by players during a microcycle, but it fails to indicate loading and recovery patterns. Monitoring daily external load variation over the course of a microcycle in contrast provides this information, and therefore consequently, monitoring this variation may more effectively promote training adaptations, recovery, and performance on match days and also alert for cumulative fatigue, overtraining and injury risk. We observed that all teams in our study experienced daily changes in external load throughout the microcycles, and that both reserve team and first team non-starting players

substantially differed from first team starting players with respect to within-week variation. This was largely dictated by the respective fixture schedules and team training plans. Since matches were the most demanding sessions of the week, those that played fewer matches (i.e. reserve team and first team non-starting players on one-game week microcycles vs first team starting players on two-game week microcycles) therefore experienced less loads, lower load peaks, and less within-week variation, which additional strength and conditioning acquisition training sessions did not fully compensate for. This notion most likely further compounds reserve team and first team non-starting player preparation for competing with first team starting players, as also previously suggested (Anderson et al., 2016; Castillo et al., 2021; Los Arcos et al., 2016; Morgans et al., 2022; Sparks et al., 2017). In training, the within-week load variation was mainly caused by strength and conditioning, in particular endurance, acquisition sessions producing peak loads and/or tapering (MD-1) and recovery (MD+1) sessions producing low loads. In the case of non-starting first-team players, peak loads produced by compensatory (MD+1C) sessions also contributed, despite these not reaching match-level loads. These observations of within-week load variation were not surprising and have also previously been suggested (Akenhead et al., 2016; Anderson et al., 2016; Castillo et al., 2021; Malone et al., 2015; Martin-Garcia et al., 2018; Owen et al., 2017).

It may be debated which load profile is optimal for players, but the issue here will be that both reserve team and non-starting first-team players experienced different load profiles and within-week variations to starting first-team players, which again, in line with the different cumulative weekly external loads, renders reserve team and non-starting first-team players potentially under- or sub-optimally prepared for the physical requirements that associate with first team matches and the two-game week microcycles. This affects both reserve-team players progressing to non-starting first team status and non-starting first-team players progressing to starting status, as they both will be challenged by their capacity to absorb the presented load or acquire adequate physical preparation, and their ability to produce peak performances on two match-days per week, with limited recovery in between.

6.5.3 Training monotony

Non-starting first-team players consistently showed the highest TM scores, particularly in high-intensity parameters, indicating a more monotonous pattern of sustained loads. Together with limited within-week external load variation compared to starting first team and reserve-team players, this effect suggests that those not starting games regularly could experience a schedule of high homogenous external loads over time that exposes players to elevated training strains with increased risks of overtraining and injury (Comyns & Flanagan, 2013; Foster, 1998), or if overall external load is low and homogenous, as in the current study, limited exposure to progressive overloads with ensuing poor performance quality.

6.5.4 Limitations

Several limitations should be acknowledged. First, two teams from only one club were analyzed, and while it is clear that adding more clubs to the analysis would be beneficial, most professional soccer clubs are organized similar to the current club, rendering the analysis and findings reported in this study representative for similar populations in professional soccer. Secondly, we have treated players according to team designations within the club, but we acknowledge that there may also be player position-specific load profiles (Baptista et al., 2019; Dalen et al., 2020; Hasan et al., 2021; Malone et al., 2015); however, as a first proof-of-principle analysis we did not include this, for reasons of simplicity. Finally, we have characterized and categorized days as well as player status (starters, non-starters, reserve) somewhat rudimentary on a rolling schedule to standardize the analysis, but in real-world these aspects may of course be more fluid: e.g. a player may start a game but be benched the next game within the same week, match days may shift, weeks may intersperse between one and two matches, and context prior to a microcycle may vary, such as content of preceding week, which may affect performance in current week. As such, the findings presented in this study should be considered accordingly and in the context of those ever-changing circumstances.

