Bridging the Gap Between Youth and Senior Football

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The candidate confirms that the work submitted is their own and that appropriate credit has been given where reference has been made to the work of others.

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Abstract:

The purpose of this research is to examine the differences in youth and senior football locomotor demands and the neuromuscular fatigue both groups experience. Previous research has examined locomotor demands and neuromuscular fatigue in senior and youth athletes, but research comparing the resulting neuromuscular fatigue from match play between youth and senior athletes is a novel research topic. A longitudinal, non-experimental, cross-sectional study was employed over 10 weeks. Participants were recruited from one professional football club between its senior and youth team. Data were analyzed with between group analyses of variance (ANOVA), independent t-tests, and linear mixed models. Results showed significant differences between groups across locomotor and neuromuscular fatigue metrics. The main locomotor differences were that senior players performed more high-intensity accelerations (ES=1.31, p=<.001) and decelerations per minute (ES=0.37, p<.01), while youth players covered greater high-intensity distance per minute (ES=-1.07,p<.001). Neuromuscular pre-match status, depicted by countermovement jump performance on forceplates, highlighted senior players greater flight time: contraction time ratios (ES=1.29, p<.001), underpinned by shorter contraction time (ms) (ES=-1.27, p<.001). Surprisingly, all other neuromuscular pre-match status metrics were not significantly different between groups (p>0.2). 48 hours post-match, senior players demonstrated significant neuromuscular fatigue, characterized by reduced jump height (cm)(ES=-1.4, p<.001), flight time (ms) (ES=-1.83, p<.001) and contraction time (ms) (ES=-0.83, p=.02). As for youth players at 48 hours post-match, there were no significant differences between pre-match metrics (p>0.35). Lastly, the number of decelerations and accelerations performed had a negative moderating effect on jump height (cm) but not contraction time (ms) ~~at~~ 48 hours post-match for senior players (DEC/JH: p<.001; ACC/JH: p=.01, but not youth players (p>0.39). Implications for practice are that senior match play entails more intense actions and greater neuromuscular fatigue. Therefore, youth players must be adequately prepared physically for the transition to senior football.

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List of Common Abbreviations:

TD/min: Distance per minute

HSR/min: High speed running per minute

HID/pm: High intensity distance per minute

SPR/min: Sprint distance per minute

ACC/min: Accelerations per minute

DEC/min: Decelerations per minute

MSS: Max sprint speed

m/s: Metres per second

SD: Standard deviation

CV: Coefficient of variation

ES: Cohen's D effect size

ST: Senior Team

YT: Youth Team

CMJ: Countermovement jump

MD+2: 48 hours post-match

PRE: 1 hour pre-match

N: Number

GPS: Global positioning system

JH: Jump height

FT:CT: Flight time: contraction time ratio

AU: Arbitrary units

%Δ: Percent change

CD: Central defender

CM: Central midfielder

CA: Central attacker

WD: Wide defender

WM: Wide midfielder

Mind the gap: An investigation into matchday locomotor demands and associated fatigue response between youth and senior footballers

1. Introduction

Football (soccer) is evolving rapidly in numerous ways. Increased commercialization has driven the sport to new heights financially, where the top 20 highest revenue generating men's clubs in world football, have combined to generate 10.5 billion euros in the 2022-23 season, a 14% increase from the top 20 over the previous year (Deloitte, 2024). Further highlighting footballs financial evolution, is the 1508% increase in weekly wages of English Premier League (EPL) footballers from its inception in 1992, to 2010. Over the same period, the average British citizen has only seen their income improve by 186% on average (Boyle, 2014). Increased revenue and player wages can attribute much of its evolution to football's global popularity. The 2022 FIFA world cup saw 5 billion people engaged with the tournament, 1.5 billion viewed the final online, while 88,966 spectators were in attendance (FIFA, 2023). An expanded fixture list for clubs to compete in, increases commercial and broadcasting opportunities for clubs to bolster their revenue (Deloitte, 2024); consequently, the evolution of football is not solely described by its financial state, but also the shifting landscape in the fixture list for both club and international competition. Likewise, as player wages have increased exponentially, so have the workloads for young and experienced players alike.

The 2023/24 FIFPRO world player union Player Workload Monitoring Report (PWMR), highlighted that 54% of elite footballers monitored, had excessive or high workload demands (>40 Appearances). The global fixture calendar, including international and club competition, sees the best players included in squads up to 83 times, and some travelling up to 162,978 km in one year. This shift in high workload is seen in comparisons between young players today and young players of the past. Young players like Jude Bellingham and Jamal Musiala, have already exceeded the number of appearances made before age 21 than their country's previous young stars. By age 21, Bellingham had already made 39 more appearances than the next highest capped player for his age and is on pace for 220 more appearances than the England player with the most club and international appearances. In Germany, Musiala is the most capped under 21 footballer by this age and has made 44 more appearances than his nation's next most capped predecessor by age 21. There is an increased reliance on young talent, who are unaccustomed to the lesser workloads of yesteryear.

Increased workloads are explained by growing fixture lists, made up of back-to-back matches (two games in one week). 30% of monitored players had at least one sequence of 6 or more consecutive back-to-back matches and some players' percentage of appearances being back-to-back matches as high as 77.3%, or 51 out of 66 matches. Nonetheless, additional matches have been added to the fixture list for players in the upcoming years; new or expanded competitions like the FIFA Club World Cup, the FIFA World Cup, and regional club competitions across the globe are adding to an already extensive fixture list for the players.Importantly, this increased load has potential harmful effects on the wellbeing of professional footballers. Greater workload demands entail higher amounts of external load and exposure to match play. There is more mental pressure, more travel, more media duties and less time off. The possible negative health outcomes of this are injury, fatigue, overtraining syndrome, circadian rhythm sleep disorders, suppression of the immune system, mental burnout, and depressive symptoms (Godderis, Mortelmans and Hendrickx, 2024).

Football cannot exist without players, and future players need to fulfill elite football Clubs' growing fixtures lists. However, out of 1.5 million boys who play organized football, only 0.012% (180 out of 1.5 million), are signed professionally by a EPL club (Calvin, 2017). Alarmingly, 98% of players awarded with academy scholarship by English clubs at 16 no longer play in the top five tiers of professional football in England by 18 (Calvin, 2017). Regardless, players of the future are still more likely to be academy players of today and thus investment in their development should be substantial to match the demands and improve progression rates.

Since the introduction of UEFA's Financial Fair Play (FFP) regulations in 2009, the economic incentive to developing youth talent has become clear (Franck, 2014). FFP prohibits unlimited spending on players in transfer windows by football clubs. However, it does allow for unlimited spending on youth development systems. In this case, European clubs can invest in their own academies to produce "homegrown" talents; players who have trained at least 3 years between the ages of 15-21 in their respective club or a club within the same national system (UEFA, 2005). Clubs competing in the UEFA champions league, or Europa league are required to roster 8 homegrown players in a squad of 25. Altogether, elite clubs who compete in European competition are required to produce homegrown players, but also incentivized to do so. Elite football clubs have recognized producing homegrown talent within their own youth development system, is a more sustainable practice than buying players in the transfer market (Franck, 2014). Homegrown players can be acquired as senior players with no direct transfer fee, or, sell on to other clubs to meet FFP rules, recorded as pure profit (Franck, 2014). Better yet, successful academy development systems can adequately prepare youth players for the transition to men's football.

Likewise, EPL clubs must follow profit and sustainability rules (PSR) as of the 2015-16 season. PSR outlines a maximum of 105 million pounds loss in a three-year reporting cycle, with a failure to adhere to these rules resulting in point deductions, negatively affecting a club's status in the EPL (Premier League, 2025). Once again, expenditure on academies does not count towards losses and therefore successful academy systems that produce “homegrown” talent are incentivized to meet financial regulations and sustain success on the pitch.

High-yielding youth player development is essential to current and future team performance, from financial and team performance perspectives (Premier League, 2025; UEFA 2005). Productive youth academies must apply sport science practices to appropriately prepare youth players to transition to the intense and voluminous demands of modern football. The aim of this paper is to outline differences in professional youth and senior football and provide evidence to affect physical preparation of youth players' transition to men's football.

1.1 Football's Physical Demands

Football is a random intermittent recovery sport where professional players cover between 10-13 km on matchday made up of walking, jogging, high speed running, sprints, jumps, decelerations and accelerations (Bangsbo, Mohr and Krustrup, 2006). GPS wearables and semi-automated video monitoring technology have allowed for robust analysis of match play locomotor demands and the factors that influence them (Castellano, Alvarez-Pastor and Bradley, 2014). Contributing factors to matchday locomotor demands includes playing position, fatigue or pacing, match half variation, match location, match status, and competitive standard (Castellano, Alvarez-Pastor and Bradley, 2014). Locomotor outputs have also been appropriately analyzed in terms of effective playing time, termed “ball-in-play” (BIP) time, and through examining the densest locomotor periods measured by meters per minute (m/min), termed maximal-intensity-periods (MIP), or worst-case-scenarios (Mandorino and Lacome, 2024). This thesis will focus on the playing position's effect on locomotor demands, and competitive standard. Specifically, the difference between youth and adult professional football.

The physical and tactical evolution of football has been described as faster paced and more physically demanding (Allen *et al.*, 2024; Barnes *et al.*, 2014; Wallace and Norton, 2014). Matchplay has evolved, and its repercussions on the health of footballers have been examined. With more intense matches and greater frequency of matches, the negative effects of increased workload are under scrutiny (Ekstrand *et al*., 2021; Windt and Gabbett, 2017). The rate of injuries may be unclear in response to increased workload; however, the total number of injuries is increased when exposure is increased (Windt and Gabbett, 2017). Hence, increased exposure via increased competition requires researchers' attention.

1.2 Injuries

1.2.1 Injuries in Men's Modern Elite Football

The UEFA Elite Club Injury Study (ECIS) surveilled injury rates and trends among 49 elite football teams, comprising 3302 players, over 18 seasons from 2000 to 2019 (Ekstrand *et al*., 2021). They defined injuries as any 'physical complaint preventing full participation in football training or match play', injury incidence as number of injuries per 1000 player hours, and injury burden as the number of lay-off days per 1000 player exposure hours (Ekstrand *et al.*, 2021).

The 2000-2019 ECIS performed time trend analyses which showed annual decreases in injury incidence in both training and matches by 3%, while injury burden of match injuries decreased by 2%, and no statistically significant change in burden of training injuries over the 18-season long period (Ekstrand *et al*., 2021). From a club perspective, this might indicate injury preventative methods applied by medical practitioners in elite football, like neuromuscular exercise prescription and external load management, have been successful despite the evolution of elite football from 2000-2019. From the player perspective, although injury rates and burdens are decreasing, they are expected to compete in more fixtures and often represent their international teams and thereby increase their exposure hours to football. It is important to note that the ECIS monitored injury data and practices of the top performing clubs in Europe whose competitive success will either stem from financial superiority or lead to financial success. Likewise, their financial success might be underpinned by best medical practice or support best medical practice. Still, injury incidence rates over the observed 18 seasons of elite clubs (6.6 per 1000 hours), are similar to 11 seasons of 4 squads (44 seasons) data from the 2nd and 3rd tier of English football between 2007 and 2019 (6.5 per 1000 hours) (Palmer *et al.*, 2023).

