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An Analysis of External Load on Different Pitch Surfaces in Scottish Professional Football: Using Global Positioning System to Analyse Match Play and Training

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Abstract

Aim: To investigate the external loads experienced during match play and training, on grass and artificial turf

Hypothesis: No differences will exist between grass and artificial turf, in both training and match play.

Methods: Using Global Positioning System (GPS), Distance covered ($m.min^{-1}$), Player Load ($AU.min^{-1}$) and High Speed Running ($m.min^{-1}$) were recorded during match play and training (Small-sided games (SSGs)) from two teams in the Scottish Professional Football League. SSGs on the same surface were compared together, before SSGs of similar playing area were analysed across surfaces. This created a "small SSG" (grass 4v4 vs AT 5v5, 7v7 & 8v8) and a "large SSG" (Grass 9v9 vs AT 9v9, 10v10 & 11v11) comparison.

Results: During match play, no differences were shown in any of the three metrics (***Distance Covered*** - 111.46±11.78$m.min^{-1}$ vs 110.99±10.55 $m.min^{-1}$ vs 112±13.48 $m.min^{-1}$ ($p=0.922$), ***HSR*** – 10.13±3.42$m.min^{-1}$ vs 10.21±3.13 $m.min^{-1}$ vs 12.14±4.18 $m.min^{-1}$ ($p=0.076$), ***Player Load*** – 10.2±1.36$AU.min^{-1}$ vs 10.42±1.5$AU.min^{-1}$ vs 11.2±1.26$AU.min^{-1}$ ($p=0.391$). (Grass vs AT_{Home} vs AT_{Away}) Data = mean±95% CI). On Grass (4v4 vs 9v9), significant differences were observed for HSR only between SSGs, (***Distance Covered*** – 107.62±4.15$m.min^{-1}$ vs 111.47±5.61$m.min^{-1}$ ($p=0.277$), ***HSR*** – 7.54±246$m.min^{-1}$ vs 8.875±1.521$m.min^{-1}$ ($p=0.002$), ***Player Load*** – 11.48±0.548$AU.min^{-1}$ vs 11.313±0.739$AU.min^{-1}$ ($p=0.72$)). On AT, p values of <0.005 were obtained for all three metrics (5v5 vs 7v7 vs 8v8 vs 9v9 vs 10v10 vs 11v11). ***Distance Covered*** – 104.37±14.93$m.min^{-1}$ vs 104.77±7.29$m.min^{-1}$ vs 95.32±17.23$m.min^{-1}$ vs 94.63±14.6$m.min^{-1}$ vs 109.31±17.14$m.min^{-1}$ vs 108.74±3.64$m.min^{-1}$, ***HSR*** – 3.54±2.97$m.min^{-1}$ vs 5.57±2.18$m.min^{-1}$ vs 2.63±2.59$m.min^{-1}$ vs 2.52±2.23$m.min^{-1}$ vs 5.85±3.8$m.min^{-1}$ vs 8.76±4.92$m.min^{-1}$, ***Player Load*** – 11.57±2.12$AU.min^{-1}$ vs 9.995±0.89$AU.min^{-1}$ vs

10.158±2.17AU.min^{-1} vs 10.21±1.95AU.min^{-1} vs 11.27±2.52AU.min^{-1} vs 10.43±2.05AU.min^{-1}. In the “small SSG” comparison, grass 4v4 was different from the AT 8v8 on all metrics ($p<0.005$). In the “large SSG” comparison, the grass 9v9 was different from the AT 9v9 on all metrics ($p<0.005$).

Conclusions: Differences in external load across grass and AT are found in training between some SSG variations of similar playing area, but not in match play.

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Author's Declaration

I declare that, except where explicit reference is made to the contribution of others, that this dissertation is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.

Introduction

1.1 Association Football

1.1.1 Rules

Association football has a uniform set of rules by which the game is played across the world, formally known as “The Laws of The Game”. These laws apply to football in all its forms governed by FIFA, the world governing body of the sport. These laws have been adapted continually across the years as the sport has evolved, being maintained by an organisation known as the IFAB (International Football Association Board) since 1886.

Football is played on a rectangular pitch, made of wholly natural, wholly artificial and when competition rules permit, a hybrid surface comprised of both artificial and natural grass. Artificial surfaces must meet the requirements set out by the FIFA Quality Programme for Football Turf or the International Match Standard (*LOTG, FIFA)*. The pitch, divided into two halves, has dimensions of 90-120m long and 45-90m wide with four boundary lines - a goal line at each end and a touch line at either side.

The game is played between two teams of eleven players, ten outfielders and a goalkeeper. Only the goalkeeper is permitted to use their hands to play the ball. A game lasts ninety minutes, split into two forty-five-minute halves. The aim of the game is to score into your opponent’s goal, with the team scoring the most goals winning. In the event of teams scoring the same number of goals the game will finish as a draw (unless competition rules dictate otherwise). Substitutions can be made at any time during the game when play is stopped, with competition rules dictating how many can be made ranging from three to twelve. Substituted players may not re-enter the field of play as a player.

The Laws of the game are enforced by a referee who controls the game in cooperation with two assistant referees. Other additional officials may be present in certain levels of the game, such as a Fourth Official and Additional Assistant Referees. Depending on the type of offence committed referees can award free kicks, direct or indirect, or penalty kick if they occur within the penalty area. Sanctions that can be issue on the field are yellow cards and red cards depending on the seriousness of the offence. Receiving two yellow cards results in a player being shown a red card, which results in that player being removed from the field of play. The same applies to a player who receives a straight red card.

1.2 Physiology of Association Football

1.2.1 Association Football

Football is best described as a "high intensity intermittent" sport involving 150-250 short bursts of intense activity per game, interspersed with longer periods of walking or slow jogging (Bangsbo et al., 2006; Bangsbo., 2014; Mohr et al., 2003; Bush et al., 2015; Barnes et al., 2014). The game is chaotic in nature with lots of multidirectional movement, accelerations and decelerations which are often reactive and unpredictable (Bush et al., 2015). The game also requires the ability to carry out repeated skill-related actions such as kicking, jumping, tackling and passing throughout the 90 minutes of play.

1.2.2 Energy Systems

Davis et al. (1992) found that professional footballers in England had VO_2Max values of 56-61ml.kg.min^{-1}, varying with position, with other studies have showing that footballers operate at approximately 70% of their VO_2Max during matches. This is based on measures of heart rate and body temperature taken during matches (Bangsbo et al., 2006), indicative of a high aerobic contribution. This is also shown with the increasing levels of free fatty acids in the bloodstream throughout a match, likely a compensatory mechanism for decreasing glycogen stores.

Bangsbo has also found that there are up to 250 short, intense actions performed by players throughout a ninety-minute match, highlighting the importance of immediate fuel sources such as Creatine-phosphate (PCr). When depleted, the body will turn to glycolysis to meet the energy requirements with muscle glycogen being the important substrate. During the longer bouts of low intensity activity performed the body will be continually replenishing the PCr stores which are being quickly depleted during the high-intensity activity. This again highlights the requirement for a high aerobic capacity (Bangsbo et al., 2006; Krustrup et al., 2006).

1.2.3 Distance Covered

On average players typically cover between 9-12.5km during match play, with over 70% of this being low intensity activity such as standing, walking or slow jogging (Bangsbo et al., 2006; Bush et al., 2015; Di Salvo et al., 2007; Barnes et al., 2014), with Barros et al. (2007) obtaining values as low as 8km for some positions (Central defenders and Forwards). Central midfielders (CM) cover the greatest distance shown to be around 10.5-12.5km (Di Salvo et al., 2007; Barros et al., 2007). This is likely due to their requirement to be close to play wherever the ball is on the pitch. Full backs or “external defenders” (FB) along with forwards (FOR) and wide midfielders (WM) have been shown to cover slightly less than CMs, with some studies showing them to be equal to CMs (Barros et al., 2007). Central defenders (CD) cover the least distances – approximately 9-10.5km. Bush et al. (2015) found that players only cover 100-300m with the ball, less than 3% of the distance the players cover. A long-term study by Barnes et al. (2014) conducted in the English Premier League, has shown that from 2006-2013 the total distance covered by players has only increased by approximately 2% on the whole.

Distance covered (km) has become a key measure of external load within the literature across multiple sports. As stated previously, football players will generally cover total distances of 10-13 kilometres (Bangsbo et al., 2006; Bush et al., 2015; Di Salvo et al, 2007) depending on position played, tactics and the level being played at. Within SSGs, distance covered will be dependent on several factors. Variables such as team size, pitch dimensions, game objectives and, most importantly, game duration will all play a part in determining the distance each player will cover.

Distance has been shown to be an important external load measure with regards to injury risk in team sports. Work by Colby et al. (2014) indicated that higher 3-weekly total distances were associated with an increased risk of non-contact injury in Australian Rules Footballers. Comparable results have now been established in elite rugby (Hulin et al, 2015) and association football (Ehrmann et al, 2015). It has also been shown to be a key metric when considering the acute:chronic workload ratio established by Tim Gabbett (Hulin et al, 2015). This study found that distance, as measured using GPS systems, can be used within this model to help predict injury risk in elite rugby players. Any “spikes” in a player’s weekly total distance would increase a player’s risk of injury, the extend determined by the “chronic” workload i.e. the rolling average of the previous four weeks. Bowen et al. (2017) backed up these findings in football, finding that 4-weekly total distances of approximately 112 000–144000m put players at high risk of a non-contact injury whilst a weekly distance of less than 9000m significantly reduced the risk.

1.2.4 High Speed Running & Sprinting

Bush et al. (2015) found that 7-12% of distance covered was done at high intensity with 1-4% covered sprinting with Di Salvo stating such efforts are usually 10-33m each. Barnes et al. (2014) showed that in the English Premier League, players covered approximately 900m at high intensity in 2006-07 compared with approximately 1150m in the 2012-13 season. Bush et al. (2015) have showed that CMs, FBs and WMs cover the greatest distances at higher speeds, reinforced by Di Salvo who noted that the same positions with the addition of FOR all carry out the greatest number of high-intensity actions, including accelerations and decelerations. This is most likely because these players are most directly involved in attacking phases of play which are likely to lead to opportunities to score.

High speed running distance can be classified as the distance covered when running above a set speed threshold. This has become a widely used metric within the literature in time-motion analysis studies and those investigating training load. Recent literature has seen various sports covered in the research into HSR, with Rugby (Hulin et al., 2015; Windt et al., 2017), Hockey (Lythe & Kilding., 2011), Australian Rules Football (Coutts et al., 2010; Duhig et al., 2016; Ruddy et al., 2016) and Association Football (Bowen et al., 2016; Bradley et al., 2009; Gregson et al., 2010; Malone et al., 2017) included. HSR is a key determinant of success in football, being a crucial part of important moments in a match such as attempting to beat defenders with the ball, attacking towards the opponent's goal and attempting to regain possession. HSR has also been identified as a key factor in non-contact muscle injuries, more specifically in the hamstrings, making it an important metric for consideration in this thesis.

HSR has been shown to be closely related to increase risk of non-contact injuries in sport (Bowen et al., 2016; Duhig et al., 2016; Windt et al., 2017), with a specific risk to the hamstrings. Within a match, footballers have been shown to carry out approximately 600-1200m of HSR depending on the position played, with central defenders covering the least distance and wide midfielders covering the greatest (Gregson et al., 2010; Di Salvo et al., 2009). In order to prepare players for these demands there must be a level of exposure so HSR within training, but the is accompanied with the risk of injury. Brukner, citing the work of Askling et al. (2007), has stated that during high-speed running it is far more likely that hamstring strains will most likely involve the biceps femoris long head. This is as opposed to the semimembranosus which is most commonly injured during acts such as kicking and lunging which involve “excessive lengthening”.

Using the acute:chronic workload ratio, it has been shown that the risk of incurring a non-contact injury is significantly greater when a footballer is exposed to a high “acute” HSR load combined with a low “chronic” HSR. This is not the case when a player has a high “chronic” workload. Low “chronic” HSR was found to have left the players underprepared for rapid increases, or “spikes”, in HSR showing the both the protective effect of HSR as well as the damaging effects if not managed correctly. They found that a 1-weekly HSR of approximately 850-1500m carried the greatest overall risk to players. Windt et al. (2017) found comparable results. They found that players who covered a greater proportion of their weekly total distance at high speed that they were at greater risk of a non-contact injury. Duhig et al. (2016) noted that large “spikes” in HSR led to a higher risk of a hamstring strain injury and that higher HSR within a single session also carried an increased risk.