6.6 Practical Applications

Different weekly external loads and within-week load variations between a reserve/academy team in a one-game week microcycle and a first team in a two-game week microcycle within the same professional soccer club, as we have documented here, presents challenges for players seeking upward progression and respective team managements. This is because different training and fixture schedules will not have fully prepared either of reserve/academy players being promoted to first team or non-starting first-team players being promoted to regular starting player for the physical realities that await them in top-level competitive clubs. Below, we suggest practical solutions that team managements may take to mitigate the observed differences between teams and the associated challenges they present, in order to ease upward transfers. Academy/reserve team management should ensure that players prior to graduation or promotion have developed the physical characteristics required to sustain higher external loads when they arrive at the higher team. This may require a process of gradually adopting a weekly structure and microcycle akin to the first team. Consideration should be given to the possibility of strength and conditioning compensatory or acquisition sessions surpassing match loads, in order to maximize physical development, adaptation, and preparation. Consideration should also be given to the possibility of introducing post-match bouts of soccer-specific high-intensity strength and conditioning training to non-starting first-team players either on match days or MD+1 in order to avoid the risk of underloading. This may need to be titrated individually, to balance their actual game-time. Team managements should pro-actively rather than reactively design effective strategies in anticipation of such scenarios.

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Chapter 7: Discussion

7.1 Overview of Key Findings

The present thesis sought to investigate talent development during the post-formation phase in elite professional soccer by examining the structural, physical, and performance-related factors influencing progression from late-stage academy environments to sustained first-team participation. To address this aim, a series of studies were conducted focusing on structural opportunity, physical readiness, match utilisation, and training exposure within elite soccer environments.

At a structural level, the findings indicate that opportunities for academy-developed players to progress into senior squads and accumulate meaningful match involvement are limited and have decreased over time (Study 1). This indicates that progression is not solely a function of player ability, but is also influenced by organisational and recruitment strategies within elite clubs. From a physical perspective, the results show that while differences in physiological and locomotor characteristics exist between developmental and senior players, these differences do not fully explain progression outcomes. In several cases, academy and reserve players demonstrated performance capacities approaching those of senior players, indicating that physical readiness alone may not be sufficient to ensure successful transition (Study 2).

In addition to physical capacity, match performance context emerged as an important dimension for understanding how performance capabilities are expressed. The findings from Study 3 demonstrated that players introduced during matches are capable of maintaining or increasing high-intensity output, reinforcing the importance of high-intensity actions in influencing match dynamics. In parallel, the profiling results indicated that academy and reserve players possess physical capacities comparable to senior players (Study 2). While the present thesis did not directly examine the performance of developing players within match contexts, the combination of these findings could potentially suggest that physically prepared players may be capable of contributing effectively when introduced into competitive environments. This could further highlight the importance of considering not only

physical readiness, but also how and when players are utilised within match settings. Such a hypothesis could be relevant for future research. Furthermore, differences in training exposure and periodisation structures between developmental and senior environments were identified. These differences suggest that players may be prepared under conditions that do not fully replicate the demands of senior competition, particularly in relation to load distribution, match frequency, and role-specific exposure (Study 4). Such discrepancies may contribute to challenges in adapting to the physical and contextual demands of first-team football.

Taken together, these findings indicate that the post-formation phase represents a multifactorial bottleneck in which progression is shaped by the alignment – or misalignment – between individual readiness and environmental opportunity. The transition to elite senior soccer therefore appears to depend not only on the development of physical and physiological capacity, but also on the extent to which players are afforded appropriate opportunities, exposure, and context-specific preparation within elite performance systems.

7.2 Constraints on Transition: Structural, Physical and Contextual Factors

Progression from academy to elite senior soccer is often assumed to be primarily determined by a player's ability to meet the physical demands of elite competition. However, the findings of the present thesis challenge this assumption by demonstrating that transition is constrained by a combination of structural, physical, and contextual factors that extend beyond individual performance capacity.

