Investigating the Effectiveness of Small Sided Games, to Prepare Professional Football Players for the Locomotor Demands, During a Worst-Case Scenario on a Match Day.

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Abstract

Aim: To compare the worst-case scenario (WCS) movement demands of football match play compared to the WCS of small sided games (SSGs) undertaken in training sessions, to evaluate the effectiveness of SSGs to prepare players for the locomotor demands of a WCS on a match day. **Methods:** 27 Male professional football players (age (18.9 ± 2.5 years), height (180.4 ± 10.3cm), body mass (74.1 ± 9.2kg)) from an English Championship football club wore 10Hz GPS systems during 26 in season competitive league fixtures, and in all training sessions throughout the course of the 4-week data collection period, resulting in 7 SSGs being included in the study. Players were categorised by playing position (Centre back (CB), Full back (FB), Central midfielder (CM), Winger (W), & Striker (S)). During match play and SSGs, players locomotor outputs for total distance (TD), high speed running (HSR), sprint distance (SD) and intensity (M/Min), for a rolling epoch length of 300s. **Results:** Regardless of playing position, WCS movement demands for SSGs greatly underestimated the match play WCS movement demands of players for all measured locomotor outputs ($P \leq 0.001$); TD (match play: 630.5 ± 53m, SSG: 502.2 ± 48.8m), HSR (match play: 89.3 ± 27.5m, SSG: 14.7 ± 7.9m), SD (match play: 29.5 ± 12.2m, SSG:0.9 ± 2.2m), & intensity (match play: 126.6 ± 10.5m/min, SSG: 100.4 ± 9.8m/min). Inter-positionally, CB (23.0%) and FB (16.3%) displayed the greatest underestimation in all physical parameters obtained in SSG WCS, compared to match play WCS, with all positions having significantly greater match play WCS movement demands compared to the baseline of CB ($P \leq 0.01$). When evaluating position specific match play WCS locomotor outputs, S showed highest demands for HSR (133.6 ± 13.5m), SD (57.6 ± 3.7m), & intensity (134.6 ± 3.4m/min) ($P \leq 0.001$), whilst W displayed the highest demand of TD (655.1 ± 24.3m ($P < 0.01$)). No significant positional differences were found during SSG WCS. Match result had no significant impact on match play WCS demands, and training session theme had no significant effect on SSG WCS movement demands. **Conclusion:** This study shows that WCS movement demands of SSGs in training drastically underestimate the WCS movement demands elicited by players during football match play, providing vital insight into the locomotor demands of players during WCS on a match day.

Declarations and Statements

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed.. (Candidate)

Date: 12/07/22

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

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List of Abbreviations

AMP - Average Metabolic Power

Acc - Acceleration

BiP – Ball in Play

CB – Centre Back

CM – Central Midfielder

CV – Coefficient of Variation

Dec – Deceleration

ES - Effect Size

FB – Full Back

FW - Forwards

GPS – Global Positioning System

HIR – High Intensity Running

HMLD - High metabolic Load Distance

HR – Heart Rate

HRmax – Maximum Heart Rate

HSR – High Speed Running

ICC – Interclass Correlation

KPI - Key Performance Indicator

LPS – Local Positioning System

LSG(s) – Large Sided Game(s)

MP – Match Play

MSG(s) – Medium Sized Game(s)

RD - Relative Distance

RPE – Rating of Perceived Exertion

S – Striker

SEE – Standard Error of Estimate

SD – Sprint Distance

SSG(s) – Small Sided Game(s)

TBL – Total Body Load

TD – Total Distance

TDC/Min - Total Distance per Minute

TEM – Typical Error of Measurement

TMA – Time Motion Analysis

TSSC – Team Sport Simulation Circuit

U23 – Under 23

VHSR – Very High Speed Running

Vmax – Maximum Velocity

W - Winger

WA – Wide Attacker

WCS – Worst Case Scenario

WD – Wide Defender

%Ex - Percentage of time Exercising

%HI - Percentage of time Performing High Intensity Work

%HRpeak – Percentage of Peak Heart Rate

%HRres – Percentage of Resting Heart Rate

%HSR – Percentage of High-Speed Running

1. Introduction

Football is commonly characterised as a high intensity intermittent team sport (Hoff, et al., 2002), with research indicating players will stand for 19.%% of a match, walk for 41%, run at a low intensity for 30%, high speed run (>5.5m.s^{-1}) for 8.7%, and finally sprint (>7m.s^{-1}) for 1.4% of a match (Mohr et al., 2003). Di Salvo et al. (2007) found that only 2.4% of running distance during match play occurs when a player has possession of the ball, and approximately 98% of distance covered occurs when they do not have possession of the ball (Reilly and Thomas, 1976). A study by Carling et al. (2012) states that during match play, players have a recovery period of >61s between high intensity bouts, with players on average only having 1 instance per game whereby they will only experience a 20s recovery period before their second bout of high speed running. During match play, performance relies on a combination of technical, tactical, physiological, psychological and locomotor determinants (Stølen et al. 2005). To allow coaches to monitor and specifically alter training sessions to promote different technical, tactical, physiological and locomotor responses, Global Positioning Systems (GPS) are universally used across professional football clubs to quantify the locomotor outputs in both training and match days. (Cunningham et al, 2020; Jennings et al, 2010; Hoppe et al, 2018; Hennessy & Jeffreys, 2018). GPS analysis has proved that elite professional football players will cover between 8-12.5km during match-play (Kubayi, 2019; & Andrzejewski et al, 2015). However, due to the unpredictable nature of football match-play, demands will alter on a game-by-game basis. One factor that will affect locomotor outputs is playing position. Abbott et al (2018) found that across the course of a season, central midfield (CM) players recorded significantly higher total distances than that of any other position (P<0.001), and that wide defenders (WD) and wide attackers (WA) produce similar outputs of both total distances (WD: 10,747 ± 420m, WA: 10,918 ± 353m), and also produce the highest maximum speeds during match-play, compared to all other positions (WD: 8.4 ± 0.4m.s^{-1}, WA: 8.6 ± 0.4m.s^{-1}).

One method of training that coaches' practice to prepare players for the physiological adaptations and locomotor demands of match-play, is the utilisation of small sided games (SSGs) (Owen, et al., 2011; Kelly & Drust., 2009; & Hill-Haas, et al., 2011). A number of factors linked to SSGs can be altered to promote different locomotor demands from players. For example, altering the playing area of the pitch can induce different locomotor outputs from players (Hill-Haas et al., 2011). The majority of studies on pitch dimension have found a positive correlation, whereby when pitch dimensions are increased, the physiological and locomotor demands increase also (Little & Williams, 2006; Hodgson et al, 2014). Owen, et al (2004), expanded on this fact further, stating that enlarging pitch size by 10m causes mean and peak heart rate to increase.

However, when further analysing the effects of increasing pitch dimensions, it is also important to note the impacts that larger playing areas will have on technical factors such as quantity of passes, shots and tackles. Previous research supports the claim that as pitch size increases, typically shot, pass and tackle frequency decrease as a result, due to the larger distance per player resulting in a lower playing intensity (Kelly & Drüst, 2009) (Tackles: small SSG, 45 ± 10, large SSG, 31±7, & Shots: small SSG, 85 ± 15, large SSG, 44 ± 9). In contrast to this, Owen et al (2004) found no increase in technical actions, when player number wasn't increased in conjunction with pitch dimensions. These differences in results could be down to Owen et al increasing pitch dimensions by only 5m for each SSG, whereas Kelly & Drust increased pitch dimensions by 10m. Owen et al also changed player number, from 1v1 in small SSGs, to 5v5 in large SSGs, whereas Kelly & Drust consistently used the same player numb er for each size SSG.

A second variable that can be manipulated is player number, and how change in team size can elicit different demands. Typically, adding players to small sided games causes a decrease in HR and peak HR ($P<0.05$) (Owen et al, 2004; Owen et al, 2011). Dellal et al (2011) found that as team size increased, % max HR decreased (2v2, 90.7%, 4v4, 85.5%). In rugby union, the same effects are transferred over to blood lactate levels, whereby 4v4 games (8.9 ± 3.2mmol.l^{-1}) induced a higher blood lactate level than that of 8v8 games (6.0 ± 3.7mmol.l^{-1}) (Kennett et al, 2012). The implementation of goalkeepers in SSGs also has an effect on certain positions locomotor demands, with forwards (FW) and CM covering higher TD in SSGs without goalkeepers, compared to all other positions ($P<0.05$), and that SSGs with goalkeepers actually promoted higher TD, HIR distances, and peak metabolic power across all positions (Riboli et al, 2020). These differences in locomotor outputs occur, due to the tactical behaviour of outfield players changing due to the inclusion of goalkeepers, whereby players no longer have to be as conscious when defending a goal or end zone (Halouani et al, 2014). However, in contrary to this statement, there is a lack of research investigating the effects of goal presence/absence on both physiological and technical responses of players in SSGs (Aguiar et al, 2012). Physiological responses to change in SSG duration, in football, has only been investigated by one major study, whereby Fanchini et al (2011) established an increase in %peak HR when SSG duration changed from 2-minutes to 4-minutes (82.4% vs 85.9%), but found no increase between 4-minutes and 6-minutes (85.9% vs 85.6%).

Research has shown that SSGs rarely elicit the same locomotor outputs as match play. Lacome et al, (2017), found that neither 4v4, 6v6, nor 8v8 formats could replicate the m.min intensity of match play, with TD and HSR values also being lower than those obtained during match play. Dellal et al, (2016) found contrasting findings, finding that total distance covered/min (TDC.Min), as well as total HSR and SD could be replicated in training, through the use of large-sided games (LSGs), finding that 9v9 and 7v7 formats could somewhat emulate distances reached during match play. Another contrasting study was conducted by Beenham et al, (2017) who claim that SSGs actually prompt greater external loads on players than match play does. One limiting factor of the research findings is that unlike most other research, this research was obtained using youth football players, rather than elite professionals.

Due to the unpredictable nature of football, whole match locomotor outputs do not display a true representation of the change in match demands. Therefore, the concept of the worst-case scenario (WCS) has been introduced and has been previously defined as the most intense phases of a game (Fereday et al, 2020). Due to the erratic timeline of football match-play, utilising fixed epochs (60s-900s) in order to gain WCS outputs are not reliable nor accurate at calculating the true WCS. Fereday et al (2020), found underestimations for TD and HSR for key epochs (TD= 60s – 10.1%, 300s – 7.5%, 600s - 6.7%. HSR= 60s – 11.7%, 300s – 22%, 600s – 24.8%). Further research into WCS in rugby union supports the findings of Fereday et al (2020), that fixed epochs underestimated locomotor outputs compared to rolling epochs (TD= 60s – 11.8%, 300s – 11.4%. HSR= 60s – 10.6, 300s – 21.3%). Referring back to the differences in positional demands, there is a similar trend for WCS, with CM (9-16m.min^{-1}) recording the highest relative distances during the WCS, compared to any other position ($P<0.05$) (Ferraday et al, 2020). The result of the game also significantly impacted the WCS demands, with total distance and high-speed running both being greater during wins compared to losses ($P<0.05$). However, despite this current research, and due to WCS being a new concept and focus for research, there is a severe lack of investigation into the WCS, especially using SSGs to prepare players for WCS demands.

The aim of this study was to compare and contrast the locomotor outputs of professional football player during match-play WCS and SSG data across the course of the season, to evaluate the effectiveness of SSGs to prepare players for the locomotor demands exerted upon them during the WCS in a game. The findings of this study will allow coaches to evaluate their current periodisation of training sessions, to implement a regimen that will prepare players for the WCS.

2. Review of Literature

2.1 Introduction to the locomotor and physiological demands of football

With football match play entailing bouts of high intensity exercise, as well as prolonged periods of low intensity exercise (Rampinini et al, 2007), football players frequently fluctuate from their aerobic energy pathway to their anaerobic energy system (Hoff et al, 2002). Due to the intermittent nature of match play, whereby players work at various intensities followed by different recovery periods, they undergo a complex interaction between both their aerobic pathway and anaerobic energy systems. As discussed previously, due to football being 90% low intensity exercise, the aerobic system is predominantly utilised during these periods of lower energy demands, and when players are moving at submaximal intensities (standing, walking, & low intensity running) (Gabrys et al., 2020). However, during more high intensity movements, anaerobic glycolysis is typically engaged during the higher intensity actions such as high-speed running, sprinting, jumping and changing direction (Nilsson & Cardinale., 2015). However, these high intensity actions highly tax the anaerobic energy system due to an increase in blood lactate, which will be recover to a basal level during lower intensity movement, whereby the aerobic pathway is activated again (Buchheit et al., 2011). In order to try and replicate the fluctuation in energy systems, small sided games can be utilised to imitate the work: rest ratios found in match play, as well as the multidirectional movement patterns players perform (Jeffreys., 2004). Therefore, players at the elite level need to have a solid aerobic capacity (Bangsbo et al, 2006., & Molinos, 2013) as well as anaerobic potential (Faude et al, 2012) in order to perform during elite competition. The importance of aerobic capacity is highlighted by (Andrzejewski et al, 2016), whereby it was identified that teams that collated higher total distance (TD) average obtained higher number of victories, especially in high-speed running and sprint distances.