A follow up study utilizing the same diagnostic criteria and sampling population criteria, researched hamstring injuries from 2000-2022. In this iteration of the UEFA ECIS, a detailed view was illustrated on the state of injuries in elite football; although overall injury rates were down across 2000-2022, the proportion of injuries being hamstring injuries rose from 12% in the first year to 24% by the final year (Ekstrand *et al.,* 2023). The proportion of injury absence days caused by hamstring injuries also grew from 10% to 20% over the same period. An annual decrease of 4%, and 5% in ligament match injury incidence from 2000-2019, partly explains the proportional shift towards hamstring injuries from 2000-2022, but the 3.9%, and 6.7% annual increase in hamstring injury incidence in the matching exposures is the primary driver (Ekstrand *et al.*, 2021; Ekstrand *et al.*, 2023). Importantly, running or sprinting was named as the mechanism of injury 61% of the time, highlighting potential associations with the evolution of football and exposure to HSR and sprinting, to increased rate of hamstring injuries (Ekstrand *et al.*, 2023). It is also important to note that hamstring injuries increased positively with each year, between 2007-2019 in the 2nd and 3rd tier of English football (R^2=0.45) (Palmer *et al.*, 2023).

1.2.2 Injuries in Youth Modern Elite Football

Football is not only an adult's game. There are 12,500 footballers between the ages 8 and 22 registered with professional academies and clubs (Calvin, 2017). Like the men's game, from under 18s onwards, the competitive playing season spans 9 months, with 4-5 training sessions and one match making up a normal weeklong microcycle (Jones *et al.*, 2019). While there isn't a direct equivalent to the UEFA ECIS for youth football, a comprehensive systematic review of 23 injury incidence studies, observed rates for elite or highly skilled footballing male populations between 8-21 years (Jones *et al.*, 2019). Injury was defined slightly differently across the studies with the majority using the consensus statement of football injuries also used by the UEFA ECIS (10/23), while others opted for less sensitive definitions of injury with 48 hours' time loss being the next most popular definition (6/23) (Fuller *et al.*, 2016; Jones *et al.*, 2019).They found that the mean injury incidence for the total reviewed population was 5.8 per 1000 hours, while for the under 17 to under 21 age groups (6/23 studies), the mean rate was higher at 7.9 per 1000 hours. In contrast, elite men's football in the last 18 years' injury rate was 6.6 per 1000 hours (Ekstrand *et al.*, 2021). Pfirmann *et al.*, 2016 also found that older youth elite footballers (16-18) faced greater injury rates and pointed to shifts from part time to full time football schedules to explain this. In this case, maturation must also be acknowledged as a risk factor for injury.

Greater levels of power and speed are exhibited by post-peak height velocity (PHV) individuals, and this impacts the intensity of match play (Philippaerts *et al*., 2007). Furthermore, mid-PHV footballers experience physiological and anthropometric changes that affect motor control and stretch shortening cycle ability, known modifiable risk factors for injury. (Tumkur Anil Kumar *et al.,* 2021). In general, biological maturation related changes are a risk factor to injury in youth elite football but not men's elite football. Nonetheless, the three most common types of injuries across both men and youth football were strains, sprains, and contusions to the lower limbs (Pfirmann *et al*., 2016). However, the well documented increase in hamstring injuries in the elite men's game is not as well researched in the elite youth game. Differing findings are found across the youth level with Pfirmann *et al*. (2016), not finding a universal most common injury location in their review. A dated study from 2000-2005 analyzing injuries from 41 premiership academies in England, found that the quadriceps muscle group was the most common injury location (39.1%) from footballers aged 9-16, while the hamstrings muscle group was the most common severe (>28 days of absence) injury location (40.8%) (Cloke *et al*., 2012). They also noted that muscle injuries only made up 1,288 out of the 10,225 (13%) of the injuries. This number is much lower than the UEFA ECIS percentage of muscle injuries in elite men footballers from 2000-2019 (39%) (Ekstrand *et al.*, 2021).

Akin to elite men's football, injury rates in training for elite or highly skilled youth were lower than injury rates in matches (Jones *et al*., 2019). Injury rates have also been noted as greater in matches for both youth and adult male elite footballers, but that elite youth had higher mean injury rates during training (6.9 per 1000 hours vs. 3.7 per 1000) (Pfirmann *et al*., 2016). Perhaps the most important analysis indicated that elite male football players had a higher mean match hours to mean training hours ratio (Pfirmann *et al*., 2016). This exposes elite male footballers to the chaotic loading demands and contact demands of match play more often than youth elite footballers, especially in the current landscape of professional footballers scheduling evolution (Pfirmann *et al.,* 2016).

Transitional phases for youth players are vital as are most common injury sites for men when assessing physical preparedness for youth players integration into senior football. Youth players transitions from part-time, to full-time, to men's football all accompany unique injury risk, and thus holistic physical development that improves neuromuscular qualities and monitors loading strategies are essential parts of long-term athlete development (Bowen *et al.*, 2020; Radnor *et al.*, 2020).

1.3 Increased Workload and Fatigue

An assumption of the increased workload figures for contemporary professional football is that there are increased levels of fatigue. Fatigue lacks a universal definition, yet it is often considered a relevant risk factor for injuries and a commonly used term describing a physical performance or state (Verschueren *et al.*, 2019). A systematic review of 68 papers based its research on fatigue defined as an "exercise induced impairment of performance" (Verschueren *et al.*, 2019). During athletic performances, athletes are hypothesized to fatigue as time played increases. The proposed mechanisms of fatigue are mainly changes in neuromuscular control, and researchers have made the correlation between increased injury incidence toward the end of halves in football, with increased levels of fatigue (Ekstrand, Hägglund, and Waldén, 2011). Insufficient evidence exists to date but the systematic review by Verschueren *et al*. (2019), examined whether acute fatigue affects intrinsic risk factors of lower extremity injury risk. They found that acute fatigue can decrease single leg postural control, decrease ankle position sense, decrease limb symmetry in hop tests, decrease measures of isokinetic hamstring and quadriceps muscles and the respective hamstring: quadriceps ratios.

The listed acute effects of fatigue impact modifiable risk factors for lateral ankle sprain injuries, patellofemoral pain syndrome, and hamstring injuries, however none of the filtered studies reported the effect of acute fatigue on modifiable injury risk factors for non-contact ACL injuries. This is in part due to single leg postural control's debated role as a risk factor for such ACL injuries. Importantly, the paper highlights the need for a universal definition of fatigue to move forward researching the proposed effects.

If negative effects of fatigue are rightfully prevented in senior players through optimal loading strategies that increase physical qualities, equally conducive interventions must be incorporated in youth development systems to aid successful transition into senior football with minimal fatigue.

1.4 Future Implications and Thesis Outline

To summarize, the evolution of football is shaped by financial and competitive demands. With record revenues generated and wages rising regularly, the sport's popularity has encouraged more competition for players. With a greater number of games comes more congested fixture lists and increased player workloads. Greater exposure hours, fixture congestion, and higher intensity match play requiring more high speed running and sprinting, combine to manifest an increase in the proportion of hamstring injuries (Ekstrand *et al.*, 2023). In response, efforts have been made to address the increased workload players are facing. For example, FIFPRO Europe and the European Leagues have filed a joint complaint to the European Commission against FIFA regarding the international match calendar (FIFPRO, 2024). Similarly, players have also suggested they would go on strike as a last resort if legal actions do not prevail (FIFPRO, 2024).

Addressing the number of fixtures is one strategy to protect players from the evolution of football, but the nature of match play will likely remain at a heightened intensity even if the number of fixtures are reduced. This means the football players of the future must be prepared for integration into a physically demanding sport. In which case, physical development of youth and adolescent athletes is critical to support the sustainability of modern elite football.

This research investigates what is necessary to prepare youth players for integration into senior football. It will compare senior and youth locomotor matchday demands and implications for neuromuscular fatigue. While extensive research on locomotor matchday demands for senior professional football has taken place, the same cannot be said for literature that contrasts youth external demands with senior external demands. Moreover, neuromuscular fatigue to match play has been examined for both youth and senior football, but a comparison does not yet exist. This work can help football practitioners honestly assess if individual youth players are ready to transition to senior football.

2. Literature Review

2.1 Youth Player Development

Shortly after the UEFA FFP regulations were implemented, the Elite Player Performance Plan (EPPP) for development of academy talent was introduced in England in 2011. The EPPP produced standardized procedures and criteria for English football clubs to meet, to lead the football world in development of young talent. A narrow description of the EPPPs tiered system and matching criteria objectives are as followed: category 1 academy provides up to 8,500 hours of contact time from U9 to U21, whereas category 2, 3, and 4, clubs provide their players with 6,600, 3,600, and 3,200 hours respectively. Within this contact time, players physical, technical, psychological, and social abilities are supported throughout the process by staff specialized in each field.

The EPL reported that 10 years on from its inception, the EPPP developed 762 more Academy graduates with professional contracts compared to its initiation season, twice as many minutes played in the EPL by English U21 players, and 1st for average transfer market value of U21 players of any nationality compared to 5th in 2012/13 (Premier League, 2022). The optimization of the EPPP's approach to developing academy talent has been sought after through extensive research across fields of sport psychology, injury rates and prevention, biological maturation, physical development, talent identification, and nutrition (Callis *et al*., 2023; Goto *et al*., 2019; Kelly *et al*., 2022; Kelly *et al*., 2024; Tears *et al*., 2018). The report by the EPL highlights the success that the EPPP has brought to EPL clubs, however more research is required to investigate the impact it has had on youth systems and football clubs not in the EPL across the English Football League (EFL). Nonetheless, the overarching goal of producing more "homegrown" talent was met and the outcomes over the last ten years suggest that academic research supporting the EPPP have been an effective intervention worthy of continuing.

2.2 Locomotor Demands

Football is not only evolving behind the scenes through economics and quantity of fixtures, but in match play through ever-changing tactical and physical demands. Comparison between the FIFA World Cup Finals in 1966 and 2010, reported an increase in passes per minute of 35% and an increase in game speed of 15% (Wallace and Norton, 2014). Difference in match speed can also be described by high speed running distances (HSR, defined as >5.5 m/s) increasing by 20% from the 2006/2007 EPL season to the 2012/13 season, where a 50% increase of the number of high-intensity actions including an 8% of total sprint distance (Sprint defined as >7 m/s) was also observed (Barnes *et al*., 2014). Over the same period and sampling population, locomotor outputs between the top 4 teams (A-tier) in the EPL and the teams in 5th position to 8th (B-tier) position narrowed (Bradley *et al*, 2015). Over the 7-season period, increases in HSR and sprints when in possession of the ball were moderate for teams in the B-tier, while only small for all other teams (Bradley *et al*., 2015). It can be inferred from these findings that the physical demand of football is evolving for more teams and players, in this case B-tier EPL clubs, in attempts to achieve A-tier status and the commercial benefits entailed. More recently, game speed trends depicted by increases in HSR and sprint distance, have continued to significantly evolve over large time periods (2014-2019), albeit with trivial to small insignificant increases when comparing annual data (Allen *et al.*, 2024).