Various thresholds have been set across the literature as the speed above which HSR will be recorded, making it more difficult to compare results from some studies. Setting this threshold too low or too high could lead to a significant overestimation or underestimation of the volume of work done at high speeds, which could have serious negative implications when used in practice in elite sport. The default value for systems such as Prozone, a real-time performance analysis system, is usually set at 19.8km/h. This value has since been used frequently in studies (Bradley et al., 2009; Malone et al., 2017; Gregson et al., 2010; Di Salvo et al., 2009), despite Malone et al. (2017) defining this as “Sprint running”. Other studies have used values similar to this. Studies by Windt et al. (2017) used a value of 18km/h, with a study by Wells et al. (2014) defining 18km/h the lowest value of the “high intensity spectrum”. Bowen et al. (2016) used a value of 20km/h, potentially just rounding up the default value of 19.8km/h. One study by Abt & Lovell established a much lower threshold than these values, using a treadmill test to discover the 2nd Ventilatory Threshold of their subjects. They obtained values between 14-16km/h as the speed at which this was achieved, a much lower value than the aforementioned thresholds. In order to capture the full picture of work carried out at high speed, the threshold for this study was set at 18km/h. This allowed the current study to stay aligned with the current literature whilst reducing the risk of overestimating the volume of HSR.

1.2.5 Player Load

Player Load (PL) is a physical vector developed by Catapult to try and quantify the external load experienced from physical activity. The vector is derived on three axes from the tri-axial accelerometer housed within the GPS units. The equation for PL is shown below:

$$\text{Player load} = \sqrt{\frac{\left(a_{y1} - a_{y-1}\right)^2 + \left(a_{x1} - a_{x-1}\right)^2 + \left(a_{z1} - a_{z-1}\right)^2}{100}}$$

It has been shown that PL has high reliability for measuring external load in team sports (Boyd, Ball & Aughey, 2011) after testing in Australian Football. This is backed up by further studies which show that accelerometer date has strong correlations with other GPS metrics such as distance covered (Boyd, Ball & Aughey, 2013). These authors were able to clearly distinguish between match play, training and specific drills using PL, as well as seeing clear parallels for specific positions in Australian football for PL and total distance covered. They have also been shown to display similar positional distinctions in Netball (Cormack et al, 2014). Hollville et al. (2016) have even compared accelerometer outputs to force plate data and found that the validity of PL was very good in comparison, which all leads to the strong conclusion that PL can be a useful metric in assessing loads within team sport.

1.2.6 Fatigue

The definitive mechanisms of fatigue during a ninety-minute football match are unclear. However, what is clear is the reduced performance shown in the later stages of matches irrespective of player position or the level at which they play. In the final 15 minutes players cover less total distance and complete less high intensity running and sprinting than any other period in the match (Mohr et al., 2003; Bangsbo et al., 1994; Reilly & Thomas, 1979). This has also been shown to be true in the second half compared with the first half.

Multiple mechanisms are possible and have been proposed to account for the reduced performance. Given the reliance on muscle and liver glycogen it has been suggested that depletion of these stores could lead to reduced high intensity performance in the later periods of matches. Saltin (1973) has stated that this may only be the case if glycogen stores are low prior to the match. Dehydration is another potential mechanism given its effects on cerebral function and in turn the negative effects on performance (Mohr et al., 2005). However, given that there are opportunities within matches to take on fluids it is only likely in hotter, humid conditions. Mohr indicated that temporary fatigue, occurring after periods of intense exercise, may be related to alterations of muscle ion concentration and the accumulation of lactate. After an intense period in a match, muscle lactate has been shown to increase by up to four times resting values accompanied by a marked drop in muscle pH (Krustrup et al., 2003).

A combination of the above factors is likely to lead to the decreased physical performance noted during football matches (Mohr et al., 2003; Mohr et al., 2005; Bangsbo et al., 2006).

1.2.7 Skill-Related Physiology

Success in football matches is determines by technical outcomes rather than physical characteristics (Bush et al., 2015), despite the noticeable differences in factors such as VO_2max with teams of a higher standard. Actions such as passing, shooting, tackling, jumping and dribbling are performed repeatedly over the course of a match combining high physical, technical and cognitive demands. The ability to carry out these skills with a high degree of success is critical to the outcome of matches. Carling & Dupont (2011) studied the success of such skills over the course of a match and whether this declined similarly as physical outcomes. The assumption has tended to be that as players fatigue that skill performance declines, however this study showed that over the course of a match and over a period of three matches in a week, no drops in skill-performance success were noted.

1.3 Small Sided Games

1.3.1 Overview

Small Sided Games (SSGs) are training based games implemented in regular weekly training sessions by coaches for various outcomes. They are often smaller versions of full matches with multiple variables such as pitch size, player numbers, added conditions and the addition/removal of goalkeepers which can be manipulated to change the emphasis desired by the coach. They have been described by Hill-Haas et al. (2011) as “Skill Based Conditioning Games”, essentially a “football-specific” means of physical conditioning. The same study has concluded that SSGs provide similar physiological benefits to traditional interval training. As such, they are a very effective way of incorporating different physical stimuli into a periodised performance plan whilst simultaneously developing both technical and tactical skills as well as decision making.

1.3.2 Intensity

The literature to date has most commonly quantified the intensity of SSGs using heart rate (beats/min or $\%HR_{max}$) and blood lactate (mmol/L) assessments (Clemente et al., 2014; Rampinini et al., 2007; Hill-Haas et al., 2011). Varying the parameters of SSGs is what will dictate the physical qualities being trained and as such as a crucial consideration for coaches.

Often, team size is the main variable looked at (i.e. 3v3, 5v5, 8v8 etc) with the assumption made that as player number increases so will pitch dimensions. The consensus from both measurements is that as team size increases, the intensity of SSGs decreases, with studies showing this to varying degrees. Two separate studies by Williams et al. (2016) and Owen et al. (2011) found that the mean heart rate of a 2v2 was 180bpm, dropping to 153bpm for a 5v5 game. However, Owen found a smaller drop in heart rate, dropping from 173bpm to 164bpm for the same SSGs. This is consistent when team sizes are increased up to 9v9 and 10v10 games. Similar trends are seen for lactate responses during SSGs. Aroso et al. (2014) found blood lactate in a 2v2 game could reach as high as 8.1mmol/L with other studies showing larger games such as 6v6 being around 5mmol/L (Rampinini et al., 2007). It would also appear that increasing the pitch dimensions whilst keeping the team size the same increases intensity (Clemente et al., 2014). These results are most likely explainable due to the increased frequency of accelerating, decelerating, changing direction and increased physical interactions with other players during smaller games. Compare this with larger team sizes on bigger pitches players will be afforded more time to recover between intense actions as they may be more distant from the ball and have more teammates to compensate for them.

Other factors known to alter intensity are task constraints and coach encouragement. Often -coaches will introduce specific rules such as touch limitation or making number of passes before being allowed to score. Such rules have been shown increase both the heart rate response and blood lactate levels (Dellal et al., 2011). Coach encouragement is very rarely absent in coaching sessions, so it is unlikely to ever be a factor within a training session, however the absence of it has been shown to reduce the intensity of SSGs slightly.

Heart rate and blood lactate measure suggest that intensity of SSGs increases as the games become smaller. However, this does not correlate with time-motion characteristics such as distance covered, and distance covered at higher velocities. Casamichana & Castellano has shown that during larger pitch SSGs players covered greater total distances per minute, reach a higher maximum velocity, cover more distance at high intensity (>18km/h) and sprint with greater frequency. Given that pitch sizes most often increase with team size, this is going to be the case as SSGs change from 2v2 up to 11v11. This is important for coaches to consider as factors such as high-speed running, and maximum velocity are very important components of a footballer's conditioning. It is crucial that players are exposed to these regularly within planned training to maximise performance and prevent injuries. As games increase in both pitch and team size, we see more positional outcomes as SSGs begin more resembling of a competitive match.

Like with interval training, manipulation of variables such as work duration and rest can alter the systems being trained within SSGs. Typically, SSGs with smaller teams and pitch sizes are carried out for much shorter durations that those involving larger team sizes. Clemente et al. (2014) have suggested parameters for aerobic and anaerobic training involving SSGs. They advise that for aerobic training games should last between 3-16 minutes each for game up to 6v6, for a total volume of up to 40 minutes. The principle being that athletes are training their ability to perform prolonged activity, with short bouts of intense activity within which they will need to recover from. For anaerobic training they suggest games last between 30 seconds and 3 minutes each, with a 1:1 work to rest ratio for a total volume of up to 16 minutes. This would be training footballers to repeatedly carry out shorter bouts of very high intensity activity, often in the presence of lactate and other metabolites. Both of these are key components that can now knowingly be trained within footballing activity.

1.3.3 Summary

SSGs have been shown to be as effective as high intensity interval training at increasing VO_{2max}, a key determinant of success in professional football. Altering numerous factors such as pitch dimensions, team size, technical/tactical limitations and the addition/removal of goalkeepers can alter the physiological response of SSGs. It has been found that having more players, smaller pitch dimensions per player, goalkeepers and no limitations or restrictions all reduce the physiological intensity of SSGs. Overall, with regards to heart rate responses, smaller SSGs are of greater intensity than large SSGs (Owen et al, 2011). SSGs are of great relevance to coaches, due to the physiological benefits but also the ability to develop both technical skills and tactical awareness as well. Different SSGs will expose players to a variety of technical factors. Owen et al. (2011) concluded that smaller games involve more dribbles, shots and tackles, whereas larger games involver more blocks, headers, passes and interceptions.

Clemente et al. (2013) provides an excellent summary of the uses of SSGs within training to elicit physiological benefits in aerobic and anaerobic fitness, with emphasis on heart rate responses (beats per min & % of maximum heart rate), blood lactate concentration and ratings of perceived exertion (RPE). The review provides a number of important distinctions and components of some of the key papers available, such as those by Owen et al. (2011) and Dellal et al. (2011). Like most of the key literature, these papers focus almost exclusively on internal load and intensity metrics as the outcomes of their interventions. This is valuable information when looking to improve the conditioning of football players throughout the course of the season. Dellal et al. (2011) make an important distinction between amateur and professional players as player fitness and technical ability will impact the observed outcomes, especially in their study which is investigating the effects of free play vs specific touch rules. Rampinini et al. (2007) added a different aspect by considering coach encouragement as a factor as well as the inclusion/removal of goalkeepers, which are regular variations in daily training methods making the data relevant to current practises. Not only does the review provide an overview of the results but provides examples of how to manipulate variables such as player number, pitch dimensions and technical restrictions in order to elicit different physiological responses.

However, whilst there is plenty of useful information to be taken from these papers, they are also limited in some respects. Only one of the aforementioned studies (Dellal et al., 2011) recorded time-motion analysis data (distance covered, sprinting distance, high intensity running distance) and it only contained one variation of SSGs which was 4v4. This study only looked at this external load data between different positions, which in such a small SSG may not be all that important due to a lack of positional requirements in a 4v4. Rampinini et al. (2007) provide a wealth of information on the responses to SSGs, however only from 3v3 to 6v6. Within each variation they look at different pitch dimensions, but common training frequently uses games of greater team numbers from 7v7 up to 11v11. They may have been held back through the use of amateur players and availability of larger numbers, however this fact also makes it difficult to relate the data to professional or elite players. Given the importance placed on regular monitoring of external load variables (Gabbett et al., 2016; Bowen et al., 2017), it is strange that so little of the literature does not investigate them within SSGs. It would be very useful to have this information in the SSG formats investigated by the likes of Owen et al. (2011) and Rampinini et al. (2007), and in a similar fashion to Dellal et al. (2011) but with more SSGs to look at. This would help to supplement the already vast quantity of data available on SSGs to help with the planning of daily and weekly training cycles.

A key distinction made in none of the studies encountered was that of surface type. No study found had investigated any differences between grass and artificial turf, which is a key aim of this study. It is hoped that this study can add to the already vast literature on SSGs by providing some information on this aspect.

1.4 Artificial Turf in Football

Currently, AT used in football is what is termed “third generation (3G)”, the most up to date structural formation of the synthetic surface. This surface technology consists of long fibres of synthetic grass combined with an infill layer of rubber or sand. Due to the fact that there is scope for variation in the construction of 3G AT, there can be large differences in the structure and functionality of AT surfaces. This is even to the extent that the difference between AT surfaces can be greater than that between AT and natural grass (Ford et al., 2006).