At the structural level, the results indicate that opportunities for academy-developed players to progress into senior squads and accumulate meaningful match involvement remain limited (Study 1). Club-trained players represented a relatively small proportion of first-team squads and demonstrated reduced match participation, reflecting restricted access to competitive exposure. These findings are consistent across all European top-division leagues, including Scotland, and are in line with previous research highlighting the increasing globalisation of soccer and the growing reliance on external recruitment strategies (Poli et al., 2018; Elliott &

Weedon, 2011). Within such performance-driven environments, coaches may prioritise experienced players to minimise short-term risk, thereby limiting opportunities for developing players (Relvas et al., 2010). Importantly, the present findings also revealed a positive association between club-trained player match involvement and team success, as indicated by national league ranking. While causality cannot be inferred, this relationship challenges the assumption that integrating academy players compromises competitive performance. Similar observations have been reported in studies examining club development models, suggesting that successful integration of academy players may reflect effective organisational alignment between development and performance objectives (Güllich, 2014; Bridgewater et al., 2011). These findings indicate that structural opportunity is not inherently constrained by performance demands, but rather shaped by strategic and organisational choices.

From a physical perspective, the results demonstrate that late-stage academy and reserve players are, in many cases, capable of achieving physical performance outputs comparable to senior players (Study 2). This aligns with previous literature indicating that high-level youth players may approach senior-level physical benchmarks (Houtmeyers et al., 2021; Buchheit et al., 2010). However, despite this comparability, progression to senior competition remains limited, suggesting that physical readiness alone does not determine transition outcomes. Rather than acting as a differentiating factor, physical capacity appears to function as a prerequisite for participation, consistent with broader talent development models (Vaeyens et al., 2008). Furthermore, the interpretation of physical performance data is complicated by the context-dependent nature of match outputs. Locomotor metrics such as high-speed running distance are influenced by tactical roles, team strategies, and match situations, and therefore do not fully distinguish between individual capacity and contextual demand (Bradley et al., 2013; Carling et al., 2008). This limitation highlights the need to interpret physical performance within the broader context of game dynamics.

The role of contextual factors is further illustrated by the findings of the substitution study (Study 3). Players introduced during matches demonstrated the ability to maintain or increase high-intensity output, supporting existing evidence that high-intensity actions are critical in decisive match moments (Faude et al., 2012; Mohr et al., 2003). When considered alongside the physical profiling results, these findings suggest that players who possess sufficient physical readiness may be capable of contributing effectively within match contexts when provided with the opportunity. While this thesis did not directly assess the performance of academy players in such scenarios, the combined evidence indicates that physical capability does not appear to be the limiting factor in their utilisation. This interpretation points towards a potential disconnect between player readiness and opportunity. While developing players may possess the physical capacity required for elite performance, their ability to express this capacity is contingent upon access to competitive match environments. Match exposure represents a critical component of performance development, providing a context in which physical, technical, and psychological demands converge (Ericsson et al., 1993). Limited exposure may therefore restrict both performance expression and developmental progression.

In addition to match utilisation, differences in training exposure further contribute to the challenges associated with transition (Study 4). The findings of Study 4 demonstrate that training load distribution differs substantially between developmental and senior environments. Academy settings typically prioritise physical development through structured overload, whereas senior environments – particularly during congested schedules – prioritise recovery and performance maintenance. This shift results in a transition from development-focused to performance-focused training structures, which may not fully prepare players for the cumulative and context-specific demands of senior competition. Within teams, additional discrepancies were observed between starting and non-starting players. Non-starting players, often including developing athletes, rely on compensatory training sessions to maintain fitness. However, these sessions may not replicate the complexity and intensity of match play, leading to fragmented or suboptimal load exposure (Carling et al., 2012b). Consequently, players may experience either

insufficient exposure to match demands or artificially constructed training stimuli that lack ecological validity.

Collectively, these findings indicate that progression to senior elite soccer is constrained by the alignment between player readiness and environmental opportunity. While physical capacity is necessary, it is not sufficient in the absence of appropriate exposure and utilisation. Structural constraints, contextual performance demands, and inconsistencies in training environments interact to shape transition outcomes, reinforcing the complexity of the post-formation phase.