The relationship between evolving physical demands and style of play has also been examined. Plakias *et al*. (2023), explored the influence of playing style on physical demands across 238 matches in the 2021-22 season of first division Turkish football and found that a transitional style of football is linked with greater HSR and greater number of HSR efforts. Similarly, when an opponent performed more counterattacks, the team analyzed had an increase in sprints and max speed values (Plakias *et al.*, 2023). Contemporary research highlights transitions and counterattacks as a strategy to enhance football performance and speak to its positively trending involvement in modern football. Thus, a positive trend toward HSR and sprint distance, and the number of HSR and sprint efforts (Eusebio, Prieto-Gonzalez and Marcelino, 2024). Connected to the number of high intensity actions including sprints, and decelerations, match play outcomes like goals scored, matches won, and league position have all been associated. For example, during open play goal scoring actions in the EPL, players involved performed a high intensity action 82.9% of the time in the 2018/19 season (Martinez-Hernandez, Quinn, and Jones, 2023). High intensity actions were defined as linear advancing motions, decelerations, turns, change in angle runs, lateral advancing motions, ball blocks, and jumps (Martinez-Hernandez, Quinn, and Jones, 2023). Meanwhile, players involved included the goal scorer, goal assistants, and their respective defenders. This wider view on involved players in goals, uncovered that defending actions were of high intensity more often than attacking actions (Martinez-Hernandez, Quinn, and Jones, 2023). This details high intensity actions and how they are performed is a crucial factor that impacts match outcome via involvement in goal scoring actions. Not only for scoring goals, but in preventing goals.

Building on the vitality of intense physical actions in contemporary football, analysis of a 4th division side in England found that the number of accelerations and decelerations were highest in matches won, when compared to losses and draws (Rhodes *et al*., 2021). In this study, the authors collected locomotor data over 45 matches in the 2018/19 season and the context in which these matches were performed. Notably, 15 games were played as a midweek fixture while 15 were played as a Saturday game following a midweek fixture. In fixtures played on a Saturday following a midweek fixture, the sample population performed significantly less high-intensity accelerations and decelerations than the preceding mid-week fixture and only won 1 match of the 15 (Rhodes *et al.,* 2021). At least two things can be interpreted from this study: one being physical capacity to perform high intensity accelerations and decelerations can impact match outcome, the other being fixture congestion and or back-to-back match scenarios impact the quantity and intensity of accelerations and decelerations performed (Rhodes *et al.*, 2021). Combining these findings with the evolution of the football calendar poses a challenge for elite football clubs who will be subjected to more congested fixture lists via expanded or novel competitions (FIFPRO, 2024).

The evolution of football has been defined as a change in speed of match play, and the quantity of matches (Barnes *et al*., 2014; FIFPRO, 2024; Nassis *et al*., 2020). It is characterized by increases in event data like passes attempted, transitions, and counter attacks. These actions are associated with increases in locomotor data, HSR, sprints, and intense physical actions such as decelerations, whose occurrence and performance are highly relevant to goal scoring actions (Eusebio, Prieto-Gonzalez, and Marcelino, 2024; Martinez-Hernandez, Quinn, and Jones, 2023; Plakias *et al*., 2023; Rhodes *et al*., 2021). The evolution of elite football's physical nature is supported by financial incentive, but what are the implications of increased speed of play and regularity of fixture congestion?

2.2.1 Tactical Effects on Locomotor Demands

Analysis of match play has specified tactics into phases of play. In a study of 1,083 elite European football matches, on-ball event data and locomotor player data were captured by a validated optical tracking system between 10-25hz (Jerome *et al.,* 2024). There were at least 7,700 observations for each of attackers, midfielders, or defenders. In this research, phases of play were defined by the status of ball possession, position of players, and position of the ball on the pitch. The aim of the paper was to determine the general and positional locomotor demands of each phase of play.

In this model, phases of play were split into three sections of the pitch. Ball possession within a team's own half was considered 'build-up' phase for the in-possession team and 'high block' for the out of possession team. Ball possession from the halfway line until halfway into the opposition's half was considered ‘progression phase’ for the in-possession team and ‘mid-block’ for the opponents. Lastly, when attacking players and the ball are positioned from the halfway point of the opponent’s half until the goal line of the opponents, this was considered the ‘chance creation’ phase and ‘low-block’ phase for the defenders (Jerome *et al.*, 2024). Considerations for speed of play were also accounted for. ‘Fast attack’ and ‘fast defense’ were when the in-possession team progressed the ball greater than 45m in less than 8s (average ball speed >5.5 m/s), had two interactions with the ball (‘pass’ or ‘controls’) and a maximum of 7s after the first 45m was covered. Likewise, ‘attacking transition’ and ‘defensive transition’ were coded as a ≤6s period following a change of possession that ended with the ball going out of play or continued ball possession after 6s.

HSR and sprint metrics were measured in accordance to previous research thresholds, although accelerations and decelerations were recorded as changes in velocity ±2m/s^2. They also calculated time spent accelerating or decelerating.

The most pertinent takeaway was that each phase of play had unique locomotor demands across locomotor metrics, across possession status, and across position group (Jerome *et al.*, 2024). As expected, phases of play that considered speed of play exposed players to greater HSR and sprint demands. The research also elucidated proportions of ball-in-play time were as followed: 36.4% in build-up/high-block, 24% in progression/mid-block, 14.2% in chance creation/low-block, 7.6% in fast attack/fast defence, 17.8% in defensive transition. Distinctly, this research observed elite football match play where tactical and physical homogeneity is expected (Clancy *et al.*, 2022; Ju *et al.*, 2025). Therefore, extrapolating proportions of ball-in-play periods to youth or semi-professional level where tactical and technical proficiency is more variable compared to men’s football, must be done with caution (Ju *et al.*, 2025). In sum, football tactics describe how a match is played and locomotor outputs are likely to be the result of tactical demands, not the cause.

2.2.2 Playing Position Effects on Locomotor Demands

Playing position has been shown to expose footballers to significantly different external loads (Sarmento *et al.*, 2024). In a systematic scoping review of 178 research articles that examined player positional locomotor differences in elite football match play, central midfielders covered the most total distance, followed by wide midfielders and wide defenders (Sarmento *et al.*, 2024). Notably, wide midfielders covered more HSR distance than wide defenders and central midfielders, while sprint distance was also highest in wide midfielders, forwards, and wide defenders (Sarmento *et al.*, 2024). Wide midfielders also performed more accelerations and decelerations in match play, exposing them to great amounts of fatiguing mechanical load (Harper, Carling, and Kieley 2019).

Like whole match mean locomotor demands, mean positional locomotor demands also vary across the spectrum of ball-in-play (BIP) periods (mean, max, different time periods). 2nd division football players in England were categorized as defenders, midfielders, and forwards, for 8 fixtures in 2018. The results highlighted that BIP m/min were significantly greater for midfielders when compared to defenders, but no significant relationship existed between forwards and any other position group when examining generic m/min (Mernagh *et al.*, 2018). Further, no significant differences were found between positional HSR/min, even during the max BIP period (Mernagh *et al.*, 2018). These findings suggest that during demanding passages of play, HSR demands are universal across positions. Acceleration data follows a similar path: although midfielders performed significantly more accelerations per minute than defenders and forwards during BIP, significant relationships did not exist between positions in the max BIP periods (Mernagh *et al.*, 2018). Lastly, midfielders performed significantly more decelerations/min. Key considerations for this paper are that it only examines one club in one season, it doesn't include sprint data, and midfielders and defenders are not specified as wide or central, where wider positions are known to require more HSR, Sprints, ACC and DEC (Harper, Carling, and Kieley 2019; Sarmento *et al*., 2024). Still, this research provides enough reason to continue examining max BIP period locomotor demands across positions in football.

2.2.3 Youth and Senior Match Locomotor Demands

The general locomotor demands of football are widely accepted (Bangsbo, Mohr and Krustrup, 2006). In recent years, efforts to expand upon that knowledge have become known. Effects of tactics, playing position, worst case scenarios (WCS), maximal intensity periods (MIP), ball-in-play time (BIP), have all emerged as more specific locomotor reports of match play that help coaching staff administer training interventions with specific external loading targets to improve performance and reduce injury risk.

One further way to record locomotor demands is to compare these contemporary categories between youth and senior elite athletes. To maximize youth to senior transition, comparison of locomotor match outputs is an essential part of deciding whether a youth athlete is prepared for the locomotor demands of men's football.

In the 2021-2022 season, a club competing in the Scottish Premier League captured whole match mean locomotor data across their senior team and U18s using 18hz GPS units (Morgans *et al.,* 2022). Over 38 fixtures for the senior team and 28 fixtures for the U18s, they found no significant differences between any whole match mean locomotor demands. This included total distance, high intensity distance, sprint distance, explosive distance and number of decelerations and accelerations (Morgans *et al.*, 2022). This research implies that U18 sides of the same club are expected to complete the same whole match mean external outputs as their senior outfit (Morgans *et al.*, 2022). However, this paper did not account for the modern integrated approach of tactics nor BIP or WCS metrics. It should also be noted that the findings were from one club only and cannot be assumed for all other clubs and their respective U18s.

From a broader perspective, world cup match locomotor demands were analyzed with 25hz optical tracking systems across U17, U20 and Men's age groups (MWC) in 2023, and 2022 (Ju *et al.*, 2025). 56 MWC 90-minute games were included, alongside 42 U20 and U17 90-minute games. Mean and coefficient of variation (CV%) values of total distance, sprint distance and high intensity running distance were recorded alongside technical and tactical events.

The results found that the performance variability measured by the youth age groups was higher than the men's (Ju *et al.*, 2025). Specifically, high intensity running distance, sprint distance, attempts at goal and receptions in the final third all had significantly higher CV% at the U17 level compared to the MWC. Nonetheless, the mean high intensity running distance was 15% less for U17 compared to U20 and MWC, and 20-25% less sprint distance than MWC and U20. This research points to youth footballers having less consistency in technical ability and this caused more variable physical and tactical demands. Further evidence is that in the MWC, there were higher completion rates of passing, line breaking passing, made more offers to receive and received the ball more. In contrast, U17 and U20 completed more defensive actions (tackles, blocks, second balls), highlighting less precise in-possession play, requiring more out-of-possession play.

Vitally, differences in decelerations between youth and MWC were not captured by the research. Nonetheless, an inference can be made that U17 and U20 performed more decelerations compared to MWC due to their increased defensive action demands (Harper, Carling and Kieley 2019).

2.2.4 Youth and Senior Training Locomotor Demands

Comparing weekly training loads between senior and youth squads, is another valid way to measure an adolescent's readiness to transition to senior football. From a loading perspective, it can help prevent a spike in acute load and potentially mitigate injury risk from a workload perspective (Bowen *et al.*, 2020). Thus, in 2021, a first division club in the Netherlands monitored external load from 11 senior players and 9 youth players (mean age: 17.6 years) over an entire season. Senior players were exposed to back-to-back game weeks and the research accounted for this difference in match exposure by analyzing external loads in single fixture game weeks separately to back-to-back game weeks (Houtmyers *et al.*, 2021). The purpose of this paper was to investigate weekly external loading differences between youth and senior squads, using distance covered and distance at different speed thresholds to measure load monotony, load intensity and total load. (Houtmyers *et al.,* 2021).

They found that the youth team's weekly load was more monotonous (measured by weekly mean external load divided by weekly standard deviation), less intense (measured by meters per minute) and greater in total distance than a senior single fixture game week. This confirms a common qualitative claim that senior football is more intense than youth football. This research implies that senior training is more intense to adequately prepare players for equally or more intense senior fixtures. Physical differences are also likely to impact this difference in intensity training.