AT brings about considerations for both the athlete and the performance team with regards to training and matches. Synthetic surfaces have the potential to impact upon the lower limb biomechanics of those competing on them (Ford et al., 2006). This, plus the potential effects on related injury frequency clearly warrants further research. The same study by Ford et al. (2006) found that the playing surface type and quality can have a notable effect on plantar foot loading during sport-related movements, such as striking a ball, accelerating or cutting and change of direction, with the potential for significant frictional and rotational forces (Ford et al., 2006). Livesay et al. (2006) found significantly greater peak torques on Astroturf (a commonly use AT in the United States) compared with grass, albeit through the use of a mechanical testing device. Williams et al. (2011) also noted peak torque and foot loading patterns, as well as rotational stiffness, as having the potential to impact upon football injuries. This seems to be counter to the purpose of artificial surfaces, given that they are intended to replicate natural grass surfaces. Potthast et al. (2010) found that players would even alter their "motion strategy" when competing on AT compared with grass, which lends weight to the research undertaken in this study. They have stated that "it can be assumed that the different surface properties…may modify the related physiological stress". This could impact upon performance (Potthast et al., 2010) on pitch and could be reflected in GPS metrics which are regularly collected, such as distance covered, and distance covered at high speed. AT surfaces have different stiffness, hardness and elastic properties compared with grass, and even between AT surfaces. Ford et al. (2006) state that the differences in surface characteristics and any resulting changes in locomotion may be important when it comes to injury risk and frequency. However, we must now discuss what the epidemiological data tells us about injuries on grass compared with AT.

The evidence is quite clear in that there is no difference in total injury incidence on artificial turf compared with grass. Numerous studies have confirmed that the number of injuries occurring on both surfaces in matches is similar (Ekstrand et al., 2006; Fuller et al., 2007; Steffen et al., 2007; Soligard et al., 2010; Ekstrand et al., 2011). In their study, Ekstrand et al. (2011) noted that the incidence of injuries during match play was 21.7/1000hours on grass compared with 22.4/1000hours for artificial turf for men, and 12.5/1000hours and 14.9/1000hours respectively for women. Other studies have found similar outcomes for match play and training, such as that by Steffen et al. (2007). In training they noted 3.34 injuries per 1000hrs on artificial turf compared with 3.01/1000 hours on grass. A key finding though as explained in the same study is that players were approximately 7.5 times more likely to sustain an injury in matches than in training. As discussed previously, this is likely due to the unpredictable nature of matches coupled with a higher intensity and the competitive nature of games.

One of the most interesting findings from the current literature is that the pattern of injuries incurred may be far more significant that the incidence. Ekstrand et al. (2006) noted that the increased number of ankle sprains shown on artificial turf was worth more research. This agrees with Steffen et al. (2007) who found a correlation of more ankle ligament injuries, and increased numbers of ligament injuries in general, on artificial turf compared with grass. This is backed up further by Ekstrand et al. (2011) who informed this pattern further when they found not only increased numbers of ligament and tendon injuries on artificial turf, but greater numbers of muscle injuries on grass. Given that these studies are all cohort studies, they are limited by an inability to associate injury to a cause. However, given the structural differences between grass and artificial turf pitches it is possible that the explanation for the injury pattern lies there. The hardness of artificial surfaces may explain findings by Soligard et al. (2010) which found significantly more back and spinal injuries as well as more shoulder and collarbone injuries. Any ground-based tackles or falls may be more likely to result in such injuries on artificial turf given the hardness of it compared with grass.

Despite a few studies showing no difference in severity of the injuries incurred on each surface (Ekstrand et al., 2006; Fuller et al., 2007; Ekstrand et al., 2011), one study noted that injuries occurring on artificial turf were often more severe. Steffen et al. (2007) showed that, during matches, there were twice as many injuries resulting in a time loss of greater than twenty-eight days on artificial turf compared with grass (3.3/1000h vs 1.7/1000h respectively, odds ratio of 2.0) with fewer minor injuries on artificial turf – i.e.

those resulting in less than seven days (2.7/1000h on AT vs 4.0/1000h on Grass, odds ratio of 0.7).

1.5 Injury Epidemiology in Football

Association football has a well-established injury profile which has been heavily researched over the past decade. The UEFA Injury Study published in 2009 by Ekstrand et al. (2009) was initiated in 1999 after concerns by UEFA over the injury risk associated with the training load experienced by players at the elite level. They sought to establish the pattern of injury in elite football over seven consecutive seasons, a study longer than any conducted previously.

This study found that injuries across a season occur at a rate of 8 injuries per 1000 hours of football, at a rate of 4.1 injuries per 1000 hours in training and 27.5 injuries per 1000 hours in matches. A review by López-Valenciano et al. (2019) found a similar rate of incidence, with 8.1 injuries per 1000 hours of exposure. More specifically, they found in matches the rate of incidence was 36 injuries occurring per 1000 match hours, compared with 3.7 per 1000 hours in training. To provide perspective to these findings, Klein et al. (2018) have provided data from their systematic review of the epidemiological data available. Investigating all data ranging from amateur, youth and professional teams, total injury incidence ranged from 0.6 to 20.3 injuries per 1000 exposure hours. This included match injury rates of up to 101 injuries per 100 match hours (Almutawa et al., 2014). The significantly greater injury rate in matches can be attributed to the increased intensity, greater levels of fatigue accumulated, and the unpredictability of match play compared with training. Players could be expected to miss just over a month of the season due to accumulated days lost to injury. The majority of these would be defined as minor according to this study, with severe injuries, those causing a player to miss more than 28 days of football, making up only 16% of all injuries.

Over the course of a season a team can expect to incur 2 injuries per player per season with the most common of these being muscle injuries, approximately 35% followed by ligament injuries (18%) and then contusions (17%). The most common location of these is the lower limb at nearly 90% of all injuries, more specifically the thigh accounting for 23% of all injuries recorded. Hamstring injuries are by in large the most frequent injury. Ekstrand et al. (2012) found that teams are likely to incur around 7 hamstring injuries per season for a squad of 25 players. The knee is the next most common location followed by the hip and ankle.

Causality is inherently difficult to establish due to the vast number of risk factors associated with injury in football, with cohort studies being limited by being unable to link cause to injury. Hawkins et al. (2001) have suggested fatigue, both central and muscular, could be a key cause of injury. Their study, along with Rahnama et al. (2002), found that most injuries occurred in the final 15 minutes of both halves. The resulting high levels of muscle damage, reduced motor control along with depleted glycogen stores may elevate the injury risk during the intense periods in the final stages of each half. Rahnama et al. (2002) concluded that contesting possession incurred a high injury risk. This agrees with Alentorn-Geli et al. (2009) who found that common movements involved with defending, attacking and contesting headers incurred an increased risk of anterior cruciate ligament (ACL) injury. High stress is placed on the structures of the knee specifically the ACL, in a number of scenarios; when changing direction with high deceleration and acceleration forces; when twisting with a planted foot, generating high torque at the knee; landing from a jump with a minimal knee flexion. Reinjury is also a common cause of injury, often with greater severity the second time. Some studies found reinjury accounted for up to 30% of all injuries in a season (Hagglund et al., 2013; Walden et al., 2005) however some studies (Ekstrand et al., 2009; Hawkins et al., 2001) found these rates to be 12% and 7% respectively.

Ekstrand et al. (2009) noted that 21% of all injuries occurring in matches were caused by foul play, as decided by the match officials. Ankle sprains were the most common of these followed by knee sprains and then thigh contusions.

1.6 Use of GPS in Sport

1.6.1 How GPS Works

Each satellite in orbit transmits a unique signal as they orbit every twelve hours, being received by devices on Earth. The signals transmitted by satellites are intercepted by receivers on Earth, which will then calculate the distance from the satellite based on the how long it takes to be received. Once the receiver has received signals from three or more satellites, the position of the receiver can be pinpointed by the process of “trilateration”, shown in figure 1.1 below.

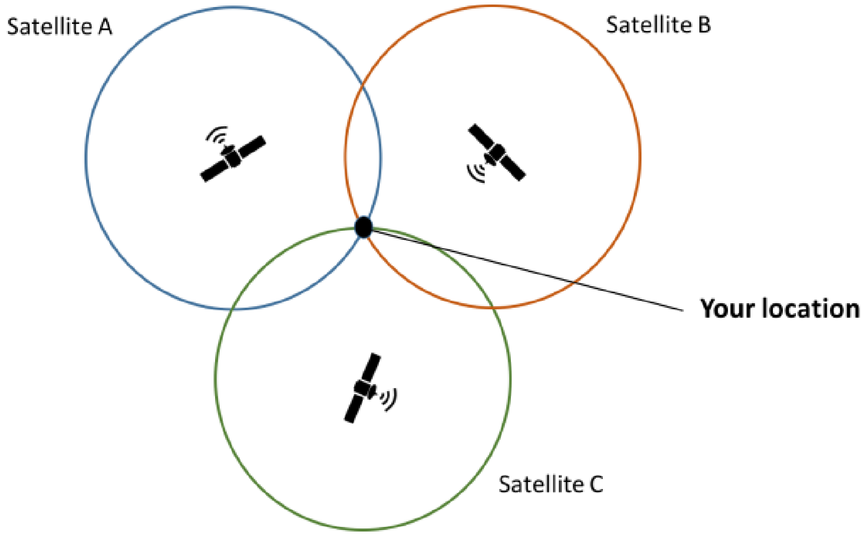

Figure 1.1*:* A diagram of how satellite triangulation works to pinpoint the location of a GPS receiver

Where the three (or more) orbits intersect will be the confirmed location of the receiver. The more satellites above the horizon will increase the accuracy of the location. Four satellites are the minimum number of satellites required to obtain a 3-dimensional position, incorporating latitude, longitude and altitude. The most accurate GPS measurements can locate a receiver to within metres of its actual position.

1.6.2 Validity & Reliability of GPS in Sport

Validity and reliability are crucial with regards to data collection in sport. If data is to be used to prescribe training loads, monitor injury risk and provide feedback to coaching staff then it must be representative of activity happening within the sport in question. Therefore, data must be meaningful in order to be able to effectively and safely impact training.

The validity of a given instrument is defined by Scott et al. (2016) as “ability of that instrument to accurately measure what it intends to measure”. If data is not valid, then we cannot be certain our data represents the desired metric. Reliability refers to the ability of an instrument to maintain consistency in the data produced with repeated tests. Reliability does not necessarily mean that measurements are valid, reliable data means you are obtaining consistent measurements for a given test over time. In an ideal world, GPS units would be both, providing accurate (valid) measurements on a daily basis (reliable). This would allow us to gain a clear profile of the work done by athletes over a given period that actually reflects the work done by them. Scott et al. (2016) conducted a review of the literature on validity and reliability of GPS units, with measurements of validity being reported as standard estimated error (SEE) or standard error of the mean (SEM). Results of reliability were reported as CoV or the typical error of measurement (TEM). They have generally been categorised the following way; <5% = good; 5-10% = moderate; >10% = poor.

The literature has investigated GPS units with sampling frequencies ranging from 1Hz to 15Hz. A sampling rate of 1Hz means data is sampled once every second. Distance is the first metric to be looked at with regards to validity and reliability. Studies by Portas et al. (2010) and Peterson et al. (2009) established acceptable validity of 1Hz units (<10%) for both distance in straight-line and curvilinear activity at speeds up to $5ms^{-1}$. However once sprinting was tested over 20-40m, much larger errors were obtained. For the SPI-Pro units the error ranged from 3-11% of the SEE, but the MimimaxX units were far less valid with SEE ranging from 5-24%. This appears to agree with results from another study (Gray et al, 2010) which looked into 1Hz units. They tested the validity of eight different GPS units over both a linear and non-linear 200m course. Units were found to be valid for measuring distance for speeds ranging from walking up to sprinting on the linear (<2.8%) and nonlinear (<9.8%) courses. However, the validity of these 1Hz units decreased as distance was reduced to 10-40m, highlighting a potential weakness of using these units for measuring team sport type activity. Such activity often involves short, intense actions with changes of direction and as such the validity for this activity needs to be tested.

Portas et al. (2010) devised six mapped courses based on pre-existing landmarks on the field of play of a football pitch. These were multidirectional and involved varying degrees of direction changes. These tests showed good validity for walking (<4.2 SEM) and good-to-moderate for running (<6.8% SEM). These tests were followed up with position specific tests for football players, created based off analysis of professional football matches using a computerized time-motion analysis software. One-minute bouts of high-intensity activity were carried out for each position based on their match movement profile, involving changes in movement velocity and direction. All these tests showed good validity ((1.3-3% SEM) highlighting the positive use of 1Hz GPS in sport. This is similar to results obtained by Coutts & Duffield, who created a running circuit involving multiple changes of direction, who obtained results for total distance within 5% of the criterion measure. Jennings et al. (2010) had mixed results from similar protocols. In a "change of direction" course the validity was shown to be poor for total distance measures at higher speeds, with only walking and jogging being below 10% he SEE. Indications within the research suggest some positive use but also limitations with regards to 1Hz GPS recording distance at higher intensities.