However, the main key performance indicator (KPI) in football is shot success and creating goal scoring opportunities (Harrop & Nevill, 2014). Previous research (Di Salvo et al, 2009., & Bradley et al, 2014) has shown that these high intensity bouts (21-23.99km/h & >24km/h) are used especially in goal scoring opportunities. Furthermore, Modric, et al (2019) identified that an increase in forwards total sprint distance resulted in them being in a higher number of goal scoring positions (r=0.80). Due to the frequency of high intensity bouts during match play, peak creatine kinase levels (a commonly identifiable indicator of muscle damage due to exercise) can be evaluated by 41.7% (+24hr) and 30.0% (+48hr), following a match (Russell et al, 2015). Elite players will cover 10.97km ± 915.4m during professional match play (Djaoui et al, 2013). Player's capability to reach and maintain such total distances, VO2 max scores are typically between 56-

69ml.kg^{-1}.min^{-1} (Reilly, 1994). The anthropometrics of elite players are typically; body mass (76.4 ± 7.0 kg), height (1.77 ± 0.06m), adipose mass (10.6 ± 2.6%), and an average age of (26.1 ± 4.0 years) (Rienzi et al, 2000). Despite Rienzi, et al (2000) seeming outdated, Kalén, et al (2019) supports these mean age figures, with the mean age increasing from 24.9 years (1992-93) to 26.5 years (2017-18) in an elite European competition. When discussing locomotor and physiological demands, it is important to irradicate goalkeepers from all reported data, as Di Salvo, et al (2008) states that goalkeepers have different physiological and locomotor demands, compared to outfield players.

2.2 Global Positioning Systems (GPS)

2.2.1 Evaluation of using GPS to determine locomotor demands of football

In the past, movement demands have been quantified by a number of different methods; time motion analysis (TMA), local positioning systems (LPS), and global positioning systems (GPS). The evolution from the time-consuming notational analysis of TMA first became modernised when in 2015, FIFA allowed players to wear LPS or GPS systems in professional match play. Despite TMA having improved since Reilly & Thomas. (1976) and Bangsbo et al. (1991), the introduction of GPS systems allowed for deeper, more accurate analysis of movement demands during match play, with levels of validity and reliability increasing as technological advancements allowed for higher sample rates (Heale & Twycross., 2015).

Despite other team sports such as rugby union (Cunniffe et al., 2009; Cahill et al., 2013; Cunningham et al., 2016), rugby league (Gabbett et al., 2011) and even Australian rules football (Murray et al., 2018), there is a lack of literature that investigates match demands in football at the elite level. A systematic review by Cummings et al. (2013) collated a total of 7 studies that investigated the use of GPS units in order to quantify of movement demands in football. Despite having a wide diversity in terms of participants, none of the highlighted studies provided movement demands of elite level match play for male football. An explanation of the lack of literature could be down to the recency of the decision in 2015 to approve GPS use in match play. More recently, Russel et al. (2015), stated that the mean TD in match play was 10893 ± 471.27m, mean RD values of 112.5 ± 10.3 M/min^{-1}, and HIR values of 710 ± 212.2m respectively (Table 2). This study was followed up with a replica study a year prior (Russell et al., 2016), where whole team values slightly differed, wit TD values being 9457 ± 549.6m, calculated RD was 103 ± 12.21 M/min^{-} and HIR decreasing to 487 ± 142.84m. One common issue with the aforementioned studies is the sample size being so small, it makes it difficult to apply findings of such a small population to larger groups.

2.2.2 Comparison of position specific locomotor demands of football using GPS

With positional differences being more specific in modern football than ever before, it is crucial that positional demands are quantified for coaches, in order to assist them in periodising training in order to condition players to suit their playing position, allowing them to perform at an optimal level during match play. Table 2 shows a brief summary of studies that specifically utilised 10Hz GPS units to quantify movement demands between positons.

Slater et al. (2018) is an example of a study that generalised playing position (defenders, midfielders & attackers), to globalise findings across a number of positions. Findings show that defenders have significantly lower demands of TD, as well as a lower %HSR values, deeming it the least demanding position. No significant differences were found between midfielders and attackers, resulting in both groups potentially being the most demanding during match play. The lack of significance in most demanding positional group is down to the generalisation of individual positions into 'positional groups', causing a potentially demanding positions data to be nullified by a less demanding position.

This directed research into position specific demands, such as Tierney et al. (2018). Again, similar to Slater et al. (2018), central defenders are the least demanding position. What is important to note however is that there are no significant differences between full back s and central midfielders, an observation that would not have been possible without further specificity of playing position, where full back demands would have been underestimated if classified as a defender. When analysing RD, players who play more centrally on the pitch are shown to have lower RD values, compared to players who play in wide positions, such as full backs and wingers. This finding could be predicted however, due to the distance wide players have to travel should play be switched from one side of the pitch to another. Abbott et al. (2018) conducted his study on elite level english premier league footballers, finding at the elite level, CM produced the highest demands for TD, but Vmax was highest for wide players ($P \geq 0.05$). More recently, Ravé et al. (2020) investigated the positional match demands of an elite European club football tournament. Interestingly, complimenting the findings of Abbott et al. (2018), but contrasting Tierney et al. (2018), central midfield players elicited the highest TD and HSR values, with W producing the highest SPD values. Frequency of accelerations and decelerations were also identified, with W having the highest demand for both parameters, which could've been predicted, given the nature of the position, encountering more 1v1 situations than any other position (Caetano et al., 2019).

There is also a broad amount of literature researching positional demands, using systems such as Vicon and Prozone to evaluate positional differences. Bradley et al. (2011) used Prozone to evaluate positional demands and found that with the constant tactical changes and adaptations in football, playing formation can significantly impact the positional demands of certain positions. Di Salvo et al. (2007) used Amisco Pro (another TMA), but the findings still echo that of studies using GPS, with midfielders having significantly greater TD demands ($P>0.001$), but no significant differences were observed for high intensity bouts.

Table 1: Summary of studies investigating the effect of match outcome on locomotor demands using 10Hz GPS, adapted from Fereday et al. (2020)

Study	Sample	Parameter	Whole team	Defenders	Midfielders	Attackers	Central Defenders	Full Backs	Central Midfielders	Wingers	Strikers
Russell et al. (2015)	5 Male 10 Hz	TD (m)	10893 ± 471.27	-	-	-	-	-	-	-	-
		RD (M/min^{-1})	112.5 ± 10.30	-	-	-	-	-	-	-	-
		HIR (m)	710 ± 212.19	-	-	-	-	-	-	-	-
Russell et al. (2016)	11 Male 10 Hz	TD (m)	9457 ± 549.6	-	-	-	-	-	-	-	-
		RD (M/min^{-1})	103 ± 12.21	-	-	-	-	-	-	-	-
		HIR (m)	487 ± 142.84	-	-	-	-	-	-	-	-
Slater et al. (2018)	22 Male 10Hz	TD (m)	-	9808.2 ± 1044.5	11516.6 ± 1848.9	11466.1 ± 1685.4	-	-	-	-	-
		HSR (% of TD)	-	10.05 ± 2.41	12.46 ± 1.95	13.75 ± 1.31	-	-	-	-	-
Tierney et al. (2018)	46 Male 10Hz	TD (m)	-	-	-	-	9669 ± 454	10152 ± 714	10395 ± 619	10523 ± 456	10502 ± 778

Table 1 Continued: Summary of studies investigating the effect of match outcome on locomotor demands using 10Hz GPS, adapted from Fereday et al. (2020)

		RD (M/min^{-1})	-	-	-	-	396 ± 76	660 ± 117	429 ± 133	636 ± 172	690 ± 186
Curtis et al. (2018)	18 Male 10Hz	TD (m)	9367 ± 2149	8985 ± 2158	-	8948 ± 2005	-	-	9941 ± 2140	9593 ± 2290	-
		RD (M/min^{-1})	92 ± 20	87 ± 20	-	87 ± 19	-	-	97 ± 20	94 ± 22	-
		HIR (m)	1700 ± 369	1328 ± 369	-	1721 ± 498	-	-	1837 ± 579	1915 ± 611	-
Abbott et al. (2018)	37 Male 10Hz	TD (m)	-	-	-	-	9,830 ± 428	10,747 ± 420	11,570 ± 469	10,918 ± 353	10,320 ± 420
		Vmax (m/s^{-1})	-	-	-	-	7.4 ± 0.3	8.4 ± 0.4	7.5 ± 0.3	8.6 ± 0.4	7.6 ± 0.5
Ravé et al. (2020)	*Not Specified*	TD (m)	-	-	-	10415	9962	-	12045	10415	-
		HSR (m)	-	-	-	643	493	-	928	756	-
		SPD (m)	-	-	-	348	217	-	353	378	-
		Acc (n)	-	-	-	36	29	-	39	47	-
		Dec (n)	-	-	-	59	22	-	62	55	-

Total distance (TD), Relative Distance (RD), High intensity Running (HIR), Maximum Velocity (Vmax), High speed running (HSR), Sprint Distance (SPD), Accelerations (Acc), Decelerations (Dec)

Data presented as mean ± standard deviation

2.2.3 Comparison of match result impact on locomotor outputs in football using GPS

Due to football being influenced by strategic changes made by coaches, games are heavily influenced by situational factors, and physical demands are no different (Bloomfield et al., 2005; Carling et al., 2008; & Lago-Peñas et al., 2009). The most impactful factor in effecting tactical, technical, and physical outputs is score line. Bloomfield et al. (2005) was one of the first to investigate how match outcome impacted the percentage of time players spent performing functional exercise (%Ex), although no significant differences were found. A logical explanation for this lack of significant difference could be down to the sample population only consisting of midfielders and strikers, who typically have high levels of physical demands regardless of result. Lago-Peñas. (2010) took this analysis one step further and broke down match outcome based on the strength of the opposition faced. Demands for TD were significantly greater during wins and draws compared to losses, with TD demands also being significantly greater when opposition teams were stronger than the control team. Interestingly, despite TD being greater against tougher teams, more high intensity bouts were higher when playing weaker teams. This could be down to a higher frequency of goal scoring opportunities, which are said to follow high intensity bouts of movement (Di Salvo et al., 2009; Bradley et al., 2014; Modric et al., 2019). What is important to note when looking at the methodology utilised by Lago-Peñas. (2010), is that the threshold values for running bands, are different to the majority of other literature. Running velocities of 5.3 – 6.4m/s^{-1} are labelled as HSR, whereas the majority of studies and practical users of GPS regard HSR to be between the threshold of 5.5 - 7m/s^{-1}. This also causes an overestimation in SPD values as well, due to the minimum velocity threshold for movement to be classed as sprinting dropping to 6.6m/s^{-1}.

Two longitudinal studies provided a combination of both positional differences, and the impact of match result. Andrewzejewski et al. (2016) analysed 306 Bundesliga 1 matches, collating data for 350 players. They found significant differences in high intensity movement for CB and FB, with distances being significantly less in games won compared to games lost ($P \leq 0.01$). Supporting the claim of Modric et al. (2019), S were also found to cover significantly greater TD in games won compared to draws and losses ($P \leq 0.05$). Chmura et al. (2018) conducted a similar study, but over the course of three seasons rather than one. Sharing Mutual findings with Andrewzejewski et al. (2016), S and W elicited higher TD in winning games ($P \leq 0.05$), with wins resulting in lower demands for CM, CB and FB ($P \leq 0.05$). Again, findings must be interpreted carefully, as the same

Table 2: Summary of studies investigating the effect of match status/result on locomotor outputs of football

Study	Participants	Parameter	Win	Draw	Loss
Bloomfield et al. (2005)	141 Male*	%Ex	32.1±6.6	32.6±7.1	31.4±7.1
Lago-Peñas et al. (2010)	Not specified	TD (m)	Strong team – 10998 Weak team – 10682	Strong team – 10917 Weak team – 10621	Strong team – 10748 Weak team – 10432
		HSR (m)	Strong team – 467 Weak team – 526	Strong team – 482 Weak team – 536	Strong team – 541 Weak team – 600
		SPD (m)	Strong team – 203 Weak team – 217	Strong team – 211 Weak team – 225	Strong team – 267 Weak team – 281
Redwood-Brown et al. (2012)	79 Male	%HI	Defender – 5.95 Midfielder – 9.39 Striker – 7.55	Defender – 6.42 Midfielder – 10.22 Striker – 7.85	Defender – 5.90 Midfielder – 9.53 Striker -7.42
Andrewzejewski et al. (2016)	350 Male	TD (km)	CB - 10.13 ± 0.59 FB - 10.79 ± 0.54 CM - 11.60 ± 0.66 W - 11.35 ± 0.63 S - 11.03 ± 0.67	CB - 10.20 ± 0.59 FB - 10.83 ± 0.58 CM - 11.66 ± 0.68 W - 11.38 ± 0.62 S - 10.87 ± 0.67	CB - 10.18 ± 0.57 FB - 10.85 ± 0.58 CM - 11.59 ± 0.68 W - 11.29 ± 0.62 S - 10.86 ± 0.72
		≥HSR (km)	CB - 1.85 ± 0.38 FB - 2.51 ± 0.37 CM - 2.88 ± 0.47	CB - 1.88 ± 0.38 FB - 2.54 ± 0.46 CM - 2.93 ± 0.43	CB - 1.93 ± 0.36 FB - 2.63 ± 0.43 CM - 2.91 ± 0.50

Table 2 Continued: Summary of studies investigating the effect of match status/result on locomotor outputs of football

			W - 2.96 ± 0.42	W - 2.90 ± 0.52	W - 2.93 ± 0.42
			S - 2.74 ± 0.45	S - 2.63 ± 0.43	S - 2.64 ± 0.49
Chmura et al. (2018)	556 Male	HSR (km)	CB - 0.22 ± 0.07	CB - 0.22 ± 0.07	CB - 0.24 ± 0.07
			FB - 0.36 ± 0.08	FB - 0.36 ± 0.09	FB - 0.37 ± 0.09
			CM - 0.34 ± 0.11	CM - 0.34 ± 0.11	CM - 0.35 ± 0.10
			W - 0.44 ± 0.10	W - 0.42 ± 0.10	W - 0.42 ± 0.10
			S – 0.40 ± 0.09	S – 0.39 ± 0.09	S – 0.09
		SPD (km)	CB - 0.15 ± 0.07	CB - 0.16 ± 0.08	CB - 0.17 ± 0.08
			FB - 0.31 ± 0.11	FB - 0.30 ± 0.11	FB - 0.32 ± 0.11
			CM - 0.21 ± 0.10	CM - 0.21 ± 0.10	CM - 0.21 ± 0.09
			W - 0.39 ± 0.14	W - 0.36 ± 0.13	W - 0.36 ± 0.13
			S - 0.36 ± 0.14	S - 0.32 ± 0.13	S - 0.31 ± 0.13

Percentage of time exercising (%Ex), Total distance (TD), High speed running (HSR), Very high-speed running (VHSR), Sprint Distance (SPD), Relative Distance (RD), Percentage of time performing high intensity work (%HI)

Data presented as mean ± standard deviation

*Strikers & Midfield players only

velocity thresholds as Lago-Peñas (2010), making all values for HSR and SPD exaggerated, and difficult to apply if different thresholds of movement are utilised.