In a first division Scottish club, the youth development squad (mean age 19.2) and the senior's squad physical qualities were compared. Maximal sprint speed (MSS) and maximal aerobic speed (MAS) were assessed using a GPS measured 40m sprint and a 1000m shuttle run. They found the senior squad to have moderately higher MSS that exceeded a practical threshold (0.1 m/s) and MAS to be moderately higher in the senior team while only approaching the practical threshold (0.2 m/s) (Clancy *et al.*, 2023). This suggests that differences between senior and youth squads' aerobic capacities are not practically significant and that locomotor outputs are not down to aerobic capacity. It might point to MSS as a more important difference between youth and senior players. MSS can impact HSR and sprint distance as players reach thresholds of 5.5m/s and 7.0 m/s more often if it is at a lower percentage of their MSS (Clancy *et al.*, 2023).

2.3 Neuromuscular Fatigue after Matchplay

Neuromuscular fatigue is defined as an ”exercise induced impairment of performance” (Verschuren *et al.,* 2019). Research has been conducted investigating whether there were acute fatigue effects from simulated football match play in academy aged players (18-23) (Salter, Cresswell, and Forsdyke, 2022). 71 players competing in a high-level international academy participated in a research design that included a fixed soccer-specific activity profile to simulate match demands, alongside muscle strength testing before the activity, after 45 minutes and after 90 minutes, reflecting stoppages in normal match play. They found that isometric hip adduction and abduction values showed likely substantial decreases after 45 minutes and very likely substantial decreases after 90 minutes. On the other hand, they only found unclear and likely trivial decreases in eccentric hamstring strength values at the same test periods (Salter, Cresswell and Forsdyke, 2022). An important note of this paper is that the muscular demands of football are likely greater than this study found due to the simulated football activity’s omission of kicking, sprinting, HSR, collisions and cognitive demands that actual match play entails.

Likewise, fatigue effects have also been researched surrounding U-18 EPL academy match play (Springham *et al*., 2024). Similar to the procedures of Salter, Cresswell, and Forsdyke, (2022), isometric hip and posterior chain muscular fatigue were measured surrounding matchplay. This research also included jump testing and self-reported fatigue measures. Testing occurred across 8 home match day cycles, including the day before match day, pre-match, two and three days after the match (MD-1, MD-Pre, MD-Post, MD+2, MD+3).

They found that countermovement jump (CMJ) jump height (JH), eccentric rate of force development (RFD) and eccentric peak force development were the most sensitive metrics to match play and returned to baseline by MD+2. Measures of isometric hip and posterior chain peak isometric force decreased post-match and while posterior chain and abductor peak force normalized by MD+2, peak isometric adductor force and maximal impulse did not normalize until MD+3.

Key takeaways from this paper are that adductor muscle capabilities are reduced even until MD+3 and relevant CMJ metrics negatively impacted by match play are JH and eccentric RFD and peak eccentric force development (Springham *et al.,* 2024). The findings related to isometric adductor capabilities confirm Salter, Cresswell, and Forsdyke, (2022), findings, whilst using a more ecologically valid procedure of actual match play versus simulated match play. However, Springham *et al*. (2024) did note greater reductions in isometric posterior chain force development MD-post, however, this was expected as real match play requires greater HSR, kicking and sprint demands. It should also be noted that procedures measuring posterior chain force were not the same between experiments (isometric versus eccentric). Overall, both papers point to the importance of training interventions targeting adductor physical quality in preventing injuries to the commonly affected area for the selected age ranges (U18-U23) (Materne *et al.,* 2021). While the findings were limited to only one club, and surrounding home matches only, this paper still provides a framework for future research examining match induced fatigue in young high-level footballers (Springham *et al.,* 2024). The work by Springham *et al.* (2024) also included commonly used CMJ testing to profile stretch shortening cycle (SSC) fatigue.

2.3.1 Stretch Shortening Cycle

The SSC describes rapid stretch and force in the muscle tendon complex to transition from eccentric to concentric muscle action. It is vital for performance in sprinting, jumping, and changes in velocity. Immediately following SSC exhaustive exercise, changes to SSC function related to metabolic disturbances are loss of stretch-reflex sensitivity, muscle stiffness regulation, reduced tolerance to imposed stretch loads (Komi, 2000). 24 hours later, the inflammatory process accounts for recovery delays while some mechanical performance recover as the metabolic disturbances return to baseline (Komi, 2000). 48-72 hours after, a secondary performance decline peaks, linked to continued muscular inflammation, damage repair, and increased creatine kinase levels (Komi, 2000). All to say, the SSC expresses fatigue in differing ways over time after SSC exhaustive exercise. Therefore, correctly assessing fatigue is crucial and in need of standardized methodology. In recent years, extensive research has utilized commercial force plate technology to assess SSC function with jump testing (Badby *et al., 2025;* Claudino *et al.,* 2017; McMahon *et al., 2018;* Xu et al., 2023).

2.3.2 Jump Profiling

Jump testing is a widely performed assessment tool that profiles an athlete’s lower limb force production qualities and SSC ability. Such tests include CMJs, squat jumps (SJ), and drop jumps (DJ). CMJs and DJs utilize the stretch shortening cycle (SSC), while the SJ does not. The DJ is the least repeatable test of the three because of its technical requirements. CMJs are easy to master and utilize the SSC, therefore they are the most performed jump test (Claudino *et al.*, 2017). They require braking and propulsive forces through triple flexion and extension at the ankle, knee, and hip joints.

Jump testing is used to monitor neuromuscular ability across phases of performance. The goal of jump testing is to assess force production qualities relative to time, based on Newton's second law of motion (McMahon *et al.*, 2018a). Force production over time, result in performance outcome metrics like jump height and flight time. Changes in either force production or time taken are measured to assess changes in jump height (McMahon *et al.*, 2018a). Furthermore, countermovement jump tasks are characterized by six key phases in this order: weighing, unweighting, braking, propulsion, flight, and landing (McMahon *et al.*, 2018a). This paper will focus on the braking, propulsion, and flight phases of countermovement jumps. The braking phase commences from peak negative COM velocity, through to when negative velocity reaches zero at peak COM displacement (at the bottom of the countermovement). Large relative net impulse produced by high forces in short times underpin performance in the subsequent propulsion and flight phases. The propulsion phase then commences once COM velocity is positive and continues until the instant of flight (McMahon *et al.*, 2018a). Flight phase is the result of the prior phases force and velocity characteristics that determine COM displacement and starts when force falls below a set threshold and ends when it rises above a set threshold.

Methods of calculating CMJ JH are also important. A systematic review of 21 studies that defined their JH calculation methods and used at least healthy adults between 2000-2022, critically evaluated estimation of JH methods. They found that the impulse-momentum (Imp-Mom) method was the most reliable, valid, and feasible methodology for measuring JH (Xu *et al.*, 2023). The imp-mom method is derived from Newton's law of acceleration and the law of the conservation of energy. This means that the kinetic energy at take off would be identical to the potential energy at max height and briefly, this is where the JH is calculated. In contrast, the more commonly collected flight time method, measures the time between take off and landing and gravitational acceleration to derive JH (Xu *et al.*, 2023). The benefits of the flight time method are its simplicity in calculation, however asymmetrical flight and landing strategies are commonplace and affect the reliability of data collection. On the other hand, the imp-mom method calculations were complex in the past to collect, but with contemporary force plate systems, this method is accessible and eliminates the limitation of flight strategies from the calculation (Xu *et al.*, 2023).

2.3.3 Jump Testing

In a meta-analysis of 151 articles comparing CMJ performance to monitor neuromuscular status, 85% of practitioners used the highest CMJ JH when assessing power, while only 14% used average CMJ JH (Claudino *et al*., 2017). However, the meta-analysis found that average JH is more sensitive to fatiguing protocols and supercompensation effects than highest JH (Claudino *et al*., 2017).

When jump testing is performed on force plates, practitioners have the choice of numerous metrics relating to the force production of the athlete. Typical extracted metrics from the CMJ are peak and mean power, force, time to peak force, flight time: contact time ratio, total impulse and others (Gathercole *et al.,* 2015). Alternative CMJ variables extracted are force at zero velocity, eccentric duration, concentric duration, total duration and area under the force-velocity trace (Gathercole *et al*., 2015). In a 2-part experiment, 11 university level male athletes tested inter and intraday reliability of alternative and typical CMJ variables. The participants performed 6 CMJs and the most consistent 4 were selected for analysis. Inter and intraday CVs all had trivial effect sizes and values <10% except for one variable, demonstrating the reproducibility of the CMJ and its underlying kinetics.

In the 2nd part of the experiment, the participants performed CMJs after a 3-stage aerobic conditioning protocol, three 20m sprints and 10 practice CMJs, examining whether alternative and or typical CMJ metrics were sensitive to the hypothesized fatiguing effects of the protocol. The researchers' main findings were that small and moderate changes were seen across almost all CMJ metrics, typical and alternative, at 0 hours post exercise. In line with Komi, 2000, changes in CMJ performance were trivial 24 hours post exercise and small to moderate changes were seen again at 72 hours post exercise (Gathercole *et al*., 2015).

Differential findings from this paper revealed that mean JH normalized by 72 hours while time related CMJ metrics are still not recovered by 72 hours post exercise. This means that CMJ metrics sensitive to fatigue are ones related to ground contact strategies employed by athletes to reach the same JH. In this case, 72 hours post exercise, the participants required more ground contact time as highlighted by positive changes in mean total duration, concentric duration, eccentric duration, resulting in a smaller mean flight time: contact time ratio, in part due to mean flight time remaining unchanged (Gathercole *et al.*, 2015). As a result of the altered movement strategy 72 hours post exercise, the group mean scores also saw a small increase in time to peak power (Gathercole *et al.,* 2015).

In summary, when analyzing neuromuscular fatigue using CMJ testing, typical metrics and alternative metrics should both be monitored near the 72-hour post exercise mark, to adequately measure an athlete's movement strategy and potential force capacity limitations.

2.4 Hypothesis

The primary aim of this thesis is to define the state of contemporary senior football, and uncover potential findings that reveal a gap between senior and youth football. The objectives are to: describe general and positional locomotor demands and quantify neuromuscular fatigue, in senior and youth players. By comparing the results, practitioners of sport are informed of potential gaps between locomotor match outputs and associated neuromuscular fatigue for youth and senior footballers. It is hypothesized that locomotor demands will not differ significantly between groups, but general physical ability described by CMJ JH, MSS and FT:CT will be superior in the senior group. Also, senior players are predicted to display lesser reductions across all CMJ performance metrics following match play, highlighting greater physical capacity and recovery ability.

3 Methods

3.1 Experimental Design

This study utilized a longitudinal, non-experimental, cross-sectional study design over 10 weeks to compare locomotor demands and neuromuscular fatigue response in one professional football club between its senior side and its youth team. The senior side participated in the 5th tier of English football on a fulltime basis, while the youth team participated fulltime in a regional league against clubs whose senior status is like that of the football club in focus. Both the senior and youth team had regular exposure to strength and conditioning. Locomotor data were collected over a 10-week period where both squads had a total of 5 single-game weeks. Matches were played at routine times for both squads. Locomotor data were collected by Apex Athlete Series 10hz GNSS devices (StatSports, Northern Ireland), 10hZ Vector S7 GPS devices (Catapult, Australia). Countermovement jump data were collected one hour pre-match (PRE) and approximately 48 hours post-match (MD+2). Countermovement jump data were collected with 1000hz sampling rate ForceDecks, FDLite, (VALD, Australia). Data were collected as routine player load monitoring for the senior team, versus a novel experience for the youth team. Research methods were deemed suitable and ethical by the University Research Ethics Committee, (Ethics Code: ETH2425-0048).