Both studies by Portas et al. (2010) and Jennings et al. (2010) both investigated 5Hz GPS as well as the 1Hz units, using the exact same protocols. Portas found good validity (<5%) for total distance in all protocols (linear, multidirectional, position specific). Jennings found slightly improved accuracy with the 5Hz units in the "change of direction" courses, however they still ranged from moderate to poor. Within the team sport trial, results were identical to the 1Hz units. One study carried out shuttle-base protocols over a seventy-metre total distance to assess validity (Rampinini et al., 2014). Similar to previously mentioned studies, the validity for total distance across the course was very good at 2.8% as the typical CoV. However, when looking) at the distance covered when at high speed and very high speed, this value drops to 7.% and 23.2% respectively. Again, as with the 1Hz units, we see a potential use within high intensity sporting activity but still some strong limitations.

Less literature is available on the newer developed 10Hz units, however there is enough to inform practice and the findings are positive. Rampinini's seventy-metre protocol showed good validity for total distance covered (1.9% CoV) and distance covered at high speed (4.7% CoV). Validity at very-high speed was just out with what is considered acceptable at 10.5%, however this is less than half of the 5Hz units result showing vast improvement. Castellano et al. (2013) looked into shorter sprinting protocols at 15 and 30 metres, finding the longer sprint restored a SEM of 5.1%, with the shorter sprint just over half that value at 10.9%. This would still appear to be a marked improvement on the lower sampling frequencies which struggled to record accurate distances in short sprints. Some research into cricket protocols was done by Vickery et al. (2014), attempting to replicate the movements of batting, bowling and fielding. These involved three 16m shuttle runs, a 5m walk followed by a 10m high acceleration and transitioning from a walk to a 5m acceleration at three different angles. For all protocols, total distance was not significantly different from the criterion measure, a twenty-two-camera based system sampling at 100Hz. It would appear that 10Hz GPS is more accurate at quantifying distance in shorter actions than both the 1Hz and 5Hz units.

15Hz units have even less evidence regarding their use compared to the 10Hz, again due to their very recent development. What information we have is relatively positive, but more work is required to build a stronger case for their use. Johnston et al. (2012) followed previous studies and used a “team sport simulation circuit”, a 1305m course involving multiple changes of direction and speed, and 50m flying sprint efforts. Neither of the two 15Hz units tested differed significantly from the criterion measure in the team sport circuit or the flying 50m sprints. The cricket protocols mentioned before (Vickery et al., 2014) also tested 15Hz units, with mixed outcomes. For most measures of total distance, the units did not significantly differ from the camera-based criterion measure, but the CoV varied from 5.5 to 17.9% in the three protocols. This was mostly as the wearer reached greater speeds or intensity of movement. Rawstorn et al. (2014) found that in a soccer-related shuttle running test the total distance output was significantly different from criterion measures, however the mean error obtained was positive for both linear and curvilinear distance. More work is clearly required to solidify the 15Hz units as valid options for practice.

It would be of great benefit to know if different surfaces carry varying degrees of risk with regards to non-contact injuries in professional football. This issue with this, however, is that it is very difficult to measure any such risk using the technology available to us. This is due to the fact that the accelerometers contained between the scapulae cannot provide accurate enough information about the player-ground interaction, which occurs within the lower body. Before we can devise an appropriate means of measuring any such response, we need to assess whether players experience different external loads or whether they move differently on different surfaces. Any obvious difference in external load or movement patterns would help us to devise a better strategy to tackle the larger question surrounding injury patterns and incidence. It would also be wise to investigate the transition between surfaces as well, given how many teams train or play on one surface but will regularly be exposed to the other when either playing away from home or being forced to train on another due to inclement weather. This is a common occurrence in Scottish football due to a number of teams having AT as their home surface, and harsh winter weather which can affect grass pitches. Being able to increase our knowledge of movement pattern and external loads will allow us to create a better strategy to try and understand the direct risk of injury associated with surfaces.

The main aim of this study is to assess the external loads experienced by professional footballers on both grass and artificial turf. It would be hypothesised that no differences would be observed in the three metrics used, in either training or matches. Through the use of modern technology that is used regularly throughout professional football globally, it is hoped that results obtained will pave the way for further research. The end aim for research is for coaches and practitioners to be able to generate impactful interventions to be implemented into their training cycles. Conclusions drawn from this study should aid in that process by providing information on the loads players are experiencing on both grass and AT during match play and a regularly used training method.

2. General Methodology

2.1 Aims & Hypotheses

As stated previously in the abstract, the aim of this study was a purposeful audit of the external loads experienced during match play and training on grass and artificial turf. Specific reference is made to three key load metrics from GPS: Distance Covered ($m.min^{-1}$), High Speed Running ($m.min^{-1}$) and Player Load ($AU.min^{-1}$). For match play, data is compared directly between three surface categories, Grass (Home), AT_{Home} and AT_{Away}, to observe possible significant differences. In training, two different comparisons were made. One to compare the "smaller" SSGs with similar playing areas, and one to compare the "larger" SSGs. The key intention was to investigate the differences between the SSG on grass with the SSGs of similar playing area on AT, for each of the three GPS metrics.

It is hypothesised that no significant differences will occur in any of the statistical analyses, in match play or in the training data.

2.2 Subjects

Due to professional circumstances over the course of this research two different football teams were used in the study. One team competed in the Scottish Premiership (top division) whilst the other competed in the Scottish Championship (second division), however both teams comprised of full-time professional players. All players were provided with an overview of the study and given the option to not have their data used for analysis. Given that the nature of the study was to provide analysis of the training and competition that already occurs, rather than implement a training intervention or testing, players were unable to remove themselves from participation.

2.2.1 Match Play Team Data

The match data was collected from the Scottish Premiership team which contained a squad of 30 outfield players, of which 22 completed matches in which data was used in this study. The average age of these players was 20.8±4.3 years. As part of pre-season preparations, a number of physical tests were conducted. The average body mass of the group was 73.4±15.8kg and body fat % was 10±4.4%. Body fat percentage was measured using a BodPod at a local university, which calculates body composition by measuring the volume of air displaced by a body within the pod unit. The average maximal oxygen uptake (VO_2max) of the group was 59.1±4.9ml.kg.min^{-1}. VO_2max testing was conducted in an incremental exercise test in which incline was increased by 1% every minute until cessation of exercise. A breath-by-breath system was used to measure oxygen uptake and carbon dioxide output and a computer system would calculate the VO_2max during the test. Maximum heart rate was recorded for each test, with a team average of 195.6±6.7beats.min^{-1}.

Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
AM: Recovery session/Top up session PM: No session	AM: Pitch based session PM: Gym based session	OFF	AM: Pitch based session PM: Gym based session	AM: Pitch based session	PM: Match	OFF

Table 2.1*:* A typical periodized week of the Scottish Premiership team from which match data was obtained

On a typical week, the team would complete 3/4 pitch-based session per week depending whether a player completed a significant portion of a match on a Saturday, usually >60 minutes. There would also be up to 2 gym-based sessions per week which would be a mixture of lower and upper body strength and power sessions. Each pitch session would last between 60 and 120 minutes depending on the weekly periodisation, with gym sessions lasting approximately 30-60minutes. In a week, players would usually be exposed to around 200-250 training minutes on pitch, with around 60-90 gym-based minutes per week.

2.2.2 Training Team Data

Training data was collected from the team playing in the Scottish Championship, with 22 players from their squad having data collected on them, with an average age of 24.1±4.5years. Physical testing conducted as part of pre-season, as before, included the BodPod system to measure body composition. The average body mass of the squad was 79.6±7.6kg with an average height of 182.3±6.6cm. Body fat percentage was similar to the first squad at 9.8±4.1%. No measurements of aerobic capacity were taken due to the plans put in place by the coach.

Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
AM: Recovery session/Top up session w/ development team PM: No session	AM: Pitch based session PM: Gym - lower body strength session	OFF	AM: Pitch based session PM: Gym - upper body strength	AM: Pitch based session	PM: Match	OFF

Table 2.1*:* A typical periodized week of the Scottish Championship team from which training data was obtained

A similar weekly periodization model was in place here as was in the Premiership team. 3/4 pitch sessions per week were carried out in a standard week with gym-based strength sessions on Tuesday and Thursday afternoons. Monday through Thursday, pitch sessions would last between 75 and 120 mins, with Friday pre-match sessions lasting between 50 and 80 minutes. Gym sessions would last between 45 and 75 minutes.

2.3 Protocols

2.3.1 GPS Analysis of Match Play

GPS units were worn as per the instructions of the manufacturer, in a neoprene vest with the unit in the pocket on the back resting between the shoulder blades. The units were switched on approximately 30 minutes prior to matches and players were given the option of wearing the vests (without the units in) during their warm-up. Units would be inserted into the vests after returning from the warm-up, approximately 10-15 minutes prior to kick off.

The units were worn for the entire duration of the match and collected from the players in the changing room upon completion of the match. Data was downloaded from all the units post-match before being cut for the two halves of match play. This was done using times recorded for the start and finish of both halves of play (in GMT) being identified on the Catapult software's graphs for the match data. The cuts were applied to all individuals, with data being reported and then transferred to a database containing all match data. This process was carried out by the same observer for each match. Physiological parameters were standardized to allow statistical comparison, with speed zones set in km/h and an absolute threshold set for High Speed Running (18km/h). No threshold was set for the minimum number of collections for a given surface, with 16 being the lowest collected (AT_{Away}) due to availability of units and lack of matches played on AT away from home.

2.3.2 GPS Analysis of Training

GPS units were worn from the very beginning of each session, with the vests and units being put on as players left the changing room to train. The units recorded entire sessions from the start of the warm-up until the players returned to the changing room post-session. The purpose of the study was to observe normal training sessions, so no instruction or input was given by the observer. Training data was collected as often as the units were available and there was no selection of which sessions were monitored. As such training would consist of warm-ups, technical/tactical drills, SSGs (small sided games), running exercises and match practice. The area of focus in this study is the SSGs, given their use as both a technical/tactical exercise and as conditioning exercises. The purpose of the SSG was not considered within the analysis of the training data. As there was no intervention, no minimum number of sessions were set for each SSG for entry into this study, any variation not recorded was not carried out in training. This is discussed later in the study where this could be considered a limitation in one instance.

2.4 Equipment

2.4.1 Catapult Optimeye X4 GPS

The GPS monitoring system used was the Catapult Optimeye X4 10Hz units. These devices have a GPS sampling frequency of 10Hz (10 times per second) as well as containing a 100 Hz tri-axial accelerometer, 100 Hz tri-axial gyroscope and a 100Hz tri-axial Magnetometer. Information is provided by the units regarding athlete position, velocity, distance and acceleration for the duration of the sampling period and is downloaded post-session using Catapult software. Other measures obtainable from the units are impact forces, orientation, acceleration zones, velocity zones, energy expenditure and Player Load which can be used to create an in-depth analysis of match and training performance in sport.

2.4.2 Metrics

The three metrics used, taken from the Catapult software, were Total Distance Covered, High-Speed Running Distance and Player Load. To account for small differences in total match time, substitutions and SSG time, data collected was calculated relative to time. As such they were expressed as metres per minute ($m.min^{-1}$) for total distance and HSR, and arbitrary units ($AU.min^{-1}$) for Player Load. These were selected due to their specificity in relation to successful football teams vs non-successful teams as well as their connection to training load and injury risk within football, as discussed in the introduction.

2.4.3 Satellite Accuracy

In order for data to be used within research, its accuracy must be assessed. The two measures commonly used to determine this are the number of satellites interacting with the receiver (the GPS unit) and the Horizontal Dilution of Precision (HDOP).

As stated previously, the minimum number of satellites required to determine a three-dimensional position of a receiver is four (Malone et al., 2017). This is therefore the minimum threshold that could be used to assess data recorded as accurate, as was the case in this study. Malone et al. (2017) suggested that a number of satellites under six could be considered too weak to be accurate, however a lack of evidence to this effect meant this study stuck with four satellites.

HDOP is a measure of how accurate data recorded by GPS is with regards to the receiver’s horizontal position. This is based on the geometric position and number of satellites interacting with the unit in question. This is a number usually between zero and fifty, with values less than 1 considered desirable (Malone et al., 2017). Values significantly higher or lower than 1 (±0.5) were removed from this study, which was only one data recording.

2.5 Analysis

2.5.1 Data Handling

All match play data was downloaded, edited and reported within 24 hours of the match/training session by the same individual. The data relevant to the current study was exported onto a Microsoft Excel spreadsheet and organised appropriately.

2.5.2 Statistical Analysis

Statistical software Minitab 18 was used to carry out the statistical analysis of data collected in this study. Organised data was copied from Excel to Minitab in order to conduct the relevant statistical tests, which will be discussed later in this paper, and then visualise the data in order to conduct further analysis and discussion.