2.3 Reliability and Validity of 10Hz GPS

With modern day GPS data playing such an important role in athlete monitoring and conditioning, the importance for a high reliability and validity levels in GPS units has never been more crucial. The data collated aids practical sport scientists on a daily basis, to make key decisions from individual player readiness and whole team periodisation (Hoppe et al., 2018). Heale & Twycross. (2016) identified that with many team sports using multiple GPS units per game/training session, not only is a high inter-unit validity required, but in order to utilise whole team outputs, a high intra-unit validity is required also.

The first commercially available GPS units were sampled at 1Hz. Gray et al. (2010) investigated the validity of these units during 5 bouts of linear, curvilinear, and curved runs of varied distances from 200m – 10m. When runs were distinctly linear and curvilinear, and over larger distances, inter-unit (CV = 1.46-3.38%) and intra-unit (CV = 1.85-2.71%) reliability was good but decreased when runs became non-linear and at shorter in distance respectively. Runs at higher velocities also caused low levels of validity, questioning the plausibility of using 1Hz units in team sports, especially football, whereby game demands result in quick accelerations as well as many multidirectional movements. More recent research conducted by Scott et al. (2016) supports the above findings, stating limitations in reliability arose when tested at shorter distances and at higher intensity measures (accelerations, decelerations, HSR, SPD & Vmax). It is important to note that Scott et al. (2016) was the first study to begin to categorise validity into good, moderate and poor categories, based off CV scores. Validity analysis conducted by Coutts & Duffield. (2010) again found that CV values increased as the intensity of movement increased. Technological improvements allowed for development of 5Hz units, that in general displayed fewer errors compared with the 1Hz units. Portas et al. (2010) found that the 5Hz unit showed higher reliability (SEE = 1.5%-2.2%) improved in areas where 1Hz (SEE = 1.3-3.0%) displayed issues, in more football specific movement patterns. An alternative study by Jennings et al. (2010) suggested that validity differences could be down to differences in GPS unit brand, or disparities in the methodology used. Johnson et al. (2012) tested 2 units for inter-unit reliability and still found that even with the higher sampler rate (5Hz), as movement velocity increased, TEM percentage also increased (Walking = 7.5%; HSR = 10.8%; SPD = 12.0%), suggesting that despite the evident improvement in performance, 5Hz unts still didn't record reliable data at higher intensities.

This leads into the development of 10Hz units, the sample rate at which the large majority of commercial units used at professional clubs are set. Castellano et al. (2011) was among the first studies to evaluate the reliability and validity of these newer 10Hz units, comparing them against time gates as a control variable. Reliability of the units was very high compared to the control, for both 15m test (CV= 0.7) and 30m (CV = 1.3%) respectively. Values for validity did however creep slightly high in the 15m sprints, with a CV value of 10.9%, deemed as a poor level of validity by Scott et al. (2016). Rampinini et al. (2014), reported that 10Hz units (TD: 1.9%, HSR: 4.7%, VHSR: 10.5%, mean MP: 4.5%, & time spent at high MP: 6.2%) were superior in reliability compared to previously used 5Hz units (TD: 1.9%, HSR: 4.7%, VHSR: 10.5%, mean MP: 4.5%, & time spent at high MP: 6.2%), for all outputs measured. The findings of Rampinini et al. (2014) are important as they not only were undertaken on football players, but the test course was designed to represent the random changing of demands that players will experience during football match play, whilst providing data for the parameters most commonly utilised by coaches (Ravé et al., 2020). The main downfall of lower frequency units (1Hz & 5Hz) was a lack of reliability and validity of data for accelerations and decelerations, and data taken over shorter distances. Varley et al. (2012) found that 10Hz units produce better reliability (Acc CV = 3.6 – 5.9%, Dec CV = 11.3%) and validity (Acc CV = 1.9 – 4.3%, Dec CV = 6.0%) compared to the lower 1Hz & 5Hz models, further supporting the claim that 10Hz units are a better option for team-based sports where demands of movement are multidirectional, and can vary from long to short distances, at a range of velocities. Table 3 provides a summary of studies that investigated reliability and validity of 10Hz units.

Recently, GPS units have been developed with even higher sample levels (15 – 20Hz), in an attempt to give even more accurate data on locomotor outputs. Previously mentioned, Johnson et al. (2014) studied differences in GPS unit sample frequencies and found no significant differences in data collected using 10Hz units, compared to 15Hz, disregarding the need to use 15Hz units. Hoppe et al. (2018) investigated inter-unit differences between two higher sample rates of 18Hz (GPS) & 20Hz (Local Positioning System (LPS)). Findings show that as sample frequency increased, a positive correlation occurred with reliability and validity for determining sprint mechanic properties (10Hz CV = 3.30-20.0%, 18Hz CV = 3.1-7.5%, & 20Hz CV = 1.6-7.3%). Hoppe et al. (2018) deduced that 18Hz GPS units are actually more reliable and valid for movement quantification in team sports compared to 10Hz, whereas for overall movement patterns, 20Hz LPS units were most reliable and valid. LPS have more recently been implemented into the design of GPS units, using internal accelerometers and gyroscopes to quantify locomotor outputs. LPS are often used as a substitute to GPS systems when teams may be required to train indoors or in stadia, where a GPS connection may not possible, but locomotor outputs can still be obtained. However, Kelly et al. (2015) disapproved of internal accelerometers ability to accurately quantify acceleration movements, stating an underestimation by 32-35%, questioning the suitability to using these in team sports. Overall, 10Hz GPS devices provide solid levels of validity and reliability when used to quantify movement outputs, and in team sports, individuals must wear the same unit over the course of a season, in order to maintain levels of inter-unit reliability (Akenhead et al., 2014).

2.4 Small Sided Games

With the technical, tactical, and physical demands of football evolving as to suit the modern game, new methods of training have had to be evolved from isolated practice of each aspect of the game into a more integrated approach (Bangsbo, 1994). Small sided games (SSG) have been integrated into training sessions for a number of years, as a solution to integrating game realistic repetitions of technical actions, whilst also eliciting similar intensities and physical demands on players (Sarmento et al., 2018). Queiroz (1985), was the first study to identify SSGs as a means of practice, for further research to investigate, and specifically noted that further research should investigate the effects of changing aspects of SSGs (such as team size, game dimensions, & technical limitations) on physical, technical, and tactical demands.

2.4.1 Effect of altering of SSG design on locomotor outputs

Following on from the suggestions of Queiroz (1985), Pratt (2001) was one of the first papers to evaluate the differences in technical moments (passing, dribbling & attempts at goal), comparing the outputs of 3v3 (30x20) and 5v5 (40x30) SSGs. Pratt found that when team size increased, the number of technical actions players undertook decreased, due to the area per player allowing individual players to have more time in possession when playing less opposition, thus resulting in a higher frequency of technical moments. Although one of the first studies to investigate the impacts of changing the format of SSGs, the fact this study was undertaken on youth footballers (U10) questions its validity when applying its findings to adults' football, especially at the professional and elite levels. Owen (2004) however took the concept of Pratt (2001) but applied it to professional football players, and further explored the physiological demands through the use of heart rate (HR) monitors. Not only evaluating team size from 1v1 to 5v5, Owen (2004) also investigated the effects of actual pitch dimensions of each game, creating small, medium, and large sided games for each team size (Table 4). The overall findings of the study were that as player number increased in the SSGs, HR decreased, due to the area per player decreasing with the

Table 3: Summary of studies investigating reliability and validity of 10Hz GPS

Study	Participants	Method	Reliability	Validity
Castellano et al., 2011	9 trained athletes, male	7x15m sprints & 6x30m sprints Criterion measure: Tape measure & timing gates	CV 30m – 1.3% 15m – 0.7%	SEM 30m – 5.1% 15m – 10.9%
Varley et al., 2012	3 sub-elite athletes, male	80 linear running trials, comparing constant velocity, acc & dec in different velocity bands Criterion measure: Laser	CV Velocity = 3.1-8.3% Acc = 3.6-5.9% Dec = 11.3%	CV Constant velocity = 2.0-5.3% Acc = 1.9-4.3% Dec = 6.0%
Johnson et al., 2014	8 trained, male	8 laps x TSSC (165m) Criterion measure: Tape measure & timing gates	ICC TD = 0.51 HSR = 0.88 VHSR = 0.89	TEM TD = 1.3% HSR = 4.8% VHSR = 11.5%
Rampinini et al., 2014	8 sub-elite football players, male	7 bouts of linear running course (4x210m, 3x280m)	CV TD = 1.9%	*Not investigated*

Table 3 Continued: Summary of studies investigating reliability and validity of 10Hz GPS

		Criterion measure: Radar gun	HSR = 4.7%	
Roe et al., 2017	9 professional rugby union players, male	3 x maximum 30m sprints Criterion measure: Radar gun	Bias Vmax = -0.77 – -1.35%	ICC Vmax = 0.95-0.96
Hoppe et al., 2018	6 trained, male	10 reps x sport specific circuit Inter-unit test	Bias TD = -11.9 – -3.3%	TE TD = 0.5-1.2
Beato et al., 2018	20 students, male & female *Gender splits not specified*	2 x 400m trials, 1 x 20m max sprint, 1 x 20m jog, 1 x 128.5m TSSC Criterion measure: Radar gun & 400m track	Bias 400m = 1.05 20m max sprint = 2.3 TSSC = 1.11	ICC Peak velocity = 0.96
Nikolaidis et al., 2018	20 football players, female	20m shuttle run test	Inter-unit (CV) TD = 2.08-3.92%	Intra-unit (ICC) TD = 0.718-0.831

Table 3 Continued: Summary of studies investigating reliability and validity of 10Hz GPS

	Track and field athletes, male (2) & female (6)	5 x 200m running track laps	TD = 1.31-2.20%	TD = 0.833

Coefficient of variation (CV), Standard error of measurement (SEM), Acceleration (Acc), Deceleration (Dec), Team sport simulation circuit (TSSC), Intraclass correlation (ICC), Typical error of measurement (TEM), Total distance (TD), High speed running (HSR), Very high-speed running (VHSR) increase in team size. When pitch size was increased, thus increasing area per player, findings show that players HR and max HR increased as playing area enlarged. When further evaluating this study however, the fact Owen (2004) only increased each pitch size by 10x10m each game, meaning area per player was not increased at a constant rate (Table A), potentially explaining the lack significant differences for max HR. Also, although stated as professional footballers, the sample age for the study was 17.46±1.05 years, again like Pratt (2001), it may also be difficult again to apply these findings to adult football, as the average age of professional footballers (26.5 years) is so much greater than the sample used (Kalén et al., 2019). Little and Williams. (2007), investigated HR and RPE responses to altering team size (2v2 – 8v8). Findings show both HR and RPE levels were higher during the smaller games, but not to any level of significance. Alteration to pitch size has been the independent variable in a number of studies (Kelly & Drust., 2009; Owen., 2011; Hodgson et al., 2014; Gaudino et al., 2014; Owen et al., 2014). Of these 4 mentioned studies, Kelly & Drust. (2009) was the only study with conflicting findings, concluding that as pitch size increased, there was no correlation with HR or technical frequency. Differences in methodology could explain the difference in results, as a notational analysis method was used to collate data, in conjunction with the use of a team based HR monitoring system, rather than the use of an ordinary HR monitor. The other studies however, all found that as pitch sizes increase, the physiological and locomotor demands increase also.

The impact of using goalkeepers has also been considered in literature, Gaudino et al. (2014) found that 4v4 games with goals and goalkeepers had higher demands of TD, HSR, Vmax, and frequency of accelerations & decelerations, compared to possession-based practice with no goalkeepers present. Riboli et al. (2020) found complimentary findings, that games including goalkeepers resulted in higher locomotor outputs. Findings like these are unexpected, as we expect movement outputs to increase as area per player gets larger, whereas the use of goalkeepers would decrease the area per player. Travassos et al. (2014) suggested that the reasoning behind the increase with goalkeepers could be down to a behavioural adaptation in players when goals are included, rather than free flowing possession-based drills, adding to the intensity of games with goalkeepers included. Altering SSGs to have different conditions on gameplay can also affect both physical and technical intensity. Dellal & Chamari. (2011) discovered that games with a 1 touch rule raised blood lactate levels more than games with eased rules, also seeing a significant increase in TD, SPD and HIR demands. In an alternative study however, Dellal (2011) stated that a free play rule allowed for more technical repetition for players. Halouani et al. (2014) found contrasting physical outputs, stating that game rules had no significant impact on the locomotor demands of SSGs.