7.3 Integration: The Post-Formation Bottleneck

The findings of this thesis collectively support the conceptualisation of the youth-to-senior transition as a multifactorial bottleneck within elite soccer development systems. Rather than representing a linear progression based solely on individual ability, transition is shaped by multiple constraints operating at structural, environmental, and individual levels.

At the structural level (Study 1), limited availability of opportunities for academy-developed players, combined with increasing reliance on external recruitment, restricts access to senior squad participation. At the individual level (Study 2), while players may possess the physical capacity required to compete at elite level, this capacity alone does not guarantee progression. At the environmental level (Study 3-4), restricted match exposure and inconsistencies in training load distribution further limit the ability of players to translate capacity into performance and adapt to senior competition. Importantly, these factors do not operate independently, but interact dynamically to shape transition outcomes. For example, limited match exposure reduces opportunities for players to demonstrate readiness, which in turn influences selection decisions and reinforces structural constraints. Similarly, discrepancies in training exposure may influence both physical readiness and perceived performance capacity, further affecting opportunities for match participation. This interaction creates a self-reinforcing system in which progression is constrained not only by

individual limitations, but by the cumulative effect of multiple interacting factors. From this perspective, the transition process can be understood as a bottleneck in which a large number of players compete for a limited number of opportunities, with progression determined by both readiness and access to exposure. This conceptualisation aligns with broader models of talent development that emphasise the importance of environmental constraints, opportunity structures and athlete environment in shaping athlete progression, rather than viewing advancement as a direct consequence of performance capacity alone (Côté et al., 2007; Davids et al., 2008; Stambulova, 2003; Stambulova et al., 2021; Wylleman et al., 2013). It also highlights the importance of considering transition as a system-level phenomenon rather than an outcome driven solely by individual performance characteristics.

7.4 Limitations

Several methodological considerations should be acknowledged when interpreting the findings of this thesis. First, the applied nature of the research, conducted within an elite professional soccer club, resulted in observational study designs that limit the ability to establish causal relationships. However, such designs are consistent with contemporary sports science research, where experimental manipulation is often constrained by ethical, logistical, and performance-related considerations. Importantly, the ecological validity of the present findings is high, as data were collected within real-world elite environments under authentic training and competition conditions. Second, the use of single-club data in Studies 2-4 may limit the generalisability of the findings to other clubs, leagues, or competitive contexts. Training structures, coaching philosophies, and organisational strategies may vary substantially across clubs, potentially influencing load distribution, match utilisation, and development pathways. Nevertheless, the depth and longitudinal nature of the dataset provide valuable insight into applied practices within elite soccer, and the integration with large-scale demographic data from Study 1 strengthens the broader relevance of the findings. Third, the reliance on wearable tracking technologies (e.g., GPS/GNSS) to quantify external load introduces certain limitations related to measurement accuracy and sensitivity. While these systems

have been validated and are widely used in elite sport (see Material and Methods sections in Studies 2-4 for detail), they may underestimate high-intensity actions involving rapid accelerations, decelerations, and changes of direction. Additionally, differences between tracking systems across seasons may introduce variability, although efforts were made to standardise data processing and interpret results conservatively. Fourth, internal load measures were not consistently available across all datasets, limiting the ability to fully integrate physiological and perceptual responses with external load metrics. As a result, interpretations of player readiness and training stress are primarily based on externally observable data. While this aligns with the thesis focus on structural and environmental constraints, future studies may benefit from incorporating a more comprehensive range of internal load indicators. Finally, while the thesis adopts a multi-level approach, it does not directly assess technical, tactical, or psychological performance factors, which are known to also influence transition outcomes (Vaeyens et al., 2008; Relvas et al., 2010). The absence of these dimensions represents a limitation, but also reflects the complexity of capturing multidimensional performance data within elite environments.

7.5 Practical Applications

The findings of this thesis have several important implications for practitioners working within elite soccer environments, including coaches, sport scientists, football directors and clubs' strategic stakeholders.