3.2 Participants

	Senior	**Youth**
Age (years) ± SD	25.57±3.13	17.2±0.6
Height (cm) ± SD	179.25±7.83	178.34±4.56
Weight (kg) ± SD	77.04±9.1	74.07±6.47
Average Minutes ± SD	87.86±15.37	92.14±15.37
Average Games/Season	45	30

Table 1: Participant descriptives split by group. SD= Standard Deviation

31 full time professional and academy footballers participated in this observation. 14 senior players (25.57±3.13 years, 179.25±7.83cm, 77.04±9.1kg) and 17 youth players (17.2±0.6 years, 178.34±4.56cm, 74.07±6.47kg). Participants were accustomed to 3-4 training sessions, 1-2 strength and conditioning sessions, and 1-2 games weekly. Participants were informed thoroughly of the

research experiment and gave written consent to the researcher directly or via gatekeeper to participate. Parental written consent and player written assent were both collected by the researcher if the youth player was under the age of 18. Data were collected across all participants who played in selected matches, but data were excluded if players completed less than 60 minutes. Data for goalkeepers were also excluded.

3.3 Procedures

All players completed a brief dynamic warmup including submaximal jumps at PRE and MD+2 before they performed CMJ trials on ForceDecks (VALD, Australia). One CMJ trial consisted of a zeroing of the ForceDecks, weighing of the athlete, and then 3 CMJs with 15s recovery in between each jump. Participants were instructed to keep hands on hips and to 'jump as high as possible' and 'land on the force plates'. They performed a countermovement to a self-selected depth. If participants did not land completely on the force plates or used arm swing, the specific jump was excluded from the trial average in data analysis and another jump was performed. Selected countermovement jump metrics were selected based on excellent inter-session reliability, and sensitivity to detect fatigue (Badby *et al.*, 2025; Gathercole *et al.*, 2015). Jump height derived from impulse momentum (cm) was calculated from the velocity of the center of mass at take-off and body mass. Contraction time was the period from the start of the movement to take-off (ms). Start of movement was the point where a 20N threshold was exceeded. Take off- time was the point where force was below 30N. Flight time was the time between take-off and landing (ms). Landing was the point that force rose above 30N. The flight time: contraction time was the ratio of flight time to contraction time.

On matchdays, over the selected period, all players wore GPS units (Vector S7, Catapult, Australia; Apex Athlete Series, StatSports, Northern Ireland) securely placed between scapulae with a vest. GPS units captured GPS data at 10hZ, accelerometer and magnetometer data at 100Hz. 10 hZ GPS units have demonstrated excellent inter- and intra-unit reliability, validity, when collecting distance covered at low to high-speeds, with good to moderate (1-11% Typical Error Measurement) reliability collecting distance covered at very high speeds (>7.0 m/s) (Scott *et al.*, 2016). 10hZ GPS units also are valid and reliable when measuring changes in velocity, although better at capturing accelerations than decelerations (Scott *et al.*, 2016). Locomotor data captured included: minutes played, total distance (km), high speed running distance (m) (>5.5m/s), sprint distance (m) >7.0m/s, accelerations (3 m/s^2), decelerations (-3 m/s^2), maximal sprint speed (m/s) and high intensity distance (m), the sum of meters covered accelerating, decelerating, and at high speed, were all collected across both groups and analyzed.

Data were uploaded to proprietary software and raw metrics were exported in CSV format for data analysis.

3.4 Statistical Analysis

All data were exported from Microsoft Excel via .csv file to Jeffrey's Amazing Statistic Program (JASP 0.19.3.). Sample size power were estimated a priori using G*Power,V.3.1 to determine a Cohen's D effect size greater than 0.2 in a between group analysis of variance (ANOVA). Between two groups, with 8 measurements at a time, G*Power,V.3.1 recommended a sample size of 100, to achieve a power of 87%. While this is acknowledged as a limitation, similar research has used comparable sample sizes due to the exclusive nature of sampling professional football players (Clancy *et al., 2023;* Harris *et al.,* 2025; Houtmyers *et al.,* 2021; Morgans *et al.,* 2022).

Descriptive statistics were reported as group mean scores with standard deviations (SD), and coefficient of variation (CV) as percentages. CV percentages calculated between-subject reliability across the testing period. Normality was assessed visually with Q-Q plots and Brown-Forsythe equality of variance tests for all locomotor and CMJ variables. Welch's T-Tests were performed to compare youth and whole match descriptives via standardised mean differences (effect size: Cohen's D) (Cohen, 2013). Linear mixed models were used as the primary means of statistical analysis where participants were selected as random effects, group and position were selected as fixed effects, and GPS or CMJ metrics were selected as dependent variables. Between group ANOVAs were used secondarily as robustness checks.

A between group ANOVA analysed the locomotor outputs as the dependent variable while the group and positions were selected as fixed effects for GPS data. Interactions were analysed using Tukey corrected post-hoc tests to compare the mean differences between the youth and senior groups.

Likewise, a between group ANOVA analysed the CMJ metrics as the dependent variable while the group and timepoints were selected as the fixed effects for the CMJ data. Interactions were analysed using Tukey post-hoc tests to compare mean differences between groups.

Cohen's D effect sizes were reported as trivial (<0.2), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), and very large (2.0-4.0) (Abt *et al.*, 2020). Statistical significance was set at p <0.05 (Hopkins *et al.*, 2009). Moderation analysis was conducted to investigate locomotor metrics' effect on fatigue between groups. Selected locomotor metrics were the independent variables, and the CMJ metric percent change (%Δ) from PRE to MD+2 was the dependent variable, while the process variable was the group name. If p<.05, results were considered significant to the degree of the standardized z-scores, with each integer representing one standard deviation. Unstandardized effects were also reported as %Δ .

Senior locomotor data were normalized to account for manufacturer differences (Crang *et al.*, 2022; Thornton *et al.*, 2019). Typical error and effect sizes from previous research were used to create an original equation standardizing locomotor data (Equation 1).

Equation 1:

Normalized Locomotor Metric = (ESx) +(TE+x)/2

x= Locomotor Metric Value, ES= Selected Metric Effect size, TE= Selected Metric Typical Error

4. Results

4.1 Descriptives

31 participants data were collected and analyzed. 14 senior players (25.57±3.13 years, 179.25±7.83cm, 77.04±9.1kg) and 17 youth players (17.2 years, 178.34±4.56cm, 74.07±6.47kg) completed 60 minutes or more of match play on one or numerous occasions across the observation period. There were 49 senior and 44 youth, unique observations of match play where locomotor data were successfully collected.

4.2 Locomotor Data

Locomotor Descriptive Data

Metric	ST-YT Difference	Group	Mean	SD	CV	p-value	ES
Minutes	-4.28	ST	87.86	15.37	17%	0.12	-0.33 (small)
		YT	92.14	10.42	11%		
Relative TD (m/min)	6.13*	ST	105.61	7.37	7%	<.01	0.66 (Moderate)
		YT	99.48	11.5	11%		
Relative HSR (m/min)	0.66	ST	7.07	2.26	32%	0.29	0.23 (Small)
		YT	6.41	3.51	54%		
Relative HID (m/min)	-4.2*	ST	13.84	3.01	22%	<.001	-1.07 (Moderate)
		YT	18.04	4.67	26%		
Relative SPR** (m/min)	-0.68	ST	1.4	0.86	60%	0.05	-0.49 (Small)
		YT	2.08	1.68	81%		
Relative ACC/min	0.25*	ST	0.92	0.19	20%	<.001	1.31 (Large)
		YT	0.67	0.19	27%		
Relative DEC/min	0.08*	ST	0.82	0.22	27%	<.01	0.37 (Small)
		YT	0.74	0.19	26%		
MSS (m/s)	0.11	ST	8.65	0.54	6%	0.38	0.19 (Trivial)
		YT	8.54	0.66	8%		

*Table 2: Locomotor descriptive data between groups. ST= Senior Team, YT= Youth Team, TD/min = Distance per minute (m), HSR/min = High speed running distance per minute (m), HID/pm = High intensity distance per minute (m), SPR/min = Sprint distance per minute (m), ACC/min = Accelerations per minute, DEC/min = Decelerations per minute, MSS = Max Sprint Speed (m/s) ***

*N=33, 8 Youth participants data from one match were excluded due to technical issues. SD= Standard Deviation, CV= Coefficient of Variation (between-participant variability), ES= Cohen's D Effect Size, *significant differences between groups, p<.05.*

The ST players performed significantly more ACC/min and DEC/min than YT players as well as TD/min. Differences in ACC/min were large (ES= 1.31; diff= 0.25) while differences in DEC/min were small (ES= 0.37; diff=0.08). TD/min also showed significant moderately sized differences favoring ST (ES= 0.66; diff=6.132), although there were unequal variances. There were no significant differences in minutes played, HSR/min, or MSS (m/s).

On the other hand, YT players covered significantly more HID/pm, albeit the groups had unequal variances (ES= -1.07; diff=-4.2). Likewise, YT players also had significantly higher mean SPR/min to a small effect (ES=-0.49; diff=-0.68). Coefficient of variance (CV) data indicates that minutes played for ST players was more variable (17%) compared to YT players (11%). Metrics HSR/min, HID/pm, SPR/min, ACC/min, and DEC/min, had high CVs across both groups indicating variable performance in locomotor outputs.

There were no significant between group differences across positions for TD/min (m) except for CMs. ST CM on average covered 11.58 TD/min more compared to YT CM (P=0.04, ES=2.25). CV data for TD/min was relatively low for all position groups (<15%). Although CV data was slightly higher in YT players, indicating greater variability across YT player positional TD/min.

HSR/min data showed high CV values within position groups in both squads. All position groups apart from YT CA had CV values >15%. Therefore, there were no significant differences (p<0.05) between ST and YT position groups for HSR/min. Still, there were moderately positive effect sizes in favor of ST CD and CM, and negative effect sizes in favor of YT CA.

HID/pm results showed lower CV values than HSR/min. The mean difference of HID/pm between ST and YT position groups was negative across all comparisons with large effect sizes, although only WD and WM showed significant results. ST WD covered a mean difference of 5.8 less HID/pm compared to YT WDs (p= 0.002, ES= -1.95). ST WM covered a mean difference of 4.93 less HID/pm compared to YT WM (p = 0.02, ES = -1.66). HID/pm CV data was higher for YT players between position groups: CA, WM, and WD (6-13% difference), and marginally lower for YT CD and CM (2%,1%).

Between Group Positional HID per Minute (m)								
Group	N	Position	ST-YT Difference	Mean	SD	CV	p-value	ES
ST	10	CD	-3.86	10.21	1.67	16%	0.09	-1.23
YT	8			14.07	1.98	14%		
ST	10	CM	-3.82	12.77	2.39	19%	0.19	-1.28
YT	7			16.59	3	18%		
ST	10	CA	-4.25	15.36	1.82	12%	0.33	-1.43
YT	7			19.61	3.54	18%		
ST	9	WD	-5.8	13.99	1.85	13%	0.002	-1.95*
YT	7			19.79	3.93	20%		
ST	10	WM	-4.93	16.86	2.15	13%	0.02	-1.66*
YT	7			21.8	5.73	26%		

*Table 3: Between group ANOVA results examining high-intensity distance (HID) (m) per minute, with position and group as fixed factors. ST= Senior Team, YT= Youth Team, CD= Central Defender, CM= Central Midfielder, CA=Central Attacker, WD= Wide Defender, WM= Wide Midfielder, N= Number of participants, SD= Standard Deviation, CV= Coefficient of Variation (between-participant variability), ES= Cohen's D Effect Size, *significant differences between groups, p<.05.*

SPR/min results are reported with caution. Because of technical difficulties, 8 YT sprint data were not collected and the sample was reduced to 33 observations. Therefore, CV values across positions were much higher for YT players (25%-128%). There were no significant differences across positions although differences between CA approached significance, with a large effect size favoring YT CA (p=0.14; ES=-2.2). Although variability was lower in ST players (31%-80%), CV values were still very high indicating great amounts of SPR/min variability in ST matches across positions in this sample.