Outfield playing possession has also been investigated, but no significant changes in total body load TBL occurred between different positions.

2.4.2 Evaluating the effectiveness of SSGs to prepare players for locomotor demands of a match

As literature has suggested (Table 4), SSGs are an ideal way to replicate a variety of match relevant repetitions of technical and physical load. Dellal & Owen et al. (2012) investigated the ability to alter 4v4 SSGs in order to replicate movement demands that are experienced by players during full 11v11 match play. Interestingly, findings of the study show that the SSG had higher TD per minute, HIR movement distances, as well as a significantly higher frequency of technical actions ($P<0.05$). Dellal. (2016) replicated these findings, but through the use of an LSG rather than SSG, and Bennham et al. (2017) again echoed the findings but in youth elite sport. Another study to claim SSGs can imitate match play intensity, Hodgson et al. (2014) found that acceleration patterns observed in SSGs were relatively greater than those observed during professional match play, although not to any level of significance. Lacome et al. (2018) further examined the idea of using SSGs to replicate match play but broke down data into position specific movements demands. The paper had mixed results, stating that CB were actually overloaded during SSGs, compared to match play, but on the other hand, S were also de-loaded in the same SSG.

The fact that there is current literature that states SSGs can replicate, to some extent, the locomotor demands of a match day, poses the argument that SSGs are the best training method in order to get match realism for all pillars of the game (technical, tactical, physical & psychological), due to the ability for SSGs to duplicate match situations so well. Dellal et al. (2008) deducted that if designed correctly, SSGs can be substituted for short duration intermittent running drills, giving players technical repetition whilst avoiding any chance of deconditioning due to a lack of running drills. A review of SSGs in other sports by Halouani et al. (2014) supports different findings, noting that more research needs to be conducted on the periodisation of SSGs, in order to avoid task injury, which is higher in SSG than any other practice form, and also maintain development for physiological capacity and technical skill levels. Kelly et al. (2013) however investigated the plausibility of a football specific aerobic capacity drill, aiming to duplicate the high levels of technical repetition, and achieving the same movement outputs, but avoiding the risk of injury that the game like nature of SSGs provide. Despite the drill accurately replicating said outputs, one major downfall of the practice is the practical implementation. SSGs are mostly utilised to capacitate large groups of players, whereas the drill fashioned by Kelly et al. (2013) was only

Table 4: A summary of studies investigating physical demands of SSGs in professional & elite football, adapted from Sarmento et al. (2018)

Study	Participants	Level	SSG Variables	Area per Player (m^2)	With GK	Results
Owen et al., 2004	Male, 22 Players	Professional	1v1(5x10, 10x15, 15x20) 2v2(10x15, 15x20, 20x25) 3v3(15x20, 20x25, 25x30) 4v4(20x25, 25x30, 30x35) 5v5(25x30, 30x35, 35x40)	25, 75, 150 37.5, 75, 125 50, 83, 125 62.5, 93.75, 131.25 75, 105, 140	No	Increase in player number resulted in a decrease in HR and Max HR.
Little & Williams., 2007	Male, 28 Players	Elite	2v2 (30x20) 3v3 (43x25) 4v4 (40x30) 5v5 (45x30) 6v6 (50x30) 8v8 (75x45)	150 179 150 135 125 197	No	2v2 drill showed a significantly (P≤0.05) lower HR response (Mean ± SD: 88.7±1.2% HRmax) than 3v3 (91.2±1.3% HRmax) and 4v4 drills (90.2 ±1.6% HRmax).
Dellal et al., 2008	Male, 10 Players	Elite	1v1 2v2 4v4 8v8 10v10	50 10 94 169 203	No (1v1, 2v2) Yes (4v4 – 10v10)	The %HRres in the 30–30-second intermittent run was significantly higher than the 1v1 (P<0.01), 4v4 (P<0.05), 8v8 (P<0.001), and 10v10 (P<0.01) games. During the 8v8 game, the presence of goalkeepers induced an ~11% increase in %HRres.
Kelly & Drust., 2009	Male, 8 Players		4v4	75 150 250	No	Mean+/-S.D. heart rates for the three games were not significantly different between conditions (SSG1, 175±9; SSG2, 173±11; SSG3, 169±6).

Table 4 Continued: A summary of studies investigating physical demands of SSGs in professional & elite football, adapted from Sarmento et al. (2018)

Dellal et al., 2011	Male, 20 Players	Elite	4v4 (30x20)	75	No	Free Play Rule: induced the lowest decreases of the sprint and high-intensity performances. 1 Touch Rule: led to reach higher solicitation of the high-intensity action.
Hill-Haas et al., 2011	Male, 20 Players	Professional & Amateur	2v2 (20x15) 3v3 (25x18) 4v4 (30x20)	75 75 75	No	Amateurs covered significantly less total distance with respect to sprinting and high intensity running (HIR) ($P \leq 0.05$).
Dellal, Chamari, et al., 2011	Male, 20 Players	Elite	2v2 (20x15) 3v3 (25x18) 4v4 (30x20)	75 75 75	No	SSGs played with one touch induced increases in blood lactate concentration and RPE, as well as greater physical demands in the TD covered in SPD and HIR($P<0.001$).
Gomez-Piriz et al., 2011	Male, 22 Players	Professional	5v5 (52.5x34) 6v6 (80x68) 7v7 (80x68) 8v8 (80x68)	178.5 - - -	No	TBL is not a valid measure to quantify training load because it is not strongly correlated with session-RPE. TBL and session-RPE in SSGs do not vary according to player position
Owen et al., 2011	Male, 15 Players	Professional	3v3 (30x25) 9v9 (60x50)	125 166.6	Yes	SSGs induced significantly ($P<0.05$, large effect) higher HR responses as compared to large-sided games (LSGs). Players spent significantly longer time in the .85% maximal HR zone ($P<0.05$, large effect) in SSGs as compared to LSGs.
Dellal, Owen, et al., 2012	Male, 40 Players	Elite	4v4(+4)(30x20) 11v11 (100x60)	75 273	No/Yes	Compared to match-play, TD covered per minute of play, HIR activities (sprinting and HIR), total numbers of duels and lost ball possessions were significantly greater within SSGs for all playing positions ($P<0.05$).

Table 4 Continued: A summary of studies investigating physical demands of SSGs in professional & elite football, adapted from Sarmento et al. (2018)

Hodgson et al., 2014	Male, 8 Players	Not Specified	4v4: (30x20, 40x30, 50x40)	75, 150, 250	No	SSGs played on medium and large pitches had a greater physical demand than on small pitches, with significantly more distance covered in all movement categories. TD covered in Acc categories ranged from 230 ± 111 (small pitch) to 356 ± 72 m (medium pitch).
Gaudino, Alberti, et al., 2014	Male, 26 Players	Elite	5v5 (27x27) 7v7 (37x37) 10v10 (52x52)	73 98 135	Yes	The TD, HSR (>14.4km/h^{-1}) as well as absolute Vmax, maximum Acc and maximum Dec increased with pitch size (10v10>7v7>5v5; P<0.05). Total distance, very high (19.8-25.2km/h^{-1}) and maximal (>25.2km/h^{-1}) speed distances, absolute maximal velocity and maximum acceleration and deceleration were higher in game with regular goals and goalkeepers (SSG-G) than in possession play (SSG-P) (P<0.001).
Gaudino, Iaia, et al., 2014	Male, 26 Players	Elite	5v5 (30x30) 7v7 (45x35) 10v10 (66x45)	75 98 135	No	High-intensity activity was estimated using the TD covered at speeds >14.4km/h^{-1}(TS) and the equivalent metabolic power threshold of >20W/kg^{-1}(TP). High-intensity demands were systematically higher (~100%, P<0.001) when expressed as TP vs. TS irrespective of playing position and SSG.
Owen et al., 2014	Male, 16 Players	Elite	4v4 (30x25) 5v5 (46x40) 6v6 (50x44) 7v7 (54x45)	94 184 183 174	Yes	Significant differences found across team size from 4v4 to 8v8 for mean TD (8v8 – 1552m, 4v4 – 1709m). Significant differences in mean HSR in

Table 4 Continued: A summary of studies investigating physical demands of SSGs in professional & elite football, adapted from Sarmento et al. (2018)

			8v8 (60x50) 9v9 (70x56) 10v10 (80x70)	188 218 280		smaller games (4v4 – 9m, 5v5 – 5m, 6v6 – 8m) compared to 10v10 (48m). No significant differences in mean SPD. 4v4 SSG had significantly higher intensity (198.5M/Min^{-1}) compared to all other team sizes.
Stevens et al., 2016	Male, 125 Players (33 Professional Senior) (30 Professional Youth) (62 Amateur)	Professional & Amateur	6v6 (40x34)	113	Yes	No differences in 6v6-SSG time-motion variables were found between professional senior and professional youth players Amateurs showed lower values than professional seniors on almost all time-motion variables (ES = 0.59–1.19).
Lacome et al., 2017	Male, 21 Players	Elite	Team Size not Specified (20x40)	Not Specified	Not Specified	Peak total distance and HSR during 4v4, 6v6, and 8v8 were likely-to-most likely lower than during matches (ES: −0.59 ±0.38 - −7.36 ±1.20). Relative to their match demands, CB performed more HSR than other positions (0.63 ± 0.81 - 1.61 ±0.52) during 6v6.
Riboli et al., 2020	Male, 25 Players	Elite	3v3 4v4 5v5 6v6 7v7 8v8 9v9 10v10	Not Specified	Both	In SSG-G, forwards required higher area-per-player than CB (ES: 2.96(1.07/4.35)), W (ES: 2.45(0.64/3.78)] and FB (ES: 3.45(1.13/4.99)). CM required higher area-per-player than CB (ES: 1.69(0.20/2.90)) and W (ES: 1.35(-0.13/2.57)) In SSG-P, CB need lower area-per-player (ES: -6.01/-0.92) to overall replicate the

Table 4 Continued: A summary of studies investigating physical demands of SSGs in professional & elite football, adapted from Sarmento et al. (2018)

	match demands compared to all other positions.

Heart rate (HR), Maximum heart rate (HRmax), Percentage of resting heart rate (%HRres), High intensity running (HIR), Total distance (TD), Sprint distance (SD), Total body load (TBL), Rating of perceived exertion (RPE), Acceleration Acc), High speed running (HSR), Maximum velocity (Vmax), Deceleration (Dec), Effect size (ES) suitable for one player. With the accuracy of the locomotor outputs however, it could serve as an easily controllable rehabilitation drill, allowing players to train at a match intensity with technical practice, but avoid the heavy physical demands SSGs hold.

2.4.3 Risk of overtraining and Physical Periodisation

When trying to replicate match demands during the training environment through the implementation of SSGs, the risk of overtraining and overloading players can potentially increase. Overtraining typically occurs when there is an imbalance between training and recovery (Kuipers & Keizer., 1988), Overtraining does not just increase risk of muscular injury (Nédélec et al., 2013), but can also have a negative effect on playing performance during matches (Dupont et al., 2010). Bouzid et al, (2018) stated that to return to rested, non-fatigued state, a 72-hour period following high intensity exercise is needed. This was supported by Gill et al (2006), who investigated physiological parameters of overtraining, and showed that creatine kinase (an indicator of muscle damage) levels returned to basal values following the 72-hour recovery period. In order to ensure that overtraining is avoided, there needs to be a sufficient enough recovery period between a high intensity training session during the week and a match day, many teams utilise a physical periodisation model. Mallo (2014) outlines that getting high intensity training completed on MD-4 and MD-3 training days, allows players to fully recover to their rested state, but also allows performance coaches to condition during the week as well. Platonov (2013), also proposed a gradual taper in the weekly microcycle, so as the week gets closer to match day, the training sessions decrease in regards to physical demand, further aiding the recovery process.

2.5 Worst case scenario demands of football

Despite there being an abundant amount of research on the full match demands of football match play, which although helpful and imperative for coaches to utilise when designing training (Mernagh et al., 2021), this research does not always account for the random fluctuation on physical demands and locomotor outputs during a full 90-minute game (Whitehead et al., 2018). This could potentially lead in an underestimation of the most intense periods of match play, that may be drowned out when combined with data for the rest of the game. Therefore, the concept of the worst case scenario (WCS), which are the greatest physical demands placed on players for a given epoch length (Fereday et al., 2020), has recently started to become a theme of research in football. There are a number of ways in which WCS can be determined, such as a split epoch method used by Akenhead et al. (2013), a rolling average method (Whitehead et al., 2018), or utilising a ball in play (BiP) analysis method. BiP only reports demands that are solely derived from periods where the ball is actively in play, as modern elite level football matches only have a BiP time of just 54.4±4 mins (Lago-Penas, Rey, & Lago-Ballesteros. 2012), again suggesting that any whole match values may drastically be underestimating movement demands on players, especially during WCS. Understanding and implementing WCS into training sessions is vitally important in order to properly prepare players for match play intensity, which in the past could previously have been under-preparing players, due to coaches designing drills based off full game average values.