Statistical significance is reported as $P \leq 0.05$ and all data is recorded at the mean with 95% confidence intervals.

3. Analysis of Match Play

3.1 Introduction

Bowen et al. (2017) carried out a study into the acute:chronic workload ratio, monitoring metrics such as total distance, high-speed running and accelerations over the course of each week. They observed a median 4-week total distance (competition and training) of approximately 128km, averaging about 32km per week. Given studies such by Mohr et al. (2005) and Bush et al. (2015) have noted match distances ranging from 9-12km, this clearly represents a large portion of a footballers' weekly load. Similar results are observed with HSR (Bowen et al., 2017; Bush et al., 2015). It is logical that, as a result, any fluctuations in load as a result of pitch surface may be able to be anticipated, and weekly loads or training methods adjusted accordingly in advance. However, as it stands, we do not have a clear picture on this. The intensity and load of matches being greater than training is also backed injury data which highlights a significantly greater number of injuries during matches. The UEFA Injury Study has provided a vast quantity of data on this, from Werner et al. (2009) showing lower values of 3.5 injuries per 1000 match hours compared with 0.6 per 1000 training hours. Hagglund et al. (2013) showed a similar trend with much greater values, with 26.6 injuries per 1000 match hours versus 4.0 per 1000 training hours. It was found in another study that 63% of all injuries recorded came from match play (Hawkins et al., 2001).

Success within professional football is highly correlated by a team's ability to maintain a high player availability. Teams who had a lower injury burden and greater match availability were linked to a higher final league position, a greater number of points obtained per match and a higher UEFA coefficient ranking (Hagglund et al., 2013). Given that the acute:chronic load ratio postulate by Gabbett et al. (2012) is a commonly used method to monitor injury risk, the three metrics being used in this study become highly relevant. They are frequently incorporated into this concept to create a greater profile of injury risk if just one was used. As such, it would be beneficial to know if we see any differences in these metrics in matches which are competed on grass compared with artificial turf. If the answer is no, as is expected, then we can consider matches on each surface as equally contributing to the acute:chronic ratio. It is the main intention of this part of this study to investigate the external load, mainly the three metrics stated previously, to assess if there are any differences noted when completing matches on grass and AT both at home and away. The home and away distinction was deemed important given the findings of the study by Ford et al. (2006). This study indicated that the structural differences between different AT pitch surfaces could be greater than those between grass and AT surfaces. As such, it was not a fair assessment too assume all AT as identical with regards to the statistical analysis. It is for this purpose that the “home” and “away” distinction has been made.

3.2 Methods

3.2.1 Subjects

Subjects in the match play analysis were all males who played for the same football team in the Scottish Premiership, who played home matches on artificial turf. Physical data on players is stated in section 2.2.1. 228 samples of data were collected for use in the statistical analysis.

3.2.2 Equipment

Catapult Optimeye X4 10Hz units were used in the data collection process in conjunction with the manufacturer's vests and software. The metrics selected for analysis were distance covered (km), High Speed Running (HSR) and Player Load, with all data made relative to time spent on pitch.

3.2.3 GPS Analysis

GPS units were worn as per the manufacturer's instructions, in the neoprene vest secured in the pocket between the scapulae. Units were switched on approximately 30 minutes prior to kick off, whilst the players were warming up on pitch. Players would put the vests on upon returning to the changing room, approximately 10-15 minutes prior to kick off. They were worn for the duration the player was on the field of play, being removed and switched off at the end of the match or upon being substituted.

Data from the GPS units was downloaded immediately post-match using Catapult software and splits were set for the first and second half for the entire team using the activity graphs on the software. This was cross matched with the kick-off times for both halves to ensure no excess activity was collected. Substitutes, or substituted players had their data edited specifically for the time spent on pitch. This was then exported to a Microsoft Excel spreadsheet and the relevant metrics inserted into a database. This process was carried out by the same observer each time.

3.2.4 Statistical Analysis

Statistical analysis was carried out using Minitab 18 statistical analysis software. Normality tests were carried out initially to determine whether data followed a normal distribution or not. Upon these findings, one-way ANOVAs with Tukey confidence intervals were carried out for each metric. Data was then visualised using OriginPro 2015 software

3.3 Results

All data collected for distance covered was made relative to time spent on pitch, according to the match time recorded by the GPS units. This was to account for small differences in match time, as this will vary due to potential additional time in both halves of a match. As such, all data is displayed as units.min^{-1}.

3.3.1 Distance Covered

Data analysis found no significant difference between the distances covered on all three surfaces (p=0.922). Figure 3.1 shows a comparison of the mean distances covered on each surface, with very similar means for each. Data is displayed in this figure with 95% confidence intervals to highlight the wider ranges of the distances achieved. The wider confidence intervals for AT_{away} is due to having only 16 data points compared to the 101 and 111 for Grass and AT_{home} respectively. The means ± standard deviation for distance covered were 111.46±11.78m.min^{-1} for grass, 110.99±10.55m.min^{-1} for AT_{home} and 112±13.48m.min^{-1} for AT_{away}.

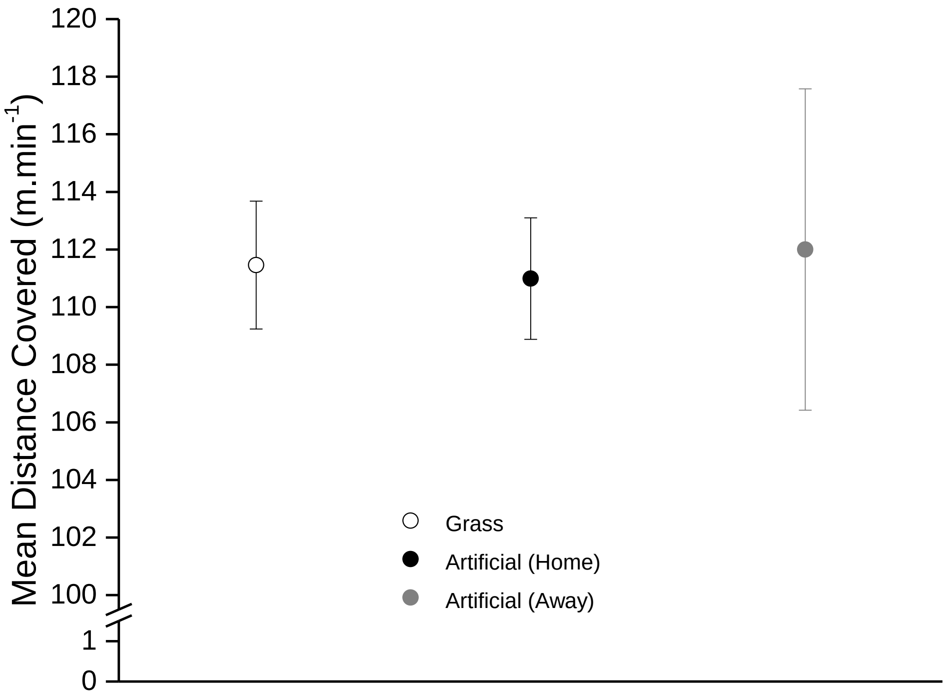

Figure 3.1: Distance covered during match play on grass surfaces, artificial turf when playing at home, and artificial when playing away from home. Data is displayed as the mean ± 95% Confidence intervals.

We can also see the similarity in the means by looking at the differences between the means, as seen in Figure 3.2. The difference of the means lying so close to zero for all comparisons, being 0.47±3.68m.min^{-1} (G-AT$_{Home}$), -0.54±7.20m.min^{-1} (G-AT$_{Away}$) and -1.00±7.15m.min^{-1} (AT$_{Home}$ – AT$_{Away}$), indicates a lack of difference between these means.

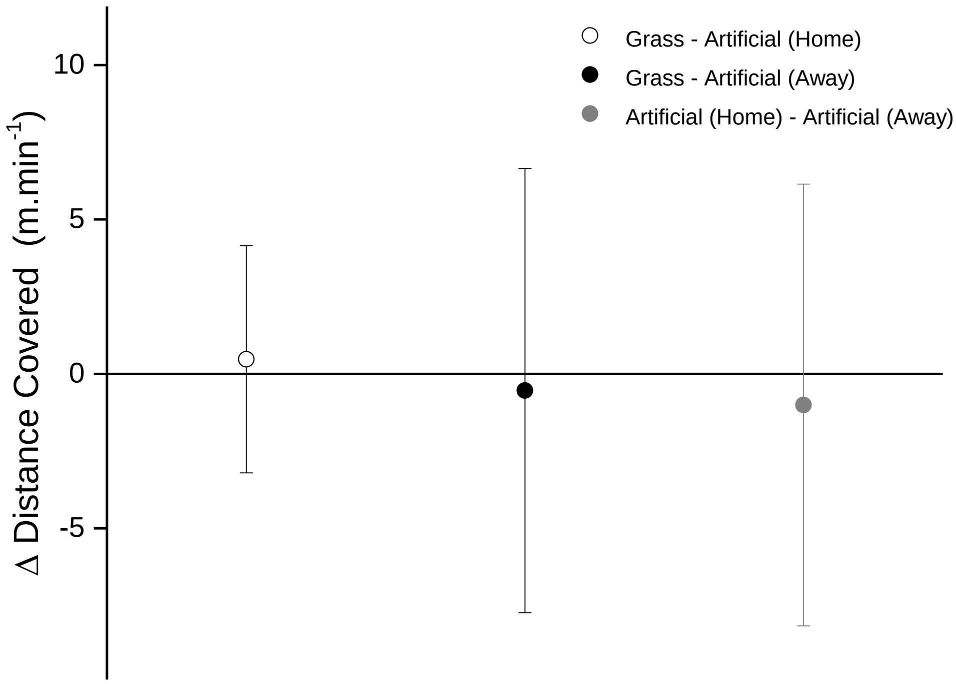

Figure 3.2: Difference of the means for distance covered during match play on Grass, AT_{Home} and AT_{Away}. Data is displayed as difference of the mean ± 95% confidence intervals

Figure 3.3 shows that the data for all three surfaces generally spans the same range of values, from approximately 90m.min^{-1} to 140m.min^{-1}. This will be dictated by a number of factors such as tactics, weather conditions and technical ability but, according to this data, not by surface type. This again highlights the similar means for distance covered on all three surfaces, with the lack of data for AT_{Away} appearing to create the largest difference in the plots.

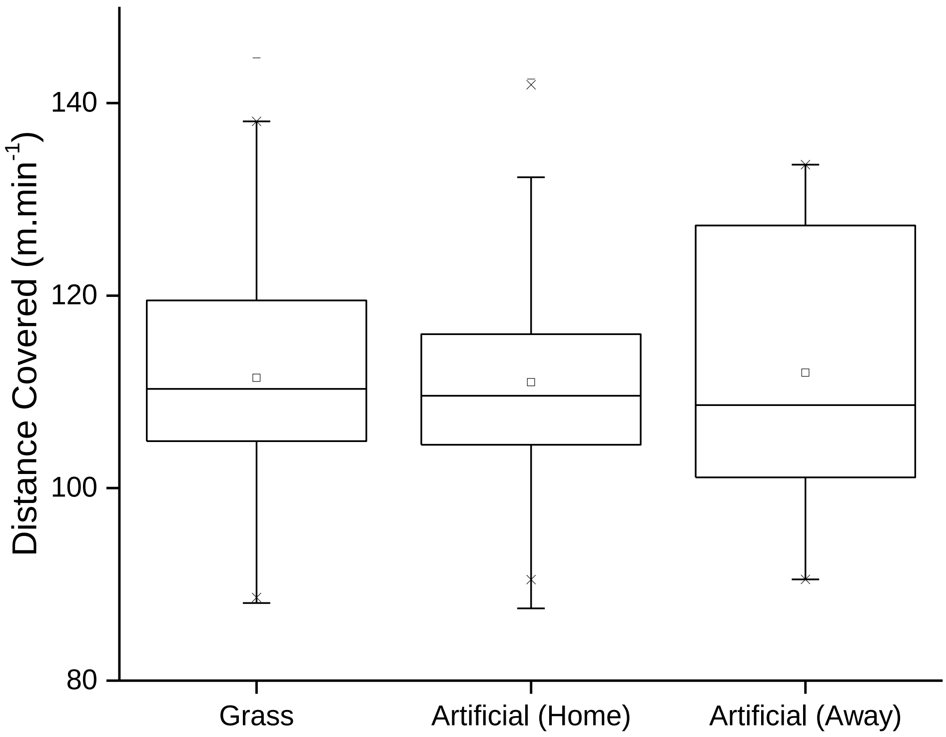

Figure 3.3: Boxplot of distance covered during match play on Grass, AT_{Home} and AT_{Away}

3.3.2 Player Load

Data analysis found no significant difference between the Player Load (PL) experienced on all three surfaces (p=0.391). As PL values are returned as a numerical value with no units all data is recorded as Arbitrary Units (AU) per minute. Figure 3.4 shows a comparison of the mean Player Load on each surface. Data is displayed in this figure with 95% confidence intervals to highlight the wider ranges of the distances achieved. The wider confidence intervals for AT_{away} is due to having only 16 data points compared to the 101 and 111 for Grass and AT_{home} respectively. The mean ± standard deviation for Player Load were 10.2±1.36AU.min^{-1} for grass, 10.42±1.50AU.min^{-1} for AT_{home} and 11.2±1.26AU.min^{-1} for AT_{away}.