ACC/min between squads and position groups showed that ST players performed more ACC/min on average, across all positions. However, only CM and WM showed significant differences (p =<.001, 0.05). Both CM and WM position groups had large effect sizes (ES= 2.14, 1.49). CD and CA groups had large effect sizes between squads, but had high CVs, diminishing the significance of the results. CVs between squad positional comparisons were small (<5%) except for CAs, and WMs. YT WMs and CAs showed 21% and 14% higher CVs compared to their ST counterparts.

DEC/min had only small to moderate differences between squad and position groups except for CM. ST CM performed on average 0.29 more ACC/min compared to YT CMs (p =0.02, ES =1.7). CV values were similar between squad positional comparisons (<7%) except for WD, where ST WD CV was 15% higher than YT WD (28%-13%).

4.3 Countermovement Jump Data

There were a total of 126 CMJ trials. 50 ST CMJ trials were made up of 26 trials PRE and 24 on MD+2. 76 CMJ trials were performed by the YTs, 44 PRE, and 32 MD+2. CMJ data between groups were analysed as a percent change from PRE to MD+2. There were 46 players who completed 60+ minutes and performed valid CMJ trials PRE and MD+2. 22 were ST players, and 24 were YT players.

CMJ Descriptives			
Group	N	PRE	MD+2
Total	126	70	56
ST	50	26	24
YT	76	44	32

Table 4: Countermovement Jump (CMJ) descriptives. ST= Senior Team, YT= Youth Team, N= number of participants, PRE= Pre-match, MD+2= 48 hours post- match.

CMJ and GPS Descriptives: PRE and MD+2 % Change		
Group	N	Missing
Total	46	10
ST	22	2
YT	24	8

Table 5: Combined countermovement jump (CMJ) and locomotor (GPS) descriptives of players who played 60 minutes or more and completed trials at both timepoints. ST= Senior Team, YT= Youth Team, N=number of participants, PRE= Pre-match, MD+2= 48 hours post-match.

PRE Descriptive CMJ Data							
Metric	ST-YT Difference	Group	Mean	SD	CV	p-value	ES
Jump Height (cm)	-1.08	ST	33.29	3.36	10%	0.77	-0.24
		YT	34.37	3.92	11%		
Flight Time (ms)	12.62	ST	542.81	24.72	5%	0.54	0.33
		YT	530.19	32.67	6%		
Contraction Time (ms)	-177.61	ST	763.23	104.58	14%	<.001	-1.27*
		YT	940.84	141.33	15%		

FT:CT (au)	0.15	ST	0.73	0.12	16%	<.001	1.29*
		YT	0.58	0.1	17%		

*Table 6: Descriptive countermovement jump (CMJ) data at pre-match (PRE) between groups. ST= Senior Team, YT= Youth Team, SD= Standard Deviation, CV= Coefficient of Variation, ES= Cohen's D effect size, FT:CT= Flight time:contraction time ratio in arbitrary units (au), *significant differences between groups, p<.05.*

4.3.1 Countermovement Jump Data at PRE

Mean jump height (imp-mom) (JH) for ST at PRE was 33.29±3.36cm. For YTs at PRE, mean JH was 34.37±3.92. There were no significant differences in JH between groups at PRE. Mean contraction time (ms) at PRE was 763.23±141.33ms for ST and 940.84±151.67ms for the YTs. A mean difference of 177.61ms was deemed significant (p<.001). At PRE, mean flight time was 542.81±36.36ms for ST and 530.16±32.69ms for YTs. The mean difference of 12.65ms was not deemed significant (p=0.64). FT:CT, was 0.73±0.17au for ST players and 0.58±0.1au for YT players at PRE. Between groups, FT:CT was significantly greater in ST players (diff=0.15, p<.001).

4.3.2 Countermovement Jump Data at MD+2

At MD+2, mean JH for ST players was 26.98±6.4cm, and 32.63±4.35cm for YTs. There was a significant difference between squads MD+2 JH values (diff=5.65, p<0.001). Contraction time at MD+2 was 646.96±151.67ms for ST players and 984.88±152.13ms for YT players. The mean between group difference of 337.92ms was significant (p<.001). At MD+2, mean flight time for ST players was 472.96±57.72ms and 515.40±36.35ms for YT players. ST showed more variability in flight time compared to YTs (CV= 12% vs 7%). Mean FT:CT at MD+2 was 0.77±0.17au for ST and 0.54±0.1au for YTs. A mean difference of 0.15au was significantly greater for ST compared to YT players. Variability was marginally higher for ST compared to YTs (CV= 21% vs 18%).

4.3.3 Countermovement Jump Data Difference from PRE to MD+2

From MD+2 to PRE, there were significant differences for ST mean JH (diff= -6.35cm, p<.001) but not YT mean JH (-1.73cm, p=0.44). The mean difference in contraction time from MD+2 to PRE was significantly smaller for ST (diff= -116.27ms, p=.04) but not YTs (diff= 44.03, p=0.68). From MD+2 to PRE, a mean difference of -69.85ms in flight time was significantly lower for ST players (p<.001) but a mean difference of -14.75ms was not significantly lower for YTs (p=0.43). From MD+2 to PRE there were no significant differences in mean FT:CT for either group.

MD+2 Difference from PRE Descriptive CMJ Data

Group	Metric	Timepoint	Mean	Difference	P value	ES
ST	Jump Height (cm)	PRE	33.29	-6.31	<.001	-1.4*
		MD+2	26.98			
	Flight Time (ms)	PRE	542.81	-69.85	<.001	-1.83*
		MD+2	472.96			
	Contraction Time (ms)	PRE	763.23	-116.27	0.02	-0.83*
		MD+2	646.96			
	FT:CT (au)	PRE	0.73	0.04	0.59	0.36
		MD+2	0.77			
YT	Jump Height (cm)	PRE	34.37	-1.08	0.35	-0.39
		MD+2	33.29			
	Flight Time (ms)	PRE	530.19	-14.78	0.35	-0.72
		MD+2	515.41			
		PRE	940.84	44.04	0.53	0.32

Contraction Time (ms)	MD+2	984.88			
FT:CT (au)	PRE	0.58	-0.04	0.47	-0.34
	MD+2	0.54			

*Table 7: Independent sample t-test and between group ANOVA explained difference in mean countermovement jump (CMJ) metrics at 48 hours post-match (MD+2), from pre-match (PRE). ST= Senior Team, YT= Youth Team, FT:CT= Flight time:contraction time ratio in arbitrary units (au), *significant differences between groups, p<.05.*

4.3.4 Countermovement Jump Percent Change from PRE to MD+2

22 ST players completed 60 minutes or more of match play and completed CMJ testing PRE and MD+2. 24 YTs players met these same criteria. Linear mixed model analysis was conducted to examine whether the selected players' locomotor outputs affected the CMJ performance from PRE to MD+2. The dependent variables were either jump height (cm) or contraction time (ms) at MD+2 while the covariates were locomotor metrics and PRE jump height (cm) or contraction time (ms). Participants were selected as random effects. The main findings reported that count of DEC and ACC had a negative correlation to MD+2 CMJ jump performance in ST players, but not YT players. For every one unit increase in DEC, ST could expect -0.15 decrease in JH (p>.001). For every one unit increase in ACC, ST players could expect -0.11 decrease in JH (p=.01). Count of ACC and DEC also approached significant effects (p=.08, 0.11) for negative effects on ST contraction time, as did SPR (m) for ST JH (p=0.12). SPR (m) had a positive effect on YT contraction time, while results were not significant (p=0.21), it had the lowest p-value of any analysis for YT MD+2 CMJ data.

Linear Mixed Model Analysis: Locomotor Metric Effect on Fatigue, for both Groups

Moderator	Output	Group	Estimate	95% CI	P
DEC (au)	Jump Height (cm)	ST	-0.15*	-0.24, 0.05	>.001
		YT	-0.03	-0.11, 0.05	0.4

	Contraction Time (ms)	ST	-2.7**	-5.69, 0.33	0.08
		YT	-0.04	-2.61, 2.52	0.97
ACC (au)	Jump Height (cm)	ST	-0.11*	-0.19,-0.03	0.01
		YT	-0.03	-0.12,0.07	0.61
	Contraction Time (ms)	ST	-2.05**	-4.6, 0.5	0.11
		YT	-0.31	-3.3, 2.7	0.84
SPR (m)	Jump Height (cm)	ST	-0.02**	-.05 0,.01	0.12
		YT	-0.01	-.02, 0.01	0.48
	Contraction Time (ms)	ST	-0.49	-1.4, 0.42	0.28
		YT	0.25	-0.15, 0.66	0.21

*Table 8: Locomotor Metrics Effect on Fatigue Metrics. Linear mixed model analysis where the dependent variable is a CMJ metric at 48 hours post-match (MD+2), where covariates are locomotor metrics and CMJ metric at pre match (PRE). ACC= Number of Accelerations, DEC= Number of Decelerations, SPR = Sprint distance in metres. ST= Senior Team, YT= Youth Team, *significant effect, p<.05, **approaching significant effect, p=.08-0.12*

5 Discussion

5.1 Locomotor Data Between Groups

5.1.1 Minutes Played

The main findings of this paper can be split into three categories. Locomotor differences between groups, CMJ differences between groups, and how did locomotor metrics moderate CMJ data. Firstly, it should be acknowledged that locomotor data was measured relative to minutes played. This contrasts with previous literature that only used players who completed full matches (90+ minutes) (Bradley, Lagos-Penas, and Rey, 2014; Ju *et al*., 2025; Morgans *et al*., 2022). Although differences in mean minutes played between groups is only approaching significance (p=0.12), a mean difference of 4.28 less minutes played for YT and a 6% smaller CV compared to the ST, indicates that ST player minutes played were more variable. This also points to more of the selected ST players as ‘replaced players’ who independent of position, covered significantly more TD/min and HSR/min than players who played the entire match (Bradley, Lagos-Penas, and Rey, 2014). A ST environment often has more pressure to win matches and use more substitutions than in a youth environment where the focus is player development.

5.1.2 Total Distance

These factors may help to explain significant differences favoring ST players in TD/min (mean diff=-6.13m). Positional differences between groups for TD/min were also examined. Across positions in this study, only ST CM covered significantly more TD/min than their YT counterparts matched for position (diff=11.58, ES=2.25). ST CM (n=10), had the highest mean TD/min of any other group in the study. This is in line with a systematic scoping review of 177 studies that found adult CM had the highest mean distance covered (Sarmento *et al.*, 2024). In contrast to this study's findings, Morgans *et al*. (2022) found there to be no significant differences between CM across ST and U18 groups.