There are a few studies that investigated the use of BiP analysis to determine WCS. Akenhead et al. (2013) used 6 x 15min epochs, to evaluate the mean distance of accelerations and decelerations in 36 professional footballers. They found in their analysis of BiP, there was no significant effect of time-dependant reductions across all 6 sample periods ($P = 1.0$). The greatest difference in full match mean high velocity acceleration and deceleration distances and the BiP high velocity acceleration and deceleration distances was also insignificant at only 6%. A more recent study (Wass et al., 2019) investigated BiP further, by analysing whole match BiP demands, against maximum BiP demands, which was their interpretation of WCS. When analysing positional differences, there was no significant differences found between all outfield playing positions, but did find that mean whole match demands significantly underestimated BiP values, as well as max BiP values for m/min (Whole match: 88.5±13, BiP: 128±15.4, Max BiP: 165.3±16), HSR per minute (HSR/min) (Whole match: 8.6±1.9, BiP: 16.9±4.6, Max BiP: 46.1±8.4), accelerations per minute (Acc/min) (Whole match: 1.1±0.2, BiP: 1.8±0.3, Max BiP: 3.8±0.4) and decelerations per minute (Dec/min) (Whole match: 0.9±0.2, BiP: 1.6±0.2, Max BiP: 3.6±0.3). Wass et al. (2019), took this analysis of max BiP further by changing the sample epoch of which max BiP values were obtained (30-60s, 60-90a & >90s). Findings show that the shortest epoch length of 30-60s actually produced more intense demands for all metrics, followed by 60-90s length, with >90s epoch samples having the least intense WCS. Riboli et al. (2021) took the concepts of both max BiP demands, and 1-min peak demands for the full game and compared the differences in obtained results (Figure 1). They found that max BiP had greater demands of total distance per minute ($P<0.05$) than 1-min max, whereas for the more high intensity actions, max BiP had significantly lower demands for HSR, very high speed running (VHSR), and acceleration/deceleration distances. One reason why 1-min max may have had higher demands at higher intensity movements, is due to the 1-min max accounting for ball not in play moments, in which certain players may have to perform high velocity movements whilst the ball is dead, in order to regain tactical shape (Gabbet et al., 2016). Further investigation by Riboli et al. (2021) was performed in order to identify whether max BiP demands was affected by the teams possession status, but there were no notable differences found, as averages for in and out of possession percentages were so similar (In: 51.6%, Out: 49.2%), and like Wass et al. (2013), there were no positional differences found in BiP demands. Despite all discussed research investigating different aspects of BiP analysis, there are not many common themes in the current research. This could be down to the participant selection of each study, with although Akenhead et al. (2013) using professional players, data collection took place during reserve fixtures, whereas Was et al. (2013) conducted their data collection during English football league fixtures, stated to be the most demanding physically (Dellal et al., 2011), and Riboli et al. (2021) then conducting their research on older elite players in the Italian Serie-A, which is stated to be more tactical with less physical demands (Foot, 2006). It is important to note that BiP has been explored in other sports, such as rugby union (Read et al., 2018; Pollard et al., 2018), rugby league (Kempton et al., 2013; Hulin et al., 2015), as well as rugby sevens (Ross, Gill, & Cronin., 2015).

2.5.1 Rolling averages vs. Fixed averages to determine the WCS in football

Following on from using BiP to evaluate WCS demands, using a fixed analysis method was investigated as a means of dividing match play into set epochs, in order to evaluate the fluctuation of game demands, in turn finding the most physically demanding period of the game. One of the first studies was Bradley & Noakes (2013), who divided the game into 'discrete' 5-minute epochs, with an aim to analyse the fluctuation of HSR demands of football match play. The study found that during WCS, mean HSR demands were double that of the mean of an average 5-minute period ($P>0.01$). There was also a drop in player HSR outputs in the 5 min period directly following the period of WCS, by 8% compared to average match values ($P>0.01$), but HSR values returned to mean match values following this period. Di Mascio & Bradley (2013) is another study that used a fixed epoch method in order to begin to quantify the demands of WCS (referred to as most intense period). Similar to Bradley & Noakes (2013), Di Mascio & Bradley (2013) found that mean 5 min values for match play HSR were lower than WCS HSR valiues (Match mean: 96.7±28.7m, WCS: 110.6±27.5m), although no significance was found between variables following statistical analysis. Values for total WCS distance demands were provided also (634.5±82.9m), unlike Bradley & Noakes (2013), and also provided change in frequency of high intensity bouts (Match mean: 8.4±2.5, WCS: 17.5±5.9), and also max running velocities (Match mean: 7.6±0.3m/s, WCS: 8.4±0.6m/s). Furthermore, Di Mascio & Bradley (2013) also investigated match play variables on WCS, like most common in game epoch whereby WCS would occur (60-65min), comparison of high intensity demands when in and out of possession during WCS (In: 51.7±37.3m, Out:

57.9±32.1m). Finally, recovery period following WCS was stated to be 140% longer ($P>0.001$) compared to match average. One issue with these two studies, however, is the use of ProZone, a type of video motion analysis software, to gain results. The issue with this method is that no sample frequency of the cameras used were identified in either study, potentially making the raw demand values of WCS unreliable and invalid (Barris & Button., 2008).

A problem that arises when using fixed epochs to quantify demands, is the potential for an overlap in WCS time, which can lead to underestimations in demands, due to the fixed nature of the sample time used. Mohr et al. (2003) was the first study to use a rolling average, utilising a rolling 5-minute epoch to evaluate the decline in locomotor output, following periods of peak intensity. They observed a 12% decline in locomotor performance following the WCS period, and in combination with a more valid method of obtaining data compared to Bradley & Noakes (2013), makes these findings more precise. Varley et al. (2012) investigated the use of rolling epochs again in an attempt to accurately quantify peak HSR values and found that fixed epochs underestimated HSR values of the rolling epoch by as much as 25%, whilst overestimating 5 min post peak values by 31%. The common theme throughout these studies shows that a fixed model often leads to an underestimation in peak demands, usually followed by an overestimation in 5 min post peak epoch values, overall resulting in research suggesting differences of peak periods and match average being closer than is the case, further reinforcing the use of a rolling method. Martín-García et al. (2018) was an original study compared to other previous research on WCS in football, as the aim was to evaluate positional differences in WCS. This study was also deferred away from looking at HSR or TD values as an indicator of WCS, but rather investigated m/min, high metabolic load distance (HMLD), and average metabolic power (AMP) to identify peak periods. Findings show that the three criterion variables used promoted other dependent variables to make bias assumptions of WCS. For example, using HMLD as the variable to identify WCS also had the highest values for HSR and SD, whereas AMP correlated with high frequency of accelerations and decelerations. One major highlight of this study, was the evaluation of epoch length, whereby 1, 3, 5 and 10 minutes were observed. Findings show that as the epoch length increased, the movement and intensity demands of the WCS decreased, but inter-positional differences increased, showing that smaller epochs may homogenise these positional WCS demands. Delaney et al. (2017) is an example of another study to evaluate position specific peak demands, but in Australian rules football, where peak period outcomes being far greater than research papers on football, which is an expected outcome when pitch size and dimensions are considered. Cunningham et al. (2020) was one of the first studies to compare the two methods of rolling and fixed or 'discrete' epochs, whilst also altering epoch length (60-600s in 60s increments). When altering epoch length, results supported those of Martín-García et al. (2018) in that as epoch length increased, relative locomotor demands decreased (60s: TD – 190.1±20.4m/min, HSR – 59.5±23.0m/min; 600s: TD - 120.9±13.1m/min, HSR – 14.2±6.5m/min), as well as fixed epochs underestimating rolling values (TD – 7-10%, HSR – 12-25%). WCS demands were further broken down inter-positionally, where CM were observed to have significantly higher WCS demands for TD (9-16m/min), and starters also experiencing higher WCS TD demands, but substitutes having greater HSR demands. The final noteworthy finding from Cunningham et al. (2020) was that wins and losses produced significantly greater WCS demands for both HSR (Win: 2.7-7.9m/min, Loss: 1.4-2.2m/min) and TD (Win: 7.3-11.2m/min, Loss: 2.7-5.7m/min), compared to draws. In a very similar studies, Fereday et al. (2020) and Olivia-Lozano et al. (2020) obtained comparable findings, whereby fixed epochs of different lengths (60-600s) again underestimated the WCS running demands compared to rolling epochs for both relative distance (RD) by 7-10% (Fereday et al., 2020) and HSR 4-7% (Fereday et al., 2020). Again, similar themes to Cunningham et al. (2020) can be seen in match outcome effects of WCS demands for Fereday et al. (2020), whereby wins and losses had significantly greater demands compared to draws. However, contrasting findings are prevalent in Olivia-Lozano et al. (2020) compared to the previous two studies, finding that wins and draws had significantly greater demands for TD (1- and 3-minute epochs) compared to loses, and only wins had significantly greater HSR (1 minute epoch) and SD (1- and 3-minute epoch) values than draws and losses. Like findings for positional differences were found, with CM having greater demands of TD (1-, 3-, 5-, & 10-minute epochs), HSR (3- & 5-minute epochs, but Wide midfield players had greater SD demands (10-min epoch).

Developing research further again, Riboli, Esposito, & Coratella (2022) aimed to develop an SSG, designed to replicate both physical and technical demands of match play WCS, in order to better prepare players for these demands on match days. The study only focussed on a 4-min peak period for match demands, and tested SSGs both with and without goalkeepers present. They found that the area per player necessary to replicate peak match demands was greater for SSGs with goalkeepers, compared to SSGs without ($P<0.001$). With this study identifying a potential strategy coaches could use in order to implement WCS preparation into training, the aim of this current study is to compare the WCS locomotor demands of match play, to the current WCS locomotor demands of their SSGs in training, to gain further understanding on how WCS data can be interpreted into practice to allow coaches to correctly prepare players for these demands.

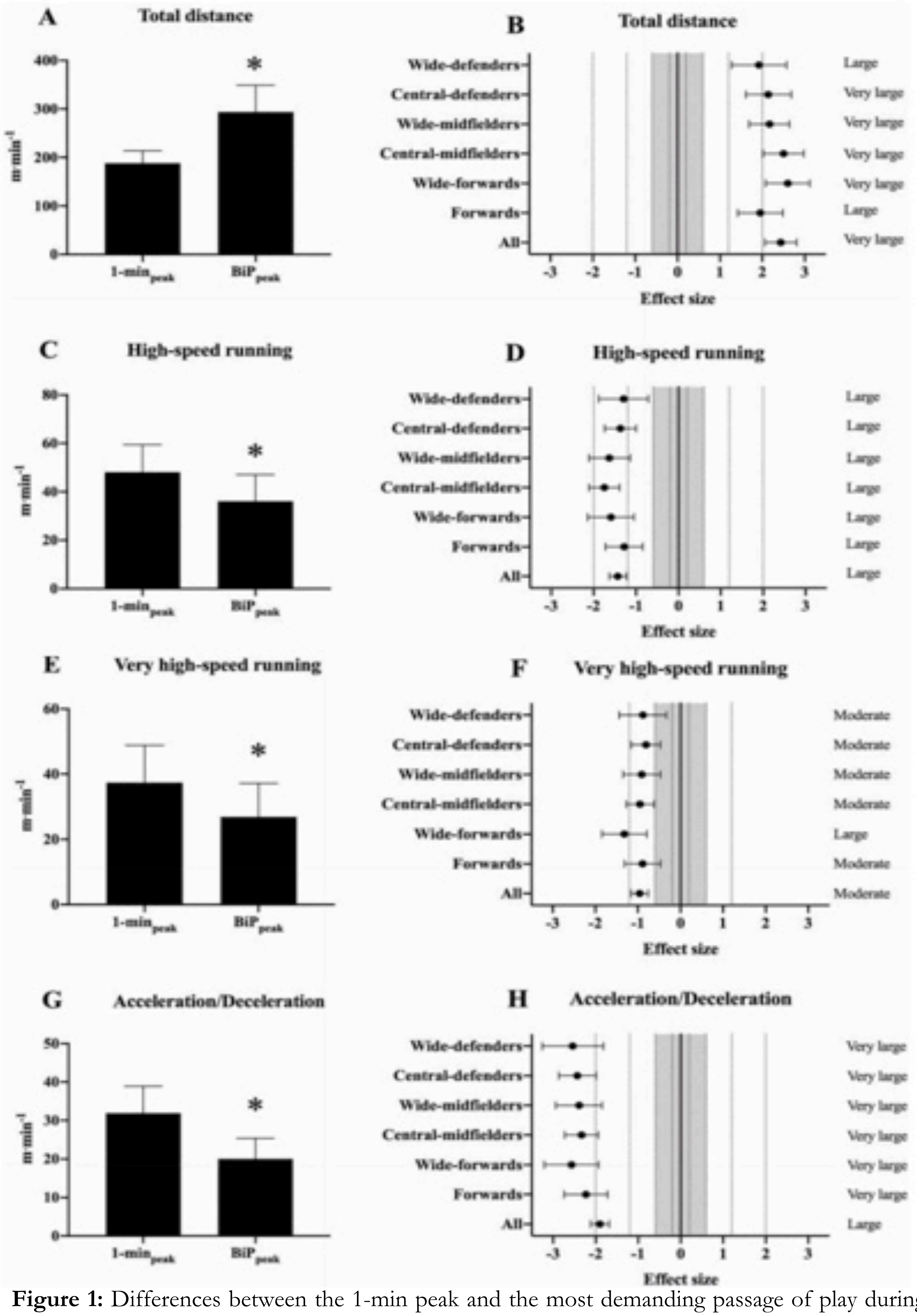

Figure 1: Differences between the 1-min peak and the most demanding passage of play during effective time with BiP (A, C, E, G) and effect sizes with 95% confidence intervals (B, D, F, H), taken from Riboli et al. (2021).