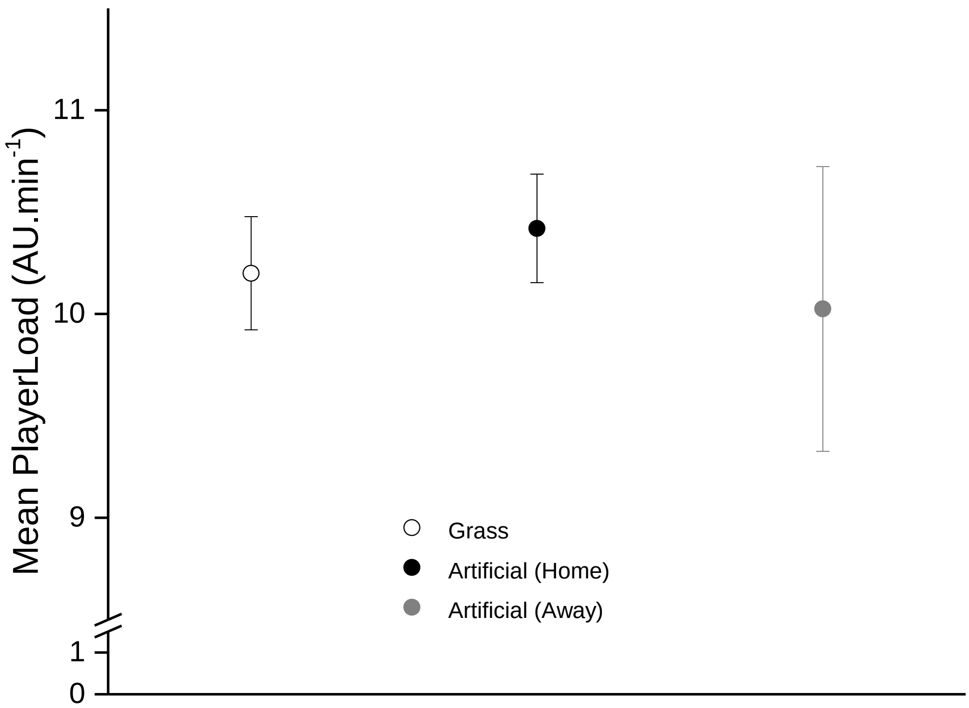

Figure 3.4: Player Load experienced during match play on grass surfaces, artificial turf when playing at home, and artificial when playing away from home. Data is displayed as the mean ± 95% Confidence intervals.

Figure 3.5 further highlights the lack of significant difference between PL values by showing the difference between the means. All means are lying close to zero, being -0.22±0.45AU.min^{-1} (G-AT$_{Home}$), 0.175±0.9AU.min^{-1} (G-AT$_{Away}$) and 0.395±0.90AU.min^{-1} (AT$_{Home}$ – AT$_{Away}$). All three surfaces not only have means close to zero, but their confidence intervals are also massively overlapping showing the similarity in their possible values.

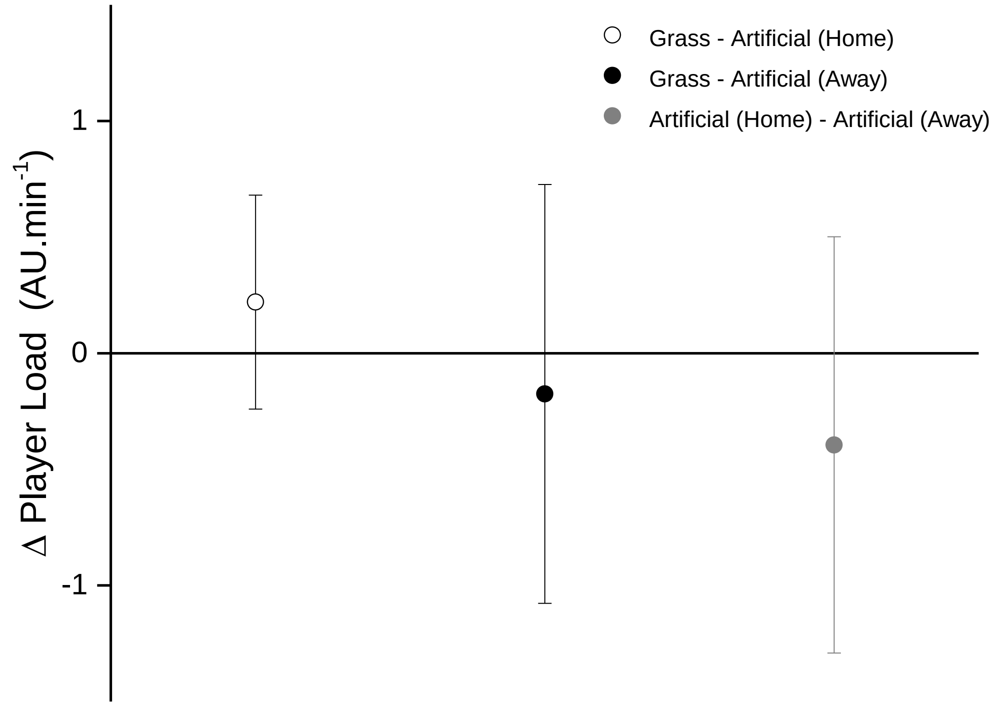

Figure 3.5: Difference of the means for Player Load experienced during match play on Grass, AT_{Home} and AT_{Away}. Data is displayed as difference of the mean ± 95% confidence intervals

Figure 3.6 further shows that PL experienced on Grass and AT is the same during match play. Overall total body load therefore should be similar when participating in a match on either surface. Means are all approximately 10AU.min^{-1}, ranging between values around 7-14AU.min^{-1}.

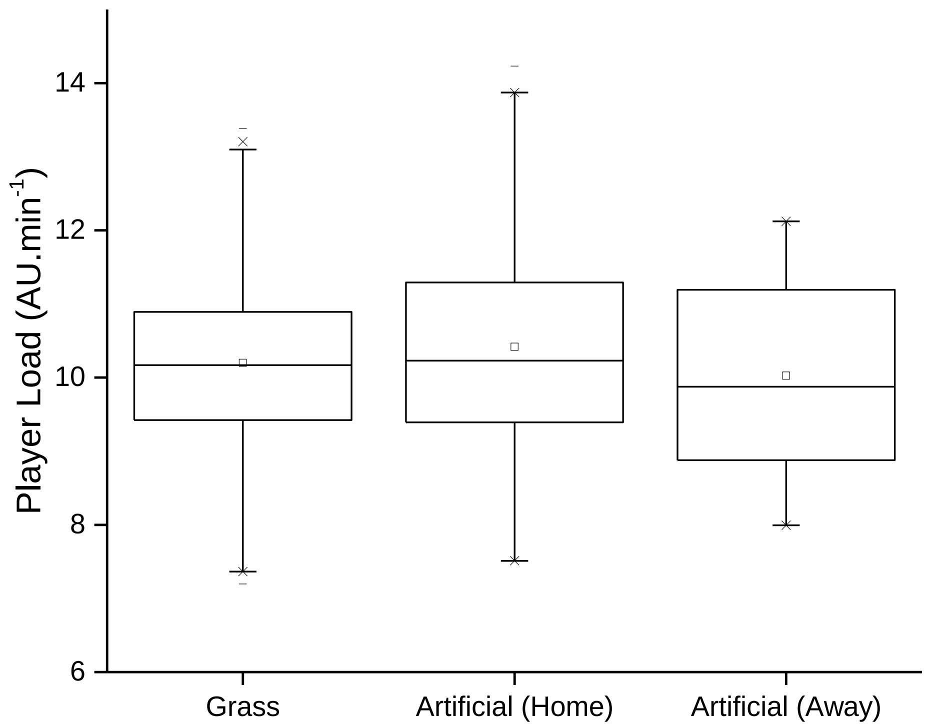

Figure 3.6: Boxplot of Player Load experienced during match play on Grass, AT_{Home} and AT_{Away}

3.3.3 High Speed Running

Figure 3.7 below shows the High-Speed Running (HSR) means during match play. Statistical analysis showed now significant difference (P=0.076) and Tukey comparisons providing the same grouping for all three surfaces. In Figure 3.7, the means ± standard deviation for Grass and AT_{Home} are almost identical, being 10.13±3.42m.min^{-1} and 10.21±3.13m.min^{-1} respectively. The mean for AT_{Away} is slightly higher at 12.14±4.18m.min^{-1} however with the wider confidence intervals, due to only 16 data points, the statistical significance could change if more data was collected.

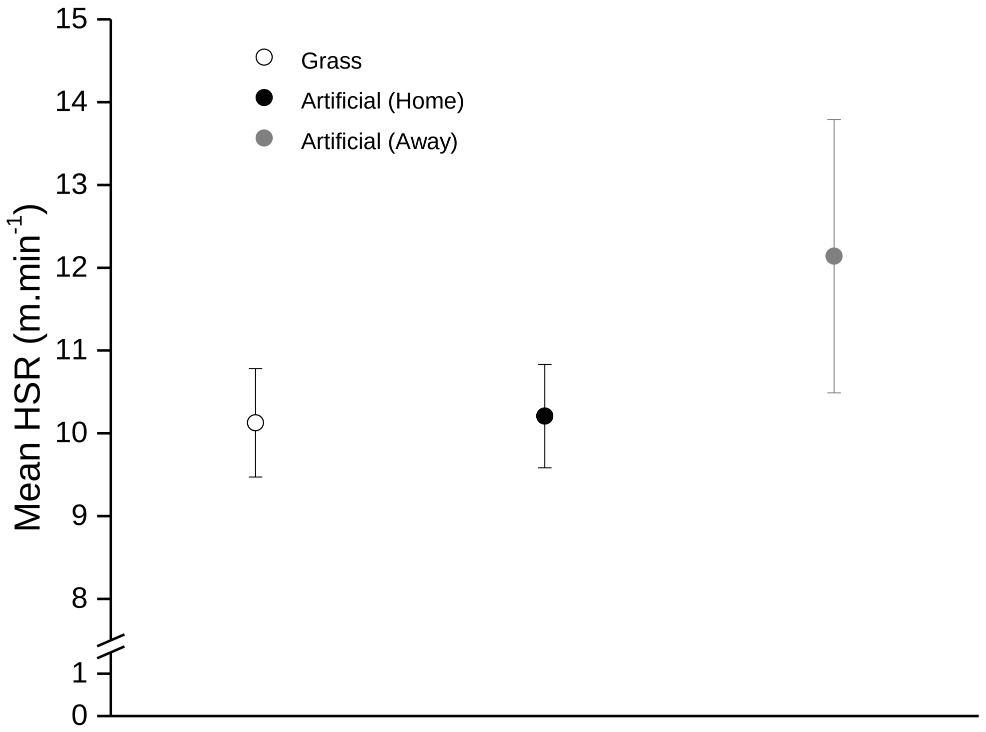

Figure 3.7: Distance covered >18km.h^{-1} during match play on grass surfaces, artificial turf when playing at home, and artificial when playing away from home. Data is displayed as the mean ± 95% Confidence intervals.

The difference in the means for HSR indicated there could perhaps be a small difference during match play, but not one that is statistically significant. Figure 3.8 shows that the difference between Grass and AT_{Home} is almost zero, indicating no difference, however the confidence intervals for comparisons between Grass and AT_{Away} and AT_{Home} and AT_{Away} only just include zero. If more data had been collected for AT_{Away} then we may be likely to see significant differences in these comparisons.