5.1.3 High Speed Running

As for HSR/min, there were no significant differences in ST HSR/min and YT HSR/min. However, high variability (CV>16% for all but YT CA, N=4) of HSR/min data should be recognized as a limiting factor in detecting significant between group differences. This variability may be explained by the sampling size and number of matches observed, with the knowledge that HSR is variable between matches in a single club setting (Carling *et al.,* 2016). Previous literature has also identified higher CV values for HSR compared to total distance values (Morgans *et al.*, 2022; Reynolds *et al.*, 2021). In this study, CA and WM covered the most HSR/min and in both cases the YT group covered more HSR/min than the ST, (CA ES= 0.75; WM ES=0.28) although not statistically significant. This study is mostly in agreement with previous findings that attacking players (CA, WM) HSR output is less variable than other positions (Carling *et al.*, 2016; Gualtieri *et al.,* 2023). However, the YT WM (n=9) group did not follow this trend (CV=41%), likely due to a wider range of player random effects (-2.03-3.08) compared to the ST (N= 10; -0.64-0.39).

5.1.4 High Intensity Distance

HID appears to be a novel metric, although usage of the same phrase commonly describes matching criteria to HSR (>5.5 m/s). In this case, HID combines HSR m (>5.5m/s), and distance covered accelerating or decelerating (>±3 m/s^2). The YT group in this study covered moderately more HID/pm than the ST (diff=4.2m; ES=1.07); the Brown Forsythe Variance Check was significant, highlighting unequal variances. Considering HSR/min differences were not significantly different between groups, the between group differences in HID/pm are explained by differences in either or both of, acceleration (ACC (m)) and deceleration distance (DEC (m)) covered. Catapult provided each of ACC (m) and DEC (m), but the STATsport GPS units only provided HID (m) but not said variables that contribute to it. Thus, it can only be inferred that YT performed more ACC (m)and DEC (m) but it is not known which is more influential and to what magnitude.

The difference between groups in HID/pm extended across positional groups as well. All position groups had moderate to large effect sizes favoring the YT, but only WD (ES=1.95; P=.002) and WM (ES=1.66; P=.02) differences were deemed statistically significant. Previous reviews have highlighted that WM and WD perform the highest number of ACC and DEC in match-play (Harper, Carling, and Kiely 2019). However, there hasn't been research investigating ACC (m) and DEC (m) nor the difference between ACC and DEC between YT and ST level.

5.1.5 Accelerations and Decelerations

Moreover, ACC/min and DEC/min were compared between YOUTH and ST level in this study. Both ACC/min and DEC/min were significantly different between groups (p<.001, p=.008). ST mean ACC/min were greater to a large effect (diff= 0.25; ES: 1.31) and the ST mean DEC/min only to a small effect (diff=0.08; ES=0.37). Given that both ACC/min and DEC/min, rely on a player's ability to change velocity rapidly, it is logical that ST players demonstrated a greater frequency of powerful actions. Differences in playing level are often characterised by differences in mean CMJ JH or relative force production (McMahon *et al*., 2017). However, metrics related to the velocity of the CMJ such as reactive strength index modified (RSImod), flight time: contraction time (FT:CT), and peak power output, have been identified as more sensitive indicators of playing level (Mitchell, Holding & Greig, 2022; McMahon *et al*., 2017; Stahl *et a*l., 2020). In support, Morris, Weber, and Netto (2022) reported that longer CMJ contraction times (with arm swing) among elite Australian Rules Football (ARF) players were associated with slower 20 m sprint times.

This aligned with our CMJ descriptive data, which showed that ST players had a higher flight time to contraction time ratio compared to YT, despite no significant differences in jump height. Taken together, these findings suggest a potential relationship between a player's ability to change velocity during locomotor tasks and during vertical jump actions. However, further robust research is needed to better understand and confirm this relationship.

5.1.6 Max Sprint Speed

On a similar note, there were differences noted in mean MSS (m/s) between groups (8.65 vs. 8.54). They were not statistically significant, but a difference of 0.1 m/s, can represent a 0.2m advantage to evade an opponent following 2s at MSS (Clancy *et al*., 2022). As such, the mean difference between groups was 0.11 m/s in favor of the ST. Likewise, at the 25th percentile, ST players were greatly faster than youth players (8.33 vs. 8.01 m/s), and 75th percentile ST players approached the practically significant threshold (9.06 vs. 8.99) for MSS. Just as higher ACC/min were displayed by the ST was hypothesized to be supported by superior power qualities, the same can be said for MSS outputs. The relative horizontal peak running power displayed by the elite ARF correlated with faster sprint splits at 5, 10, 20, 30, and 40m (Morris, Weber, and Netto, 2022).

Previous research agrees that professional players display greater MSS capabilities in comparison to youth players (Clancy *et al*., 2022). Notably, in this study the variability across both youth and ST players MSS was much higher than measured in previous literature (Clancy *et al*., 2022). One key difference between papers is that in this study the playing level in focus is the 5th tier of English football, whereas the mentioned study examines the 1st tier of Scottish football. In general, professional players have greater physical qualities underpinning their performance than non-professional or PDP players (Clancy *et al.,* 2022; Stahl *et al*., 2020). It also might be noted that a higher standard of professional sport requires greater homogeneity of physical qualities than lower standard of professional sport to accommodate tactical flexibility (Stahl *et al*., 2020; Ju *et al*., 2025).

5.1.7 Tactical Considerations

Underpinning total locomotor output, were the tactical demands of the match (Bradley & Ade, 2018; Eusebio, Prieto-Gonzalez and Marcelino, 2024; Jerome *et al.*, 2024; Ju *et al.*, 2025; Plakias *et al.,* 2023). Although the tactical demands were not measured or observed formally, certain observations may still be relevant to the analysis of this research. Prior literature has examined the unique locomotor demands of tactical phases of play in elite men's football (Jerome *et al*., 2024). They explained that greater HSR and sprint distance rates per minute were seen in attacking and defending transitional phases and fast attack/fast defence phases of play (Jerome *et al.*, 2024). Similarly, the proportion of time accelerating and decelerating in said phases of play were also significantly greater than all phases of play but chance creation/low-block (Jerome *et al.,* 2024).

Research of 138 matches from the U17, U20, and Men's world cup from 2023 and 2022 detailed that PDP football, was characterized by significantly more defensive actions like tackles, blocks, and second ball recoveries compared to elite male footballers (Ju *et al.*, 2025). Meanwhile, at the 2022 men's world cup, there was significantly greater pass completion percentage, highlighting less turnover of possession. It might be speculated from this research that PDP football involves a greater proportion of time during attacking transition/defending transition phases of play. This would require a greater proportion of time accelerating and decelerating (Jerome *et al.*, 2024).

Potentially, this was one factor that explained the significant differences in HID/pm that favored the YT in our research. Of course, HID/pm accounts for distance covered accelerating and decelerating. Qualitatively speaking, the YT at this club had a much more inconsistent style of play compared to the ST. The YT matches have had much greater proportions of tactical phases being transitional attack/transitional defence because of ineffective ball retention, especially compared to the ST. Thus, greater proportion of a match being played in transitional phases should lead to greater amounts of time spent accelerating, decelerating, and HSR demands.

While the World cup research did not break down time spent accelerating or decelerating, it did compare HSR outputs between playing level and inter match variability. They found no significant differences between U20 and men's HSR mean output, but significantly less HSR mean output in U17 world cup matches (Ju *et al.,* 2025). They also found the men had greater mean sprint outputs. This contrasts our analysis that the YT in this sample had greater SPR/min. It must be mentioned that statistical power for this SPR/min data was reduced due to technical difficulties. Nonetheless, U17, U20 sprint distance and HSR inter-match variation were also significantly greater than in men's world cup matches (Ju *et al.*, 2025). This aligns with this study, and it might add to the theory that in PDP football, less technical and tactical consistency described by lower pass completion percentage and greater defensive interactions, is associated with greater proportion of ball-in-play time in transitional phases (Jerome *et al.*, 2024; Ju *et al.*, 2025).

Implications of these findings add to previous literature that match play locomotor outputs do not solely distinguish youth from senior elite football. Tactical and technical consistency drives the proportion of match-play in certain phases of play. Each phase of play has unique locomotor demands and should be researched in PDP environments to examine whether this is indeed the cause for increased HID/pm and SPR/min in YT athletes.

5.2 Countermovement Jump Data Between Groups

5.2.1 PRE Data

There were significant findings in the CMJ data between groups. As hypothesized, the CMJ strategy employed by the ST players was more time efficient, described by greater FT:CT values. However, most other findings went against the hypothesis. This included non-significant differences between ST and YT mean baseline CMJ JH, and that neuromuscular ability at MD+2 was reduced to a greater effect in ST players than YT players. A lack of significant difference in CMJ JH between groups contrasted with previous research that described CMJ JH as a differentiating metric between playing levels (McMahon *et al*., 2017; Mitchell, Holding, and Greig, 2022; Stahl *et al*., 2020).

However, ST players in this research did employ significantly shorter contraction time ($p<.001$, ES=-1.27) to achieve very similar flight times ($p=0.54$, ES=0.33) to the YT players. This in turn produced significantly greater mean FT:CT values for ST players. It is noted that FT:CT was selected over RSImod in this analysis because it was collected more consistently without technical issues. Still, FT:CT has a near perfect relationship to RSImod and therefore analysis comparing FT:CT can be compared to studies that used RSImod (McMahon, Lake, and Comfort, 2018). Therefore, our findings do align with that of McMahon *et al*. (2017), who found that greater RSImod is displayed by senior players compared to PDP aged players (mean age 19.3yrs) in elite rugby league. In that paper, senior players displayed greater JH but similar contraction time to the youth group.

McMahon and colleagues also reported that gross measures of force and power were significantly greater for senior elite rugby players compared to the PDP group, while there were no significant differences between the relative outputs. This meant that the senior players had more body mass compared to the youth group which is beneficial in rugby, a collision sport where momentum is vital. In this research the mean difference in body mass was also significantly higher in senior players but their gross peak braking and propulsive force characteristics were not significantly greater than the YT players. Likewise, senior mean relative peak braking and propulsive forces were not significantly greater than YT players at baseline. Thus, velocity of movement expressed by FT:CT appears to be a greater discriminant of playing level in this case compared to the amount of propulsive and braking forces in a CMJ.

Comparing this baseline in-season CMJ data to recently collected in season-data from a youth environment (mean age: 17.9 years) in England tells a different story. In a test-retest reliability study, 43 youth players from category 2 and 4 academies, performed CMJs across two testing days 7 days apart (Badby *et al.*, 2025). Mean CMJ JH was similar to our data at 34cm, but almost all other shared metrics favored the participants in the study conducted by Badby *et al.* (2025). The hypothesized discriminant of playing level, FT:CT, is greater in the PDP players in that study, compared to the senior players in this study (0.84 vs 0.73). Of course, this is underpinned by shorter contraction time which when paired with similar or better flight time is an advantageous ability.

5.2.2 Cueing

One key difference in methodologies between studies was that in the work by Badby *et al.* (2025), they cued their participants to "jump as fast and as high as possible". External verbal that cued participants to jump 'fast' or 'fast and high' during CMJ performance has shown to significantly affect RSImod by reducing contraction time in players (Xu *et al.*, 2024). In this study, participants were cued to "jump as high as possible, and land on the force plates". This external verbal cue focused on repeatability to streamline data collection process surrounding tight matchday schedules but did not emphasize velocity of CMJ movement. In a within participant reliability study of 25 male recreational, resistance trained athletes, researchers found no significant differences in CMJ JH when participants were cued with a combined cue relating to height and velocity, compared to one just considering height (Xu *et al*., 2024). Therefore, if this study incorporated a combined external cue strategy, it could expect similar CMJ JH with an improved FT:CT.