2.6 Research Objectives

The primary research objective of this study was to evaluate if SSGs can replicate the WCS that players experience during match-play, with the null hypothesis stating that there will be no difference between the WCS demands during match play, and the WCS demands during SSGs. There were three secondary research objectives, with the first being if playing position has any significant impact on the WCS demands in both match play and SSGs. The null hypothesis is there will be no positional differences in WCS demands in either match play or SSGs. Another secondary question, is does match outcome effect the WCS demands during match play? The null hypothesis states that match result does not have any impact on WCS demands during match play. The last of the secondary objectives entails evaluating SSG dimensions, and whether altering SSG dimensions impact the outcome of WCS demands? The null hypothesis would state that changing the pitch dimensions of SSGs will have no effect on the WCS outputs.

3. Methodology

3.1 Experimental Design

The study was a 9 month, season long observational study, whereby the locomotor outputs of worst-case scenario (WCS) in small-sided games (SSGs) were compared to the WCS during match-play, to evaluate the effectiveness of SSGs to prepare players for the WCS during match-play. The study was conducted between September 2020 and May 2021, during the professional development league 2020-2021 season (25 games). As per the club's current player monitoring procedures, all locomotor demands were obtained during both SSGs and match-play, using 10Hz Catapult GPS units (Vector, Catapult Innovations, Melbourne, Australia). Due to the observational nature of the study, the players training, and game schedules were not influenced by this study. Procedures were carried out in compliance with the clubs current training and match schedules.

3.2 Participants

27 Male professional football players from the same U23s squad (age (18.9 ± 2.5 years), height (180.4 ± 10.3cm), body mass (74.1 ± 9.2kg)) participated in the study. Ethical approval was provided by Swansea University Ethics Committee (Appendix 1: BG_21-10-20). The sample consisted of central defenders (CD), wide defenders (WD), central midfielders (CM), wide midfielders (WM) and forwards (F). All participants were deemed fit to perform by the clubs medical and conditioning staff, and therefore physically competent to cope with match-play and training demands. Players provided their informed consent to participate in the study, through a consent letter signed by the head of academy on behalf of the players (Appendix 1). Players followed the same diet as prepared by club caterers, and hydration was ensured through a urine sample taken prior to training each day.

3.3 Procedures

15 minutes prior to each data collection, each player's personally assigned a 10Hz GPS unit (Vector, Catapult Innovations, Melbourne, Australia) would be turned on, in order to establish the best possible connection with satellite, in order to ensure the highest reliability and validity of data collected. The GPS units were located in a pocket on a compression vest or playing shirt, that is located on the cervical segment of the spine, to ensure validity and reliability of GPS outputs. The thresholds were set as the clubs currently active settings (Sprint (SD) - >7m/s, High Speed Running (HSR) - >5.5-6.9m/s, Moderate speed running - >5-5.4m/s, low speed running – >4.17-4.9m/s) (Di Salvo et al., 2009).

Players would then partake in either match-play or SSGs and would then turn the GPS units off following training or games, to avoid any noise in data following activity. Following training, all collected data for each player was clipped using the clubs specific GPS software (Openfield version 1.22.0, Catapult Sports, Melbourne, Australia) on a secure laptop, by using a velocity graph as a reference for any noise in the data collection. This velocity graph allowed data collectors to see if any data was not collected accurately, of which that data set was not included in the final results. Following this, all locomotor outputs of each individual player (TD, HSR, SD, & intensity (m/min)), for training sessions and matches was exported into a raw excel file format, which obtained each reading at (sample rate of 10Hz) obtained during the recording period. To quantify values of the WCS, the raw GPS excel file for each match or SSG, for each player, was inserted into a bespoke computer software. This software, working at rolling epochs as suggested by Cunningham et al, (2020), used the raw data file provided by the GPS, to calculate peak outputs of TD for 300s epochs, and provided WCS parameters for every individual player who partook in that specific game/training session. HSR and SD values were also given by the bespoke software, but the recording threshold had to be set at 5.5 $m.s^{-1}$ for HSR values, and 7 $m.s^{-1}$ for SD values. Intensity values had to be obtained via the use of the clubs specific GPS software, by correlating the WCS time stamp with the GPS data.

3.4 GPS Units

All GPS units were sampled at 10Hz. The possibility of using 5Hz and 1Hz units was contemplated, but previous research indicates that a sample of 1Hz is too small to gain a reliable reading for COD movements, and also underestimates longer distance efforts (Gastin & Williams, 2010). 5Hz units, although a sufficient sample rate for total distance (Coutts & Duffield, 2010), faulters when measuring HSR and rapid COD (Rampinini et al., 2015). Therefore, due to the higher accuracies at a range of velocities (coefficient of variation (CV) = 3.1%) and instantaneous velocities (CV = 1.9%) (Varley et al., 2010), a 10Hz sample rate was utilised to ensure the greatest reliability and validity of outputs.

3.5 Games

There were 25 Premier League Development League games, that were recorded, that were completed over a season long period of 9 months, between 14th September 2020 and 3rd May 2021. To qualify for inclusion in final data, players were required to partake in ≥2 games, as well as the full 4-week period whereby SSG data was gathered. To be accounted for in each game, a player had to play a minimum of 60 minutes of match play, whether that be obtained as a substitute or as a member of the starting 11. Games took place at several different times throughout the season, with different kick off times, different venues, and at different parts of the year. These effects were not accounted for through the use of a linear mixed model, although It is acknowledged that these diurnal factors may effect match demands and match outcome, as stated by Russell et al. (2015).

3.6 Training Session Styles

Due to the observational factor of the study design, the club proceeded to stick to their current training periodisation method, across the 4-week data collection period, whereby sessions were classed into one of the following 4 categories: strength, resistance, speed, and match prep.

Strength (MD-4) – Strength sessions are typically high intensity, with short drill duration (10s – 3min, work: rest ratio of 1:1 – 1:3), and small player numbers (1v1 – 4v4 SSGs). These sessions and SSGs are designed to overload players with changes of direction, as well as a high number of accelerations and decelerations. The SSG dimensions for strength was 25m x 15m, to promote the physical demands mentioned above, thus making it the smallest SSG used in the study.
Resistance (MD-3) – Also high intensity, resistance sessions alter as the volume of work increases, alongside player number (7v7 – 11v11 LSGs), drill duration (5 mins – 12 mins, work: rest ratio of 1:0.25 – 1:0.5), and the whole pitch can be used as a playing area. The manipulation of these factors alters the demands of players, so HSR, total distance and sprints (frequency and distance) are increased during these sessions. In order to replicate match day values for sprint and HSR, the SSG dimensions for resistance days was 50m x 45m, based off of 187m^2/player, as suggested by Riboli et al (2022).
Speed (MD-2) – During speed sessions, the volume dramatically decreases, with drills focussing more on phases of play, using either whole halves or thirds of a full-sized pitch. Drill durations sit between strength and resistance sessions (3 mins – 6 mins, work: rest ratio of 1:0.5 – 1:1.5), and generally the main focus is on high frequency of accelerations and decelerations. SSG dimentions on a speed day were 40m x 35m, a reduction of 10m x 10m compared to a resistance session.
Match prep (MD-1) – Match prep consists of low intensity and low volume, with tactical instructions being the primary focus. Drill duration is typically 2 mins – 4 mins (work: rest ratio of 1:0.5 – 1:1.5), with the main focus being to preserve players for the match the day after. The dimensions for match prep SSGs was 35m x 25m, 10m x 10m smaller compared to the speed SSG.

All SSGs were a 6 vs 6 platform with goalkeepers, and in order to match with the match play WCS period, all SSGs lasted 300s (5 minutes). Per day, players partook in 3 SSGs each, with a rest period of 2.5 minutes between each game.

3.7 Statistical Analysis

All statistical analysis was performed using Jamovi software, whereby 95% confidence intervals were used for each linear mixed model ($P>0.05$). To test the main research objective, and test the hypothesis that WCS demands of match play will be greater than SSG WCS demands, the linear mixed model had a locomotor output as a dependant variable, game (SSG or match) as factors, and instance as a cluster variable. This was repeated 4 times, to obtain data for each tested parameter. To test the positional differences in WCS demands, a similar linear mixed model was run, where dependant variable still stayed as physical parameter, but factors were now position, rather than game. Instance was still a common cluster variable. To analyse match outcome, again a linear mixed model was used, but the factor was gain changed to match result, but no cluster variables were analysed. To evaluate differences in SSG dimensions, a final linear mixed model was run, with session type as the analysing factor, and instance was used as a cluster variable. All models were run at fixed effects. No power equation was utilised to calculate relative confidence intervals for the large sample size used, although the importance of using a power calculation when dealing with a large participation group is recognised.

4. Results

4.1 Match play WCS versus Small Sided Game WCS Analysis

Evaluating the whole team mean across all matches (Table 1), SSGs drastically underestimated the TD, HSR, SD and M/Min demands that players experienced during match play WCS (P<0.001). Supporting the findings of the whole team analysis, CB and FB had significantly greater WCS demands during match play for all physical parameters (P<0.001). Whilst also having significantly greater WCS outputs during match play for TD, HSR and SD (P<0.001), CM only had a significant difference in M/Min at a significance level of P<0.01. Both W and S had significantly greater WCS outputs for all physical parameters (P<0.001) (Table 4).

4.2 Inter-Positional Analysis

When investigating inter-positional differences in WCS demands, CB were used as the baseline comparison for all other positions. For match play, S had considerably greater outputs than CB in all variables (P<0.001). W and CM also had increased demands of TD and intensity (M/Min) (P<0.001), compared to CB, with FB having greater demands in the same parameters (P<0.01). For SSGs, no significant differences between positions for any parameter was found, meaning playing position did not have a significant impact in the WCS demands during SSGs. For peak matchday WCS values, S recorded peak mean outputs for HSR (133.6 ± 13.5m) (Figure 1A), SD (57.6 ± 3.7m) (Figure 1C), and intensity (134.6 ± 3.4m/min) (Figure 1D), and W recorded peak mean TD (655.1 ± 24.3m) (Figure 1A). CM recorded peak SSG mean values for TD (532.9 ± 42.9m) and intensity (106.6 ± 8.6m/min), with W recording peak mean SD (2.4 ± 4.8m), and S recording peak mean HSR (18.4 ± 11.0m) respectively. The findings of the inter positional analysis suggests that S produce higher frequency of high intensity bouts (>5.5 m/s) during their WCS, with W producing the highest frequency of low intensity actions (<5.5 m/s), during the WCS.

4.3 Effect of Match Result on WCS

For WCS TD outputs (Figure 2A), CB, FB, CM and W all had slightly higher mean values during games that were drawn, but with no significant difference found compared to Wins or Losses. CM had the greatest mean TD output for wins (659 ± 20.8m), FB for draws (703 ± 35.8m), and S for losses (678± 22.2m). Highest mean HSR outputs (Figure 2B) were obtained in draws for CB, CM and S, but in wins for both FB and W. S obtained peak mean values in all result outcomes (Win: 150 ± 19.2m, Draw: 153.4 ± 21.2m, Loss: 112.5 ± 15.9m). Peak mean SD outputs (Figure 2C) were obtained in wins for CB, FB, and W, but again in draws for CM and S. S again obtained the highest SD values for all result possibilities (Win: 58.5 ± 7.5m, Draw: 59.9 ± 8.3m, Loss: 54.3 ±

6.2m). An outcome of a draw resulted in highest M/Min (Figure 2D) for CB, FB, CM, and W, but in losses for S, of which recorded peak SD when games resulted in a loss (136 ± 4.1m/min). For a draw, FB obtained the highest intensity (140 ± 6.7m/min), with CM achieving highest intensity values during wins (132 ± 3.9m/min). There were no significant differences found between game outcomes, for any physical parameter.

4.4 Tactical Periodisation effect on WCS Outputs

Figure 3 shows the impact of session theme on the outputs of WCS during SSGs. Resistance SSGs had higher mean TD and HSR values compared to any other theme (TD: 550 ± 33.6m, HSR: 19.7 ± 5.9m), which is expected, considering resistance days are utilised to condition players at low intensities whilst collating high locomotor outputs. Despite strength themed days designed to mitigate high intensities in short bouts, Resistance days also recorded the highest WCS intensity during SSGs (110 ± 6.7 m/min).

Table 5: Comparison of significant differences between SSG WCS vs. Match Day WCS for whole team, centre backs (CB), full-backs (FB), central midfielders (CM), wingers (W) and strikers (S).