First, the results suggest that talent development strategies should extend beyond the assessment of physical performance characteristics and incorporate a broader understanding of how opportunity and exposure influence progression. While physical readiness remains essential, practitioners should recognise that players who meet performance benchmarks may still require targeted support to facilitate transition.

Second, the importance of match exposure highlights the need for structured integration pathways that provide young players with meaningful competitive opportunities. This may include increased use of controlled match exposure, strategic rotation policies, or carefully managed loan systems (i.e. whereby a player is loaned out to play for a different club that typically plays at a lower level while the player is still under contract by their original club) designed to maximise developmental benefit rather than simply provide playing time.

Third, the observed discrepancies in training exposure between developmental and senior environments emphasise the need for greater alignment between academy and first-team structures. Practitioners should consider how training load distribution and periodization strategies can be adapted to better prepare players for the demands of senior competition, particularly for those transitioning between environments.

Finally, the variability in load exposure between starting and non-starting players highlights the importance of individualised training approaches within team settings. Ensuring that all players receive an appropriate and context-specific training stimulus may help to reduce developmental gaps and support readiness for transition.

7.6 Future Research

The findings of this thesis highlight several avenues for future research aimed at improving understanding of the youth-to-senior transition in elite soccer. First, future studies should seek to adopt multi-club and multi-league designs to enhance the generalisability of findings and explore how structural and organisational differences influence transition pathways. Comparative analyses across clubs with varying development philosophies may provide valuable insight into best practices for facilitating progression. Second, there is a need for more integrated, multidimensional research approaches that combine physical, technical, tactical, and psychological performance data. Such approaches would allow for a more

comprehensive understanding of player readiness and the factors that differentiate successful and unsuccessful transitions. Third, longitudinal tracking of individual player pathways beyond the academy phase would provide valuable insight into how early developmental characteristics relate to long-term career outcomes. This may include examining the role of loan systems, reserve team participation, and alternative development routes in shaping progression. Fourth, future research should further investigate the role of match exposure, not only in terms of quantity but also quality and context. Understanding how different types of match experience influence development may help to optimise player utilisation strategies during the transition phase. Finally, there is scope to develop more refined models of load monitoring and performance readiness that account for the complexity of training and match environments. Integrating external load, internal load, and contextual performance indicators may provide a more accurate representation of player development and readiness for elite competition.

7.7 Conclusion

The present thesis sought to investigate talent development during the post-formation phase in elite professional soccer by examining the structural, physical, and performance-related factors influencing progression from academy environments to sustained first-team participation. The findings demonstrate that progression to elite senior soccer cannot be explained solely by physical performance capacity. While late-stage academy and reserve players were often shown to possess physical characteristics and performance outputs comparable to senior players, this did not consistently translate into increased transition or sustained participation at the elite level. These findings challenge the traditional assumption that insufficient physical readiness represents the primary barrier to progression. Instead, the results highlight the importance of structural and contextual constraints within elite performance environments. Limited access to meaningful match exposure, discrepancies in training load distribution between developmental and senior settings, and organisational strategies prioritising short-term performance collectively restrict opportunities for players to demonstrate and further develop

their capabilities. Importantly, the observed positive association between club-trained player involvement and team success further suggests that the integration of academy players is not inherently incompatible with competitive performance. Taken together, the findings of this thesis provide an original contribution to the literature by demonstrating that the transition from academy to elite senior soccer is shaped not only by player readiness, but by the alignment between readiness and opportunity within structurally constrained environments. This positions the post-formation phase as a system-level bottleneck, in which progression depends on both the capacity to perform and the opportunity to express that capacity. From an applied perspective, these findings emphasise the need for more integrated development strategies that extend beyond physical preparation and address the structural and contextual conditions under which players transition. Enhancing alignment between academy and senior environments, optimising match exposure opportunities, and adopting more individualised approaches to load management may represent key steps toward improving progression outcomes in elite soccer. Ultimately, progression to elite senior soccer is not limited by a lack of physical readiness, but by a mismatch between player readiness and structural opportunity within elite performance environments.

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