5.2.3 Reliability

The between-participant reliability of this research's CMJ data differs from recent literature (Badby *et al.*, 2025; Gathercole *et al.*, 2015). Previous literature has found contraction time to have 4-8% CV while this paper found contraction time to have 14%, and 15% CV respectively for ST and YT players (Badby *et al.,* 2025; Gathercole *et al*., 2015). This pattern is repeated with all CMJ metrics in this research having greater CV values than all selected metrics in the mentioned papers (Badby *et al.*, 2025; Gathercole *et al.*, 2015). The longitudinal nature of this research that could include improvements or decrements in CMJ performance over time might explain greater variability in flight time. Previous literature in academy rugby players (mean age: 16.9 years, mean CMJ JH: 42cm), showed significant decreases in CMJ JH over a 7 week in season period with 1 match per week (Oliver, Lloyd, and Whitney, 2015). However, similar comparisons of CMJ performance across the research period were not included in this study. Nonetheless, metric reliability is similar between ST and YT players, highlighting that heterogeneity of CMJ performance is evident in both groups. This likely reflects that neuromuscular status did not depreciate over time as much as research by Oliver, Lloyd, and Whitney (2015).

5.3 Fatigue Data

5.3.1 Jump Outcome

It was hypothesized that ST players would display greater CMJ performance than YT players at PRE and MD+2, depicting greater general physical capacity and resilience to neuromuscular fatigue. The MD+2 data returned mixed results, but the most relevant performance outcome, JH, was significantly reduced in ST players ($p<.001$; ES=-1.4) but not YT players ($p=0.35$; ES=-0.39). JH MD+2 results from the YT players were in line with previous research that showed JH normalized 72 hours after an aerobic conditioning protocol and 60m of sprinting (Gathercole *et al.*, 2015). However, in slight contrast to U18 category 1 academy footballers 48 hours after match play (Gathercole *et al.*, 2015; Springham *et al.,* 2024). Springham *et al.* (2024) found small significant reductions in JH using the flight time method at MD+2, but found no significant reductions with the JH (imp-mom) method. On the other hand, Gathercole and colleagues used JH (imp-mom) when they detected normalized JH at 72 hours post fatiguing protocol. Comparison between JH means that used different equations are performed with caution as inter-method measurements utilizing the same technology can still vary from 0.6-4.1cm (Eythorsdottir *et al.,* 2024).

Importantly, variability for JH was higher at MD+2, indicating that between-participant differences are greater 48 hours post-match than pre-match. This implies that individual monitoring of players may be more pertinent than group monitoring following match play. In the second tier of English football, chronic and acute loads effect on CMJ performance were examined over an entire season (Harris *et al.,* 2025). Findings were that when acute HSR (m) and sprint distance were high and chronic loads were low, CMJ JH decreased (Harris *et al.,* 2025). This may point to future practice that considers the acute and chronic loads of the study period when assessing CMJ performance at MD+2. Also in that study, they directed practitioners to reduce subsequent acute loading demands if CMJ performance were significantly reduced. These findings alongside the results in this study, inform practitioners to monitor inter-individual differences in CMJ performance and also the recent loading demands of players when deciding on acute training interventions.

5.3.2 Time Related Metric Analysis

Further analysis showed that YT players CMJ performance showed no significant differences at MD+2 from PRE, albeit the effect sizes showed mostly trivial to small differences unfavorable to CMJ performance. Flight time had a moderately negative effect size, but results were insignificant ($p>0.35$). Insignificant findings between MD+2 and PRE for YT players regarding contraction time differed from the work by Gathercole and colleagues. In Gathercole *et al.* (2015), the participants all performed the same aerobic conditioning protocol, 8.61±1.25km and 60m of sprint distance. They found contraction time increased significantly ($p<.05$; ES= 0.27) at the 72 hour mark, while flight time remained the same.

Interestingly, effect sizes were slightly higher in this research (ES=0.32), but a more varied response ($p=0.53$) might be explained by the varied fatiguing protocol in this research. Distinctly, the work by Gathercole and colleagues measured CMJ performance 72 hours after a fatiguing protocol whereas this paper measured CMJ performance 48 hours after a fatiguing protocol. However, our research indicated that contraction time increases were not significant so further monitoring 72 hours would not be necessary for performance monitoring. Overall, insignificant findings across flight time and contraction time metrics for YT players, led to insignificant changes in the FT:CT strategy.

Stark contrasts existed when time related metric changes were measured in ST players. ST players did have significant reductions in flight time ($p<.001$; ES= -1.83) and contraction time ($p<.001$; ES=-0.83), although the FT:CT did not significantly change at MD+2. These findings are unique in that contraction time has reduced, however significant reductions in flight time are indicators of inferior neuromuscular performance and align with previous research (Springham *et al., 2024*). Shorter contraction times produced from the ST players may be performed as protective measures to reduce displacement and overall work as a result (McMahon *et al.,* 2018). This contrasts findings from Avela *et al.* (1999) that reflex sensitivity is reduced at least 48 hours post fatiguing exercise. Reduced reflex sensitivity should result in longer contraction times as found by Gathercole *et al.* (2015), however the ST athletes in this research exhibited opposing results. Further investigation into the kinematics of the CMJs would help confirm that the shorter contraction times were paired with smaller countermovement depths in effort to reduce the total work for ST players (McMahon *et al.,* 2018). Similar to the section above, between participant variability was higher for contraction time (ms) and FT:CT at MD+2 and therefore inter-individual responses need monitoring. Harris *et al. (*2025) found that when acute loads were high in HSR (m) and sprint distance while chronic loads of the same metrics were low, FT:CT reduced and braking phase duration increased. Thus, a holistic approach considers acute and chronic workloads when considering fatigue at MD+2 between players.

5.4 Locomotor Data Effect on Countermovement Jump Data, Between Groups

Moderating effects of locomotor metrics were also considered as part of the investigation between ST and YT players. This sought to investigate whether specific locomotor metrics affected ST and or YT players CMJ performance on MD+2. Once again, ST players CMJ performance were affected more negatively by locomotor metrics at MD+2 than the YT players. Only total values of high intensity actions, count of accelerations, decelerations, and total sprint distance (m) were selected as moderator variables for fatigue outcomes JH and contraction time. This simplified approach selected the actions with the high eccentric demands and high changes in velocity that expose athletes to greater mechanical load (Harper *et al.*, 2024).

First, the selected locomotor metrics did not display significant moderating effects on JH or contraction time for YT players at MD+2 ($p>.21$). In contrast, the count of both accelerations and decelerations had significant moderating effects on ST players JH. The count of decelerations had a significant negative moderating effect on JH and contraction time. Decelerations are mechanically demanding tasks that require high amounts of eccentric work and induce more muscle damage (Harper *et al., 2024;* Hody *et al.,* 2019). It is logical then that higher amounts of decelerations correlate to steeper decline in CMJ JH at MD+2 for ST players, following the time course of muscle recovery (Komi, 2000). Eccentric contractions also have greater fatigue effects on unaccustomed participants (Hody *et al.,* 2019). This might imply that ST players were not adequately prepared for eccentric actions in match play considering their greater reductions in CMJ performance. Therefore, considerations of previous workload again become of interest when seeking to explain neuromuscular fatigue at MD+2 (Bowen *et al.,* 2020; Harris *et al.,* 2025).

Additionally, the count of ACC and DEC approached a significant effect (p=0.11, 0.08) on MD+2 contraction time. This is likely a protective strategy used by ST players at MD+2 to reduce displacement and total work performed (McMahon *et al.,* 2018). These findings also relate to the locomotor findings that showed ST players performed significantly greater ACC/min and DEC/min. Overall, it appears ST players have greater physical quality enabling higher rates of ACC/min and DEC/min, however they are not fully recovered by MD+2, likely associated with the higher rates of ACC/min and DEC/min performed.

Lastly, it is unexpected that sprint distance had no significant moderating effect (p>.21) on either ST or YT contraction time although a negative effect on ST JH approached a significance (p=0.12). Sprinting requires maximal eccentric force production and has high central nervous demands (Hasegawa *et al.,* 2024). Harris *et al.* (2025) found that acute spikes in sprint distance reduced CMJ JH and increased braking phase duration in elite footballers 60 hours post training. On the other hand, elite trained sprinters showed significant reductions in CMJ JH three- and 10-minutes post 400m race and increased braking phase duration at three minutes post 400m race when compared to baseline scores (Hasegawa *et al.,* 2024). However, JH and braking phase duration at 24 hours normalized, and no further analysis were conducted past the 24 hour post mark. This implies that while sprinting is a mechanically demanding action, it’s fatigue effect displayed by CMJ performance may be relative to the participant, and previous training history (Harris *et al.,* 2025; Hasegawa *et al.,* 2024).

6 Conclusion

One limitation of this study is the number of participants and thus its inability to extrapolate findings across other senior and youth programs where playing styles and physical performance practices differ. While GPS outputs were normalized to account for inter-manufacturer differences, ideal methodology would have both groups using GPS units from the same manufacturer. Future studies can build on this paper and existing literature, by including tactical analysis of senior and youth match play when comparing locomotor metrics. This will give a comprehensive review of potential mechanisms for differences in locomotor metrics between youth and senior match play, rather than solely descriptions of locomotor output.

The central aim of this study was to describe the state of contemporary football in the professional senior and youth environments. By examining the locomotor demands and related neuromuscular fatigue metrics from match play, the physical nature of modern football was defined and differentiated between youth and senior players. The main results were that senior football required players to have greater physical quality to perform high intensity (3± m/s^2) accelerations and decelerations more often. As a result, senior footballers demonstrated significantly increased neuromuscular fatigue 48 hours post-match compared to youth players. On the other hand, youth footballers covered more distance at high speeds, accelerating and decelerating. Although youth players demonstrated inferior physical quality described by lower MSS and FT:CT, they displayed significantly less neuromuscular fatigue 48 hours post-match compared to senior players. Nonetheless, for both groups, there was greater between-participant variability in CMJ metric values compared to previous reliability research conducted in controlled environments. This suggests that inter-individual differences in CMJ performance at MD+2 can be used to identify players who have not recovered fully from match-play, and thus inform acute training prescription. In addition, when transitioning youth players to senior football, practitioners must examine physical quality (MSS and FT:CT) to ensure they can perform comparable ACC/min and DEC/min to senior players. Likewise, youth players must be technically and tactically efficient to maintain the high passing competition rates and greater proportion of ball-in-play time in build-up phases that senior football requires.

By considering the results of this study, football practitioners should direct their attention to assessing and improving youth players physical qualities (MSS and FT:CT), before thrusting them into senior football. When youth players are at least around the mean value for both MSS and FT:CT, their tactical and technical efficiencies can then be evaluated fairly from the subjective expert opinion of multiple staff members. When the player meets all necessary criteria, their acute and chronic workload should influence the timing of integration into senior football. In all, the senior footballers of the future are youth footballers today and need the best care to transition seamlessly to elite senior football. Football clubs are incentivized and required to develop young players and sport science literature aims to inform practical applications that assist football practitioners to adequately develop players for senior football. By bridging the gap between neuromuscular fatigue data examinations across youth and senior football and locomotor metrics effects on neuromuscular fatigue, football practitioners can utilize this thesis to inform their version of best practice in developing young players into senior players.

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