	Team		CB		FB		CM		W		S	
Parameter	Match	SSG	Match	SSG	Match	SSG	Match	SSG	Match	SSG	Match	SSG
TD (M)	630.5 ± 53.0†	502.2 ± 48.8†	601.4 ± 63.3†	477.2 ± 27.0†	623.6 ± 43.7†	521.8 ± 35.9†	645.9 ± 57.5†	532.9 ± 42.9†	655.1 ± 24.3†	496.2 ± 40.6†	653.2 ± 11.4†	442.5 ±110.2†
HSR (M)	89.3 ± 27.5†	14.7 ± 7.9†	78.3 ± 25.8†	13.2 ± 8.4†	87.1 ± 19.8†	12.7 ± 9.4†	88.1 ± 33.8†	15.4 ± 8.4†	94.0 ± 9.3†	16.9 ± 5.4†	133.6 ± 13.5†	18.4 ± 11.0†
SD (M)	29.5 ± 12.2†	0.9 ± 2.2†	25.4 ± 7.1†	0.4 ± 1.0†	23.0 ± 5.4†	1.0 ± 2.2†	30.5 ± 13.6†	0.7 ± 1.6†	29.6 ± 7.0†	2.4 ± 4.8†	57.6 ± 3.7†	0.0 ± 0.0†
Intensity (M/MIN)	126.6 ± 10.5†	100.4 ± 9.8†	120.9 ± 12.1†	95.4 ± 5.4†	124.7 ± 8.7†	104.4 ± 7.2†	129.2 ± 11.5*	106.6 ± 8.6*	131.0 ± 4.9†	99.2 ± 8.1†	134.6 ± 3.4†	88.5 ± 22.0†

* - P < 0.01
† - P < 0.001
(All data displayed as Mean ± SD)

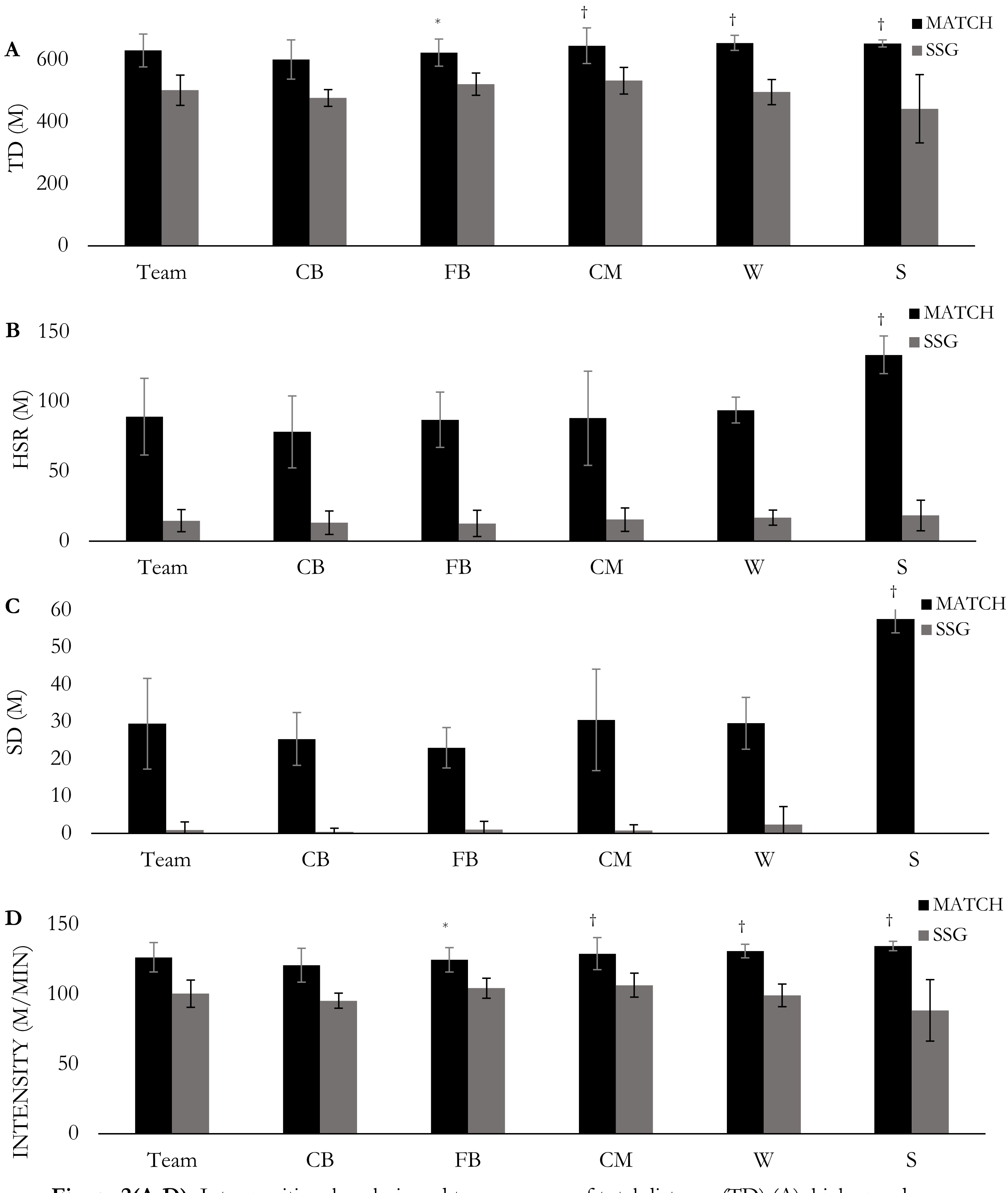

Figure 2(A-D): Inter-positional analysis and team average of total distance (TD) (A), high-speed running distance (HSR) (B), sprint distance (SD) (C), and meters per minute (M/MIN) (D).
(* - P<0.01, † - P<0.001)

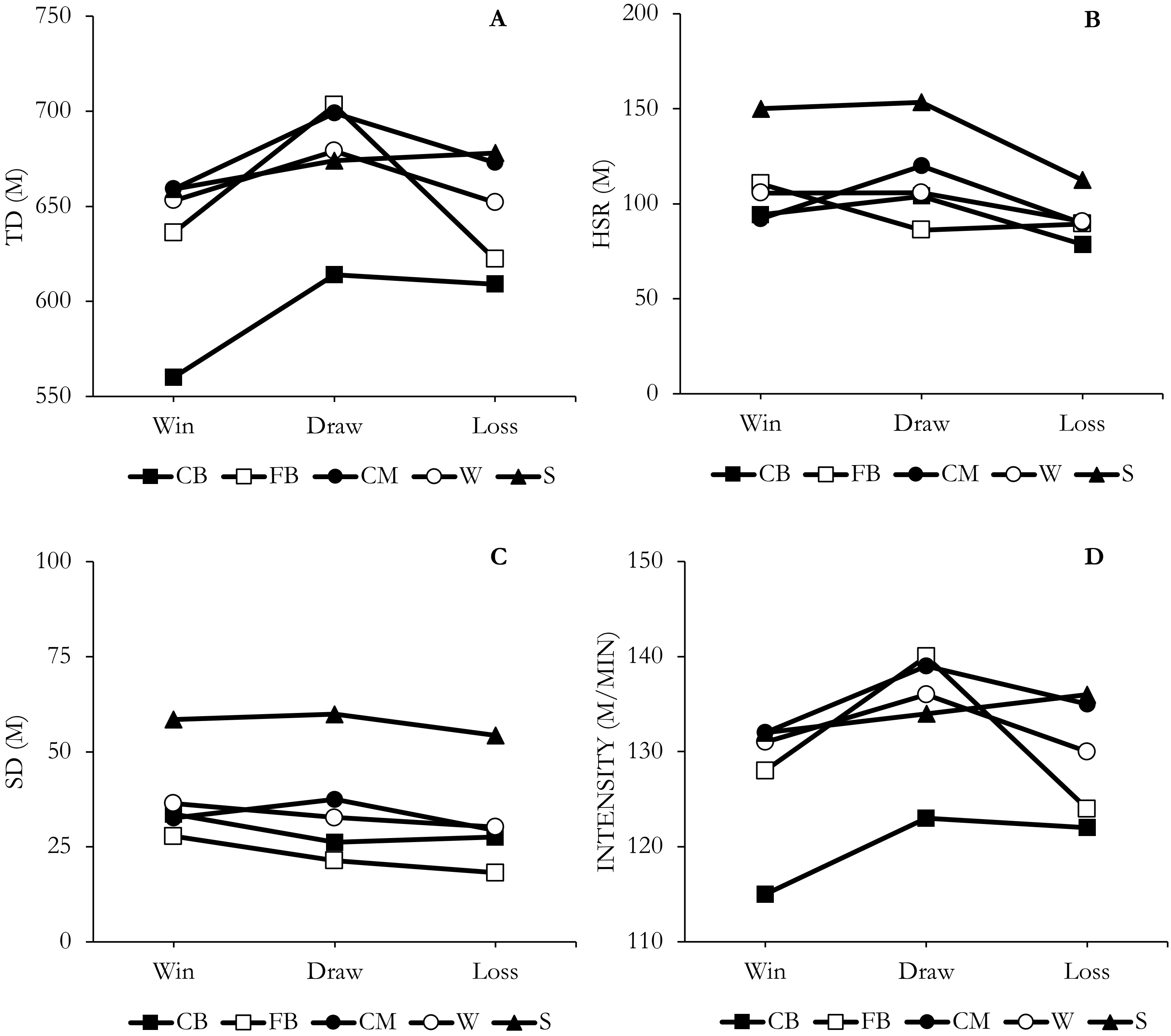

Figure 3(A-D): The impact of match result on position specific WCS for total distance (TD) (A), high-speed running distance (HSR) (B), sprint distance (SD) (C), and meters per minute (M/MIN) (D).

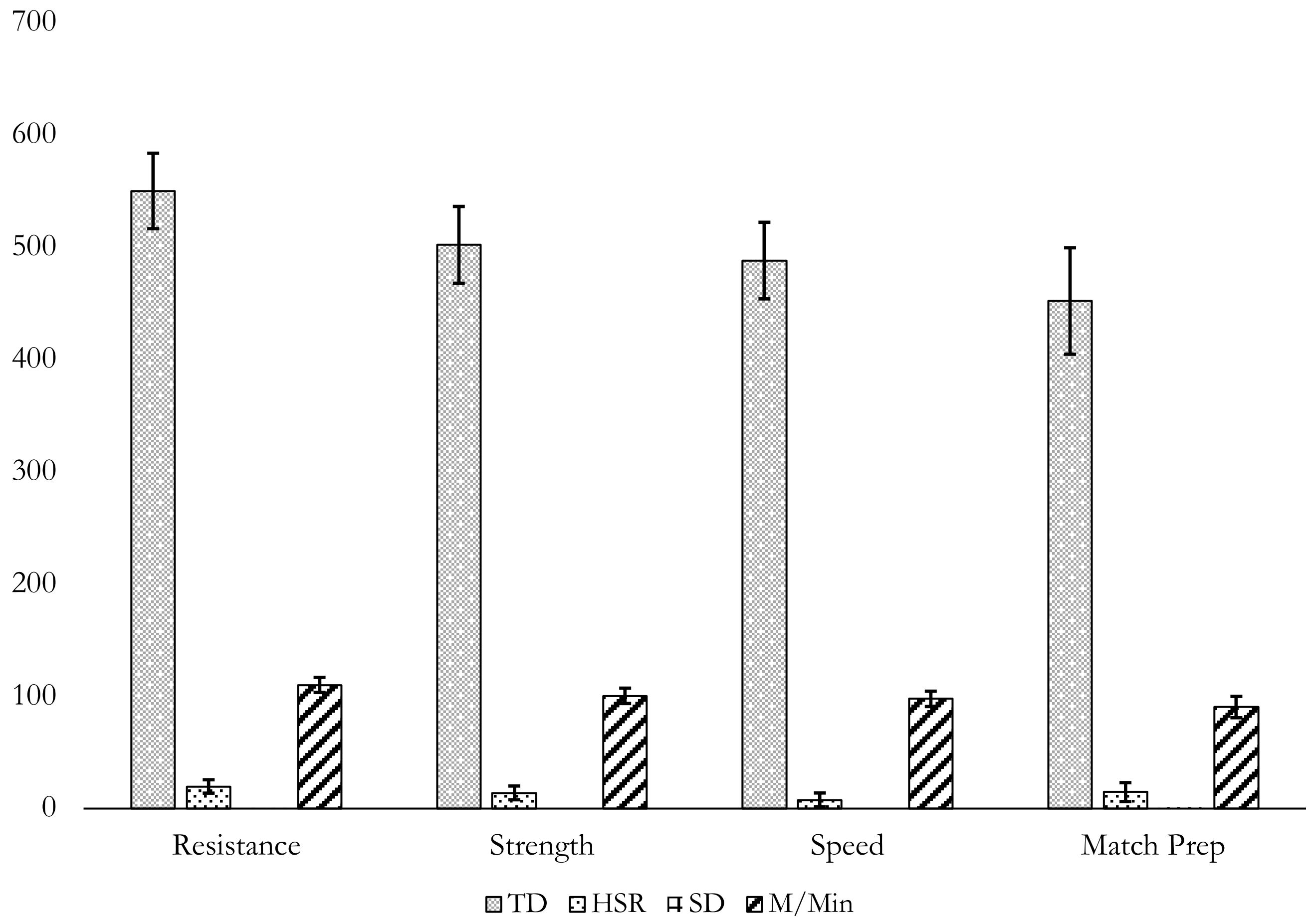

Figure 4: Visual representation of the effect of tactical periodisation theme on small-sided game worst case scenario outputs for Total Distance (TD), High Speed Running (HSR), Sprint Distance (SD), & Intensity (M/Min)).

5. Discussion

The primary aim of this study was to compare the Worst Case Scenario (WCS) locomotor demands of professional football players during match play, to the WCS demands of Small Sided Games (SSGs) during training, using 10Hz GPS units. In order to evaluate the effectiveness of utilising SSGs as a form of integrated conditioning, to prepare players for match day WCS demands. A secondary aim of the study was to evaluate and compare the difference of WCS demands between different outfield playing positions, as well as the impact of match result on these demands. When comparing the WCS demands for match play against SSGs, SSG WCS drastically underestimated the locomotor outputs for total distance (TD), High speed running (HSR), sprint distance (SD) and intensity (M/Min) (Table 1) for both mean team values, and all positions. Using Centre back (CB) as baseline values (Tierney et al., 2016; Delaney et al., 2018), this study reported that during match play WCS, Strikers (S), Wingers (W), Centre midfielders (CM) and Full backs (FB) all had higher demands of TD and intensity, with S also having significantly greater demands of HSR and SD. Findings also show that CB have the lowest physical demands, supported by Abbott, et al (2018), whereas S have the highest demands during the WCS.