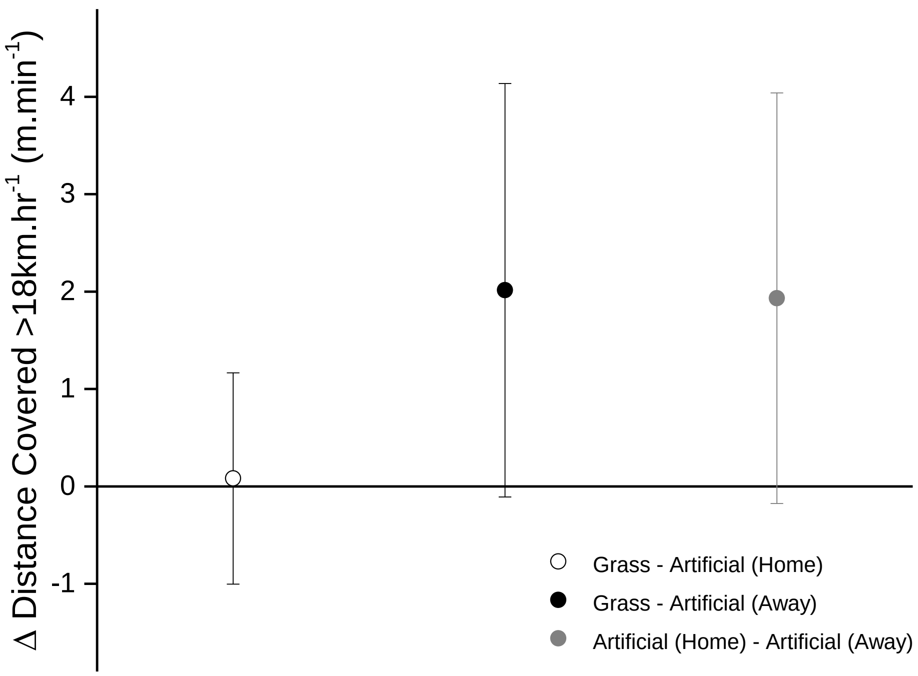

Figure 3.8: Difference of the means distance covered >18km.h^{-1} during match play on Grass, AT_{Home} and AT_{Away}. Data is displayed as difference of the mean ± 95% confidence intervals

3.4 Discussion

As stated previously in the introduction, the key intention of this study is to investigate the external loads associated with surface type in association football. We address this through investigating metrics such as HSR and Player Load, due to their strong associations with injury risk during football matches and training (Duhig et al., 2016; Ekstrand et al., 2012; Askling et al., 2007) and their regular use in training load monitoring (Bowen et al., 2017; Gabbett et al., 2016; Nielsen et al., 2018). The current epidemiology literature highlights a pattern of ligament injuries on AT as opposed to soft tissue injuries, as such future study will require more specific exploration of the shoe-surface interaction. However, we must build up to that, initially looking into whether there is and difference in the physical demands placed on players between grass and artificial turf. Measurements of total body load, such as distance covered, HSR and Player Load will provide possible insight into the demands placed on the body during match play and if players move differently with regards to both volume and intensity of their movements. This can be attempted using the GPS metrics available to us given the validity of these metrics in measuring total body load and their relation to injury risk. As match play is when the large majority of injuries occur, this is the first step in the overall assessment of load.

Data presented here highlighted no significant differences in distance covered during match play, Player Load or HSR distances when comparing grass and artificial turf. This agrees with the work of Andersson et al. (2008) who found no differences during match play for distance covered, high intensity running or number of sprints. The values obtained here align with the current body of literature with regards to distance covered and HSR distances, with studies from Europe and South America (Barros et al., 2007; Rampinini et al., 2007; Krustrup et al., 2005; Mohr et al., 2003; Di Salvo et al., 2007, Hennig and Briehle., 2000; Bangsbo et al., 2006). No study could be found where the validated PL metric was measured during elite level professional football match, however as this was an investigative study the findings intended to create further questions rather than definitive conclusions. Studies have regularly reported distances ranging from ~9-13km (Bloomfield et al., 2007; Bangsbo et al., 2006; Bush et al., 2015; Di Salvo et al., 2007; Barnes et al., 2014) which would reflect as ~100-145m.min^{-1}, showing a significant overlap with the data provided here. Given that data appears to be valid with regards to current literature, conclusions can be drawn, and inferences made which are relevant to the match loads experienced by professional footballers.

Given that match play is when injuries most commonly occur (Steffen et al., 2007; Soligard et al., 2010; Ekstrand et al., 2011) understanding the loads experienced during matches can try to help us understand more in-depth analysis, such as when comparing matches completed on grass and artificial turf. The data collected and presented within this study indicates that there is no difference in any of the three metrics when comparing G and AT. Practically, this would suggest that the loads experienced on players are the same, but we know that players are likely to encounter different type of injuries on grass than they would on AT. Also, studies have shown players often complain of greater pain and fatigue in the calves and lower back after playing on AT compared with grass (Williams et al., 2016; Poulos et al., 2014**)**. It is apparent that differences in injury pattern may be the result of more specific factors which are not identifiable within the standard load metrics. As such further investigation is necessary, potentially into more specific loading mechanisms within the GPS technology, such as within the gyroscopes. It is sensible to suggest that as there is no difference in these load metrics, which have been shown to influence injury epidemiology, that interaction at the foot-surface interface is where we may be more likely to find answers to the questions proposed.

A question that could be asked with regards to switching between surfaces is the impact that this could have on an individual's "chronic" load, i.e. the cumulative load experienced over a period of 3-4 weeks. Our data has indicated that there were no significant differences in the external load experienced on either surface for any of the three metrics. As a result, this suggests that there do not need to be any extra considerations with regards to the "acute:chronic load" concept, when considering the three metrics used. Andersson et al. (2008), despite finding similar results to this study, noted players recording increased physical effort on AT. This could lead to greater ratings of "internal load", such as RPE, after training or matches on AT compared with grass. As stated previously, the work by

Gabbett et al. (2016), Bowen et al. (2017) and Malone et al. (2017) have found that sudden and unplanned increases in the acute (i.e. 1 week) workload when compared with the chronic (i.e. 4 week) workload significantly increases the risk of soft t(issue injury. The results of this study allow us to conclude that matches on AT will unlikely lead to unexpected spikes in external load due to the lack of significant difference. As such teams will not have to alter their weekly load in advance to compensate for any changes accrued from a match. Further investigation from here could look into specific aspects of training, such as passing drills, skills-based drills or work involving shape, formations or patterns of attacking and defensive play. These components can be completed at varying intensities and quantifying these will allow better preparation and planning for coaches with regards to daily and weekly overall training loads, particularly in the build up to matches.

Given that football is a chaotic sport, competed intermittently with short high intensity periods followed by longer periods of lower intensity activity (Bangsbo et al., 2006; Bangsbo., 2014; Mohr et al., 2003; Bush et al., 2015; Barnes et al., 2014). The high intensity periods can be characterised by unanticipated changes of directions, accelerations, decelerations, high speed running and sprinting. This will lead to significant force vectors at the lower limbs, particularly around the foot and ankle. How the foot interacts with the surface becomes important and part of this will be down to the structure and nature of the surface. As stated by Potthast et al. (2010), players will alter their movements and responses due to the differences in the turf, especially in movements such as cutting and striking the ball. Strutzenberger et al. (2014) found large increases in both ankle inversion and dorsiflexion on AT compared with grass, most notably during weight absorption, such as when decelerating or changing direction. Surface hardness can be highly variable but in general is found to be high for a lot of AT surfaces (Emery et al., 2016). In decelerating or cutting actions, increased stiffness of the surface fibres will increase the forces on the ankle leading to possible inversion and damage of the ligaments. Softer grass surfaces will react differently, offering more absorption of the force applied. When twisting and rotating after a foot plant, stiffness of the turf could prevent the studs of the shoe to move creating torque at the knee joint as player tries to pivot. Stress would then be placed on structures of the knee such as the cruciate and collateral ligaments. More in-depth research is required to be able to add objective information to these hypotheses.

3.5 Conclusions

It is apparent from the data collected in this study that no significant differences are present in the measures of overall (distance covered and Player Load) and more specific (HSR) external loads obtained via GPS. It appears that games played on AT and grass can be considered similar with respect to external loads. Players would seem to work at similar intensities across both surfaces, albeit this study never factored in any other contextual variables. Within the wider periodised programme, coaches and players would not appear to have to make many, if any, extra considerations when games on AT occur in the fixture calendar. Whilst there are many other contextual factors associated with match play, such as formation, weather and tactics, matches on AT do not seem to differ greatly with respect to the metrics observed here. As such, matches on either surface are unlikely to lead to "spikes" or any unexpected short-term increases in the acute:chronic workload ratio (Gabbett et al., 2016) which could increase the risk of soft tissue injuries.

In order to gain greater insight into the effect that surface may have on total load of players, it would be prudent to add in the internal load variables. Observing this aspect of load will create greater depth of insight into whether players are experiencing more stress on their physical systems on one surface compared with the other. Using variables such as heart rate, RPE and blood lactate concentrations would be valuable and align with other literature when comparing grass and AT from a physical perspective (Dellal et al., 2011; Castellano et al., 2013; Rampinini et al., 2007)

Future study could also consider the specific fixtures where teams have played each other on each surface, allowing direct comparisons between identical fixtures on different surfaces. Whilst this may have to be done over multiple seasons to provide a large enough volume of data, this would allow a better, more accurate analysis of the metrics observed. However, any future study will be complicated similarly to this one in that match play has a vast number of variables and factors associated with it that it is very difficult to draw comparisons relative to the real world.

4. Analysis of Training

4.1 Introduction

Studies such as The UEFA injury study have proved extensively that relative to “on legs” exposure, training injuries are far less common. However, in terms of absolute exposure, training accumulates far more hours than match play does for every player. Players will train between three and five times per week for approximately one to two hours each time, not including non-football sessions. These sessions are comprised of various components all with different technical requirements and movement competencies. These can range from warm-ups, sometimes including speed, agility or plyometric work, passing drills, possession drills, formation/shaping drill and games-based practices. For the purposes of this study, we will be focussing on games-based practice, more specifically Small Sided Games (SSGs). This will refer to any game variation in training where two teams of equal numbers, including goalkeepers, play against each other as a simulation of match play.

SSGs are used extensively in training in football across the world, potentially off the back the back of a large volume of research into their use (Impellizzeri et al., 2006; Aguiar et al., 2012; Rampinini et al., 2007; Clemente et al., 2014). This research has shown how effective SSGs are at improving the physical capacities of players, such as VO_2 max, whilst training technical and tactical actions like those experienced in match play. By manipulating the many variables, coaches can alter the specific physical responses players will achieve whilst being able to emphasise their own desired “football specific” outcome. For example, by reducing pitch size you will increase the number of player interactions due to the decreased pitch area available to the players. This will give players less time before being forced into a technical action, such as a pass, dribble or shot. Such a constraint would help players improve their ability to play under pressure from opponents and will often be used in preparation to play against teams who enforce such tactics.

SSGs are and effective alternative to off the ball running (Clemente et al., 2014), with regards to training physical capacity. Many variables are available to make games more aerobic or anaerobic depending on the training phase of the season. Such constraints can be game duration, number of repetitions of games, recovery between games, pitch dimensions, team numbers, addition of goalkeepers and coach encouragement. Careful planning is required to fully maximise the benefit the team will obtain. Alterations of these can alter the lactate response within the muscles, the heart rate response and the occurrence of the different technical skills used within match play (Owen et al., 2011; Clemente et al., 2014). The below table from Clemente et al. (2014) shows succinctly how the variables affect physical responses.