This study was the first to report findings and contrasts of match play WCS demands and compare them to WCS demands of SSGs in training. This present study found that SSG WCS demands were significantly lower to the demands needed during match play WCS. When looking at TD and intensity values, the area per player value of 187m^2/player used was adequate in order to imitate match play WCS demands of TD and intensity. However, the opposite can be said for SD and HSR, where a potential explanation for this, may be despite previous research stating that 187m^2/player is sufficient to reach the velocity thresholds required to record HSR and SD, players need a larger playing area in order to reach those higher velocities. Despite there being a lack of research into WCS demands of SSGs, Riboli et al (2022) investigated different playing area per player in SSGs to try and gain peak 4-min demands that replicated 90min match averages. They found a positive correlation between the increase of playing area per player in SSGs, and the peak 4-min locomotor demands more closely replicating that of a 90-min average. This present study further analysed SSG demands, by looking into differences in positional demands, as well as difference in specific training theme demands in correlation with the physical periodisation model utilised by the club (Hicks et al., 2019). There was no significant difference in WCS demands of SSGs across all positions, as well as a no significance found in demands across all four training themes utilised in the study (Resistance, Strength, Speed, & Match prep). The potential reason behind this, is due to the resistance SSG, although designed to promote higher velocities of movement, did not produce demands high enough to replicate match play values, thus having a further impact and less differentiation between each SSG. It was unexpected that the strength day

SSG did not promote a higher intensity value compared to the other SSGs, but this could be potentially down to the team size just being too large for such a small area, and whether in or out of possession, players cannot collate any reasonable distance. Dellal et al (2012) supports findings that there is no significant difference in position specific running demands in SSGs but did find that putting a technical condition on the game (1 touch or 2 touches maximum) did significantly increase intensities across all positions, compared to ordinary free play. However, it must be noted that due to the 'free flowing' nature of SSGs, it is very common that players do not play in their regular playing position, but often end up in areas on the pitch where in match-play they would not be present in, like a CB ending up playing as a S for example (Clemente et al., 2021). This would result in positional SSG outputs being unreliable and not representative of players sticking to their usual playing position. These findings were expected, and supported by previous research (Clemente et al., 2021, Dellal et al., 2012, & Pinheiro et al., 2022), players often did not stick to their full match playing position, due to the free flowing nature of SSGs, which would cause results to become more generalised. The implementation of goalkeepers was an attempt to promote a more structured feel to the games, but didn't have the desired impact. When investigating the lack of significance in training theme, Owen et al (2017) provides a key example of how physical periodisation can be implemented correctly in football, in order to ensure players are able to perform to their peak physical potential on match day, with reduced risk of injury. The study shows that players peak physically during the week on a resistance themed day (MD-4), and then taper down towards a match prep (MD-1), before spiking in physical loading again on a match day. In this present study, although there is a gradual taper towards MD-1, there is no significant differences in WCS outputs throughout the week, thus questioning the validity and application of the physical periodisation model used. This reiterates the point of the importance of session design, on insuring players get the correct conditioning on the correct day, in order to reduce risk of injury and achieve maximum performance levels come match day. Utilising live GPS data tracking is one method practitioners can use to integrate WCS conditioning into training sessions and guarantee players are training to intensities that mirror what training theme that coaches are aiming for.

The fact that all SSGs utilised in this study underestimated the WCS of match play does question the relevance of SSGs when attempting to reproduce the same WCS demands as a match day. As discussed above, this is possibly due to the specific SSG dimensions used in this study, of which we observed fail to replicate the WCS demands. There is however a various number of ways SSGs can be manipulated that weren't investigated in this study, such as game duration, team size, as well as different inhibition rules you may place on the game (touch limit, additional free players, etc). I believe that there is still more research that needs to be done on SSGs ability to replicate the WCS demands of match play before coaches eliminate them as a form of practice, especially as they offer so much in relation to technical repetition and game relativity (Jeffreys., 2004).

This study further investigated the positional differences in match play WCS demands, whereby W were found to have the greatest WCS TD demands (655.1 ± 24.3m), whereas S had the greatest WCS demand for HSR (133.6 ± 13.5m), SD (57.6 ± 3.7m) and intensity (134.6 ± 3.4m/min). Olivia-Lozano, et al (2020) studied WCS at different epoch lengths, and found contrasting findings for an epoch length of 5 mins, whereby CM had greatest WCS demands for TD, and W had significantly greater WCS demands for HSR and SD. Another study conducted by Fereday, et al (2020) supports the findings of Olivia-Lozano, et al (2020), in that he found midfielders had the greatest WCS demand for TD but found that midfielders also had highest HSR values. However, Fereday, et al (2020) categorised positions into three distinct blocks of defenders, midfielders, and attackers, whereas this study and other studies have analysed positional differences as split individual positions. This results in CB and FB, as well as CM and W raw running values being combined, therefor the data for a 5 min epoch can under or overestimate demands for certain positions. Akenhead, et al (2014), investigated full game positional demands, in which he found that S and W obtain the highest number of repeated bouts of high intensity exercise (both HSR and SD). This highlights a limitation of the current study, whereby we were unable to quantify and analyse the frequency of high intensity bouts and calculate frequency of accelerations and decelerations during the WCS. Chmura, et al (2018) found supporting findings, that S and W achieve higher frequency of high intensity movements, compared to all other positions. All studies however found that CB have the lowest WCS demands for all parameters investigated, with further studies also presenting the same findings (Aquino et al., 2018; Curtis et al., 2018). Although Curtis et al (2018) undertook their study on collegiate athletes rather than professionals, the same theme of positional locomotor demands applies. Differences in positional findings could be down to several reasons. One potential factor is the specific positional roles each team may have for each position, for example, the team used in this study play with a high press, thus leading to S and W having a greater WCS demand for SD and HSR (Carling et., 2008). A team who plays a more reserved style of play may result in CM having greater WCS demands, with S being allowed to recover when their team is defending. However, it must always be noted that due to the random nature of football match play, different in game scenarios, such as making out of position recovery runs to cover for teammates, will always be present during match play, that will always negatively impact the credibility of their position specific demands (Fereday et al., 2020). The main implication of these findings is that WCS demands in football are dependent on playing position, which should be accounted for when creating training programmes for players, ensuring target locomotor values are relative to their playing position.

Alongside the analysis of WCS positional differences, this study also investigated the impact of match outcome on WCS locomotor demands. For a 5-minute epoch length, previous research supports the finding that match result has no significant impact on team average and position specific WCS demands. Playing formation and tactical setup may have caused this lack of difference in demands based on match outcome. As a team, the players are encouraged to play with a high press against all opposition, whether winning or losing a game. When in possession, the teams tactical setup is to maintain possession and play regularly with wide players, causing a generalisation of WCS demands, explaining why players had similar WCS outputs in all three potential match outcomes. In further literature however, there is a diversity in findings of match outcome on running demands. Fereday et al (2020) found that TD and HSR demands were significantly higher in matches that ended in a win. Supporting these findings, Olivia-Lozano et al (2020) found that when epoch length of WCS is shorter (1-min and 3-min), WCS demands are significantly greater in wins, compared to draws and losses, but did not however find any significant differences when epoch length was 5-min like this present study. Supporting the findings of this current study, Rumpf et al (2017) found no significant difference in locomotor demands between all possible match outcomes, but this study was undertaken on international tournament football, which arguably may entail higher intensities than normal professional match play. Certain studies have also found differences in position specific locomotor demands, relative to match outcome. Chmura et al (2018) found that demands of SD and HSR were higher for S and W during wins, but were contrastingly higher in losses for CM, FB, and CB, supported by Andrzejeweski et al (2016), who found that CB and FB had significantly lower demands of high intensity exercise in wins compared to losses.

Although this study does well to quantify the most intense period experienced during match play, the WCS still doesn't truly represent the intermittent nature of football match play, whether that be at 60s, 300s or 600s epochs. With the WCS concept being based upon the most intense periods of a game, using WCS as a focal point of training programmes may not be an ideal method to design around, based on the risk of over training athletes and players not being fully recovered in time for match day. There are however current limitations for how WCS can be measured, for example, there is no current research into the physiological effects of the WCS, and the body's physical adaptations following those most intense periods, and although difficult, an insight into the metabolic and physiological adaptations during and following WCS will provide a more rounded understanding of this concept. This study was also only limited to external and linear movement patterns, whereas football is often labelled as a multidirectional sport (Bangsbo., 2014). Further research into the multidirectional nature of football match play and how that alters during the WCS will again further the understanding around the WCS.

This study was the first to report WCS demands of both match play and SSGs in men's football and evaluate how SSG WCS demands change throughout a physical periodisation model, aiming to fully prepare players for WCS demands during match-play. However, one main downfall of this study, is that frequency of high intensity bouts such as acceleration/deceleration, change of direction, and number of sprint actions were unable to be analysed, due to the bespoke WCS software used not allowing for frequency of actions to be analysed. These actions should be considered, as they are all metabolically demanding movements, which often lead to key in-game moments such as transition periods and goals (Faude, Koch, & Meyer., 2012), and leads to quicker fatigue in players (Alghannam, 2012). To further develop the analysis of metabolic demanding bouts, no physiological markers were obtained for the WCS. Obtaining blood lactate samples or even heart rate values pre, during and post WCS would give an indicator of internal loading that players experience during the WCS, rather than just external outputs to evaluate, to further establish the holistic approach in understanding WCS. Dellal et al (2012) found that blood lactate was significantly lower in SSGs compared to full 11v11 match-play, further supporting the differences in intensity between match-play WCS and SSG WCS. Riboli et al (2022) investigated the effect of SSGs with and without goalkeepers, which highlights one limitation that the present study has is that all SSGs had goalkeepers present in SSGs, thus decreasing area per player, potentially leading to a decrease in the WCS demands of the SSGs, further resulting in the severity of the underestimation of match play WCS demands. Furthermore, other studies have further investigated the effects of uncontrollable co-variates, such as time of day (Fereday et al, 2020), home vs away matches (Diez et al, 2021), and the impact of playing formation (Bradley et al, 2011) on locomotor demands. Further research could look to implement all of these extraneous variables and explore their impact on WCS specifically. As noted in the methodology, a number of participants in this study were youth players (>18 years) playing for the professional U23s team. Similar to Abbott et al (2018) future research could investigate the WCS in youth elite football and compare findings to the WCS of men's professional football, in order to assess whether youth players are physically capable of competing in men's football, should they be required to train and play in matches against older and more physically developed athletes. Additionally, the large majority of WCS research in football focusses on the physical demands of the WCS, but many studies fail to account for the frequency and importance of technical actions in match-play, first highlighted by Rampinini et al (2009). Therefore, quantifying and analysing the number of technical actions during WCS could be a focus area of further research, potentially identifying possible correlations in physical output and frequency of technical actions. Finally, despite this study heavily investigating WCS in SSGs, further research could look to examine the implementation and application of using WCS as a conditioning tool for coaches, to ensure players are fully prepared for the WCS on match day.

5.1 Conclusion

This study compared the locomotor demands of the WCS during match play, in comparison to SSG WCS during training sessions. SSG WCS was found to drastically underestimate the demands that players will experience during WCS on a match day, regardless of playing position or final match outcome. The findings obtained during this study should allow practitioners to alter their current training methods to include physical preparation for the WCS on match day, with an emphasis on aiming to replicate the intensity and parameters found in match play, during training sessions.

5.2 Practical Implications

- If a physical periodisation model is to be used, SSG design is crucial to ensure that all conditioning is integrated, so target distances are obtained during football specific drills, rather than isolated running. A combination of SSGs and top-up running drills can be a way to ensure players stay conditioned by hitting target distances.
- Dependant on playing position, match play WCS indicators can range from 120.9m/min 134.6m/min, for markers of peak match intensity.
- If WCS preparation is to be implemented into training programmes, target locomotor outputs must be modified and moderated live for each player, in order to account for differences in positional demands and to avoid de-conditioning for certain positions.

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7. Appendices

7.1 Letter of Support and Consent for Player Participation

Letter of Support and Consent

William Gill – Sports Science MSc by Research Study:
'Investigating the Locomotor Demands of Soccer Players.'

This is a letter of support from the Swansea City AFC Academy (SCFCA) for the research being conducted by William Gill under a Masters study through Swansea University into the locomotor demands of soccer players during a 'worst case scenario', and how small sided games can be developed to prepare players for these demands.

The study will be supported by SCFCA by the following:

1. The researcher will have access to data from certain SCFCA players who will be fully briefed on the study and participate as required.
2. The researcher will use the findings to fulfil the requirements of his MSc Research Paper.
3. The researcher may publish peer-reviewed articles from the research if required.

This will be done under the following conditions:

1. The confidentiality and anonymity of the participants is maintained throughout.
2. The data is owned by the SCFCA, and Swansea University.

It is expected that the SCFCA will be given the opportunity to view and comment on any outputs from the research (e.g., final research articles) prior to them being sent for publication to ensure that the SCFCA is content that the SCFCA is not implicated in any way.

In light of the information given, I consent to the research being conducted.

Yours Sincerely,

Nigel Rees

Academy Manager – Swansea City AFC Academy

Signature ....