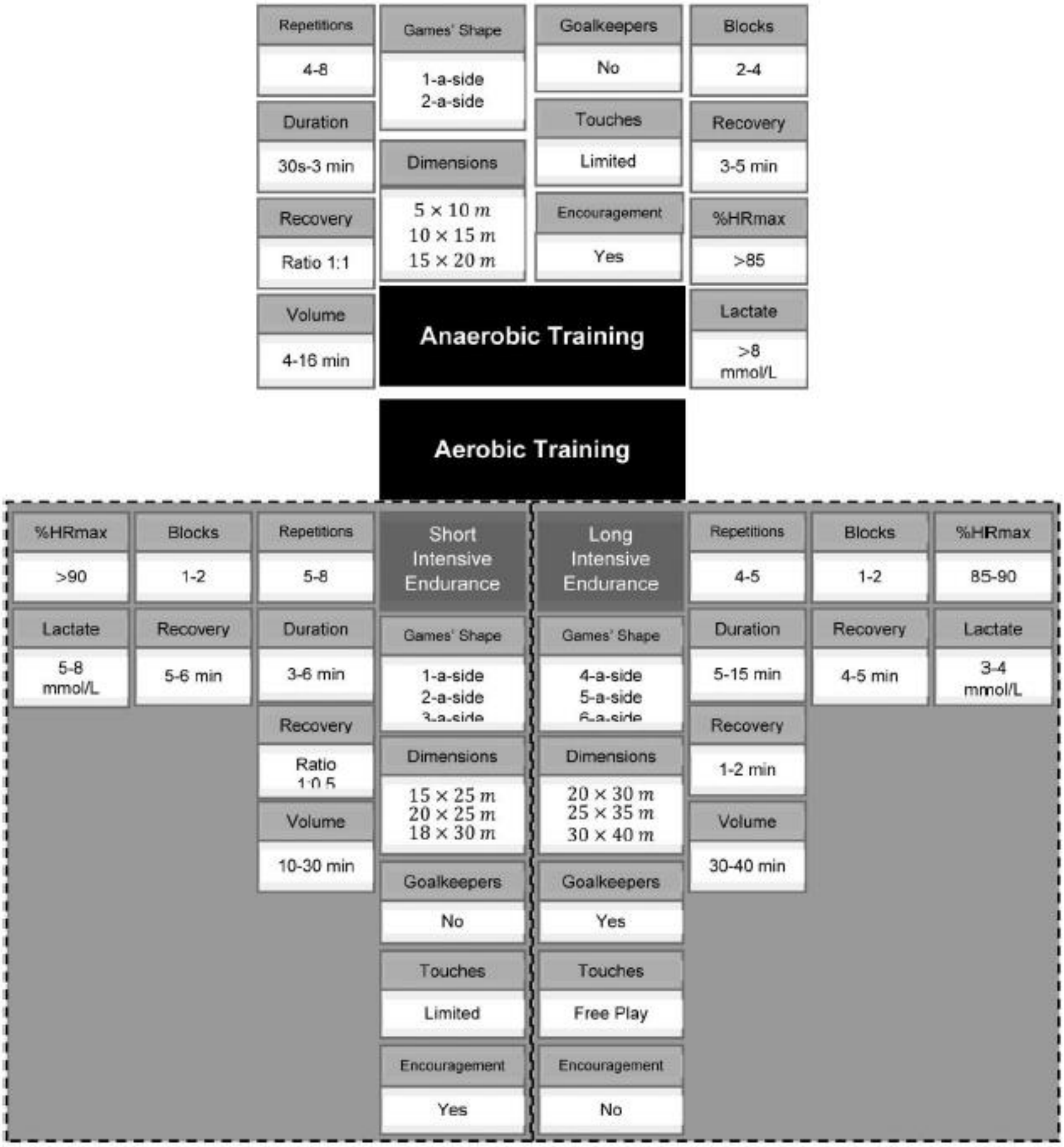

Figure 4.1: A display of the variables which affect the intensity and physical response to small sided games. Taken from Clemente et al., 2014

SSGs provide a movement specificity that is very difficult to obtain within any other method of training. Passing drills, shaping drills and shooting drills, to name a few, often lack the intensity or realism to reflect match play. However, SSGs create an environment where all the technical skills can be required at any time, to meet the demands of the game. Owen et al. (2011) described nine different technical actions in their study into SSGs. These were block, dribble, header, interception, pass, receive, shot, turn and tackle.

Altering the above parameters will change how the SSG is played in respect to these skills, as they will be used is varying frequencies depending on their need. For example, if a SSG is played on a large pitch creating a lot of space between players, then each player will have more time in possession of the ball before being required to execute certain skills. They would be able to dribble further before experiencing contact with an opponent and on the flip side, players out of possession will be required to tackle less frequently due to reduced contacts. Another example would be that small SSGs, such as 3v3 or 4v4, would be played on a relatively small pitch, leading to a large frequency of shooting, as well as tackling and blocking compared with larger games on bigger pitches.

It is the aim of this section of the study to investigate any differences in load between grass and AT in regular, weekly training session. Specifically, the intention is to isolate SSGs from training sessions and analyse the load experienced. This was not an intervention, but an analysis of the methods being undertaken already by a professional team to ensure as much relevance to current training methods as possible. It would be hypothesised that no differences will exist between SSGs between surfaces.

4.2 Methods

4.2.1 Subjects

Subjects in the training analysis were all professional male players playing for two teams, one in the Scottish Premiership and one in the Scottish Championship, with physical data on players is stated in sections 2.2.1 and 2.2.2 respectively. For all the data collected in training, the grass-based data came from the team playing in the Championship and the AT-based data came from the team in the Premiership.

4.2.2 Equipment

The same Catapult Optimeye X4 10Hz units were used in the training data collection process as in the match data collection. The metrics selected for analysis were the same, being distance covered (km), High Speed Running (HSR) and Player Load, with all data made relative to time spent on pitch.

4.2.3 GPS Analysis

GPS units were worn as per the manufacturer's instructions, in the neoprene vest secured in the pocket between the scapulae. Units were switched on approximately 15-20 minutes prior to training commencing, being placed inside the vests before players entered the training pitch. Units were worn for the entire duration of training including the warm-up and were removed and switched off after training had finished. The units were then switched off with all data being downloaded post-training.

Data from the GPS units was downloaded immediately post-training using Catapult software by the same observer each time. Drills were individually cut and name as to their description, such as "warm-up", "passing", "conditioning", "SSGs" or "games" etc. For the SSGs, these were also cut into each individual game so as to obtain data from each individual game itself, as well as not to account for any activity during recovery periods. This had to be done manually each time as each SSG often does not last the exact time as planned, due to playing until the ball is dead, a goal is scored or if the game is being played to a high standard it may continue longer.

Data was then exported to Microsoft Excel where the data was collected and organised in a database, organised by SSG variation and the irrelevant metrics removed.

Each data point included in this study represents the distance covered ($m.min^{-1}$), Player Load ($AU.min^{1}$) or HSR ($m.min^{1}$) for each a player in a given SSG. All data for each SSG was then calculated for the mean with 95% confidence intervals.

4.2.4 Statistical Analysis

Statistical analysis was carried out using Minitab 18 statistical analysis software. Normality tests were carried out initially to determine whether data followed a normal distribution or not. Upon these findings, a one-way ANOVA with Tukey confidence intervals were carried out for those which displayed a normal distribution, and a Kruskal-Wallis analysis for those metrics that did not. Data was then visualised using OriginPro 2015 software.

4.3 Results

4.3.1 Intra-surface Comparison – Grass

4.3.1.1 Individual Playing Area

Table 4.1 shows the pitch dimensions for the SSGs carried out on grass, including the total playing area and the individual playing area for a player on one team. Distances were initially calculated in yards due to the fact that pitch landmarks were most often used to determine the dimensions of SSGs. For example, for the 9v9, the initial dimensions were 74x70yards. This involved playing the full width of the pitch but reducing the length to playing from one penalty area to the other (on a pitch with full dimensions 110x70 yards). Data was then converted to metres for consistency.

SSG	No of data points	Length (yards)	Width (yards)	Total Playing Area (y^{-2})	Total Playing Area (m^{-2})	Individual Playing Area (m^{-2})
4v4	71	40	38	1520	1390	347
9v9	39	74	70	5180	4737	526

Table 4.1*:* The Individual Playing Areas (IPAs) for a given individual on one team for SSGs completed on grass during training

As table 4.1 tells us, players had approximately $179m^{-2}$ more playing area per player in the 9v9 compared with the 4v4.

4.3.1.2 Distance Covered

Only two different SSG variations were collected on grass due to time and equipment limitations, 4v4 and 9v9.

No difference is noted between the distance covered during 4v4 and 9v9 SSGs on grass, as seen in figure 4.2. The means ± standard deviation for 4v4 and 9v9 are $107.62\pm4.15m.min^{-1}$ and $111.47\pm5.61m.min^{-1}$ respectively. A statistical comparison between the two showed no statistical significance ($p=0.277$). Data in figure 4.2 is displayed with 95% confidence intervals to show the spread of the data collected.

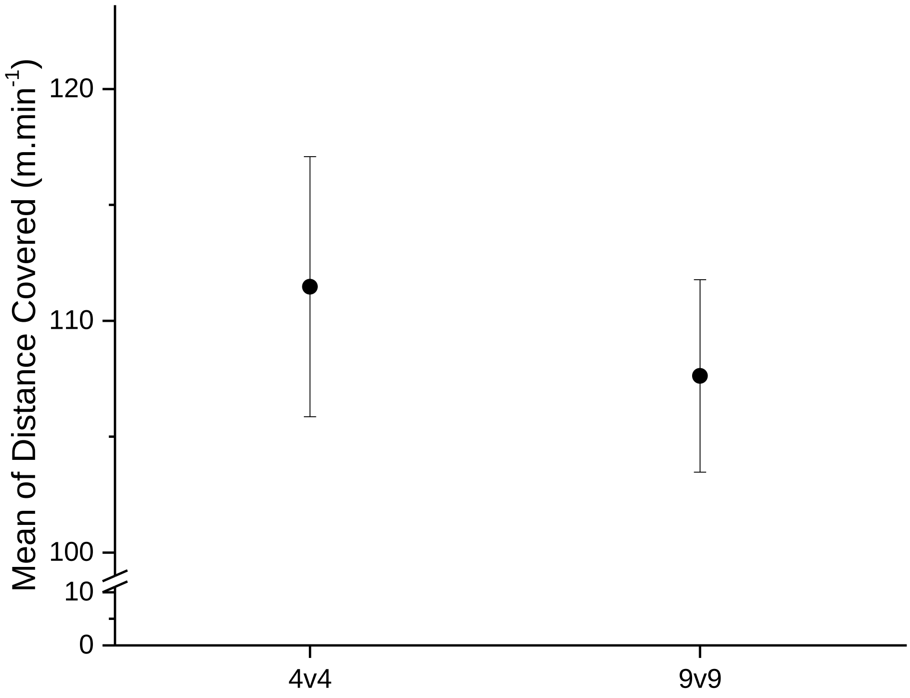

Figure 4.2: Distance covered during small sided games on grass during training. Data is displayed as the mean ± 95% Confidence intervals.

Considering the difference between the means for 4v4 and 9v9 SSGs, distance covered does not appear to be different. Zero is contained within the confidence intervals, however they do range from approximately -11-3m.min^{-1}, with the difference lying around -4m.min^{-1}. With regards to the mean values of around 110m.min^{-1}, it is unlikely that we are seeing a noticeable difference.

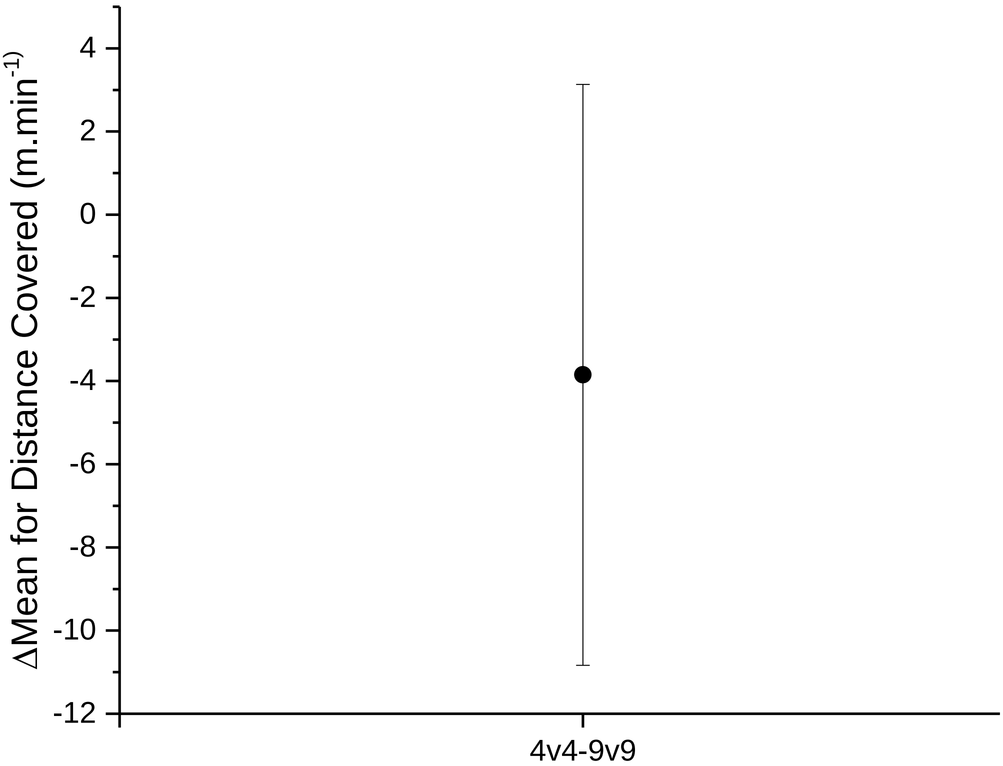

Figure 4.3: Difference of means for distance covered during SSGs on grass during training. Data is displayed as mean±95%confidence intervals

Figure 4.4 further highlights that there is not clear difference in the difference covered during SSGs on grass. The bulk of the data for both variations lies between 90-120m.min^{-1}, with 4v4 having a slightly greater range, especially in lower values, likely due to smaller pitch sizes in 4v4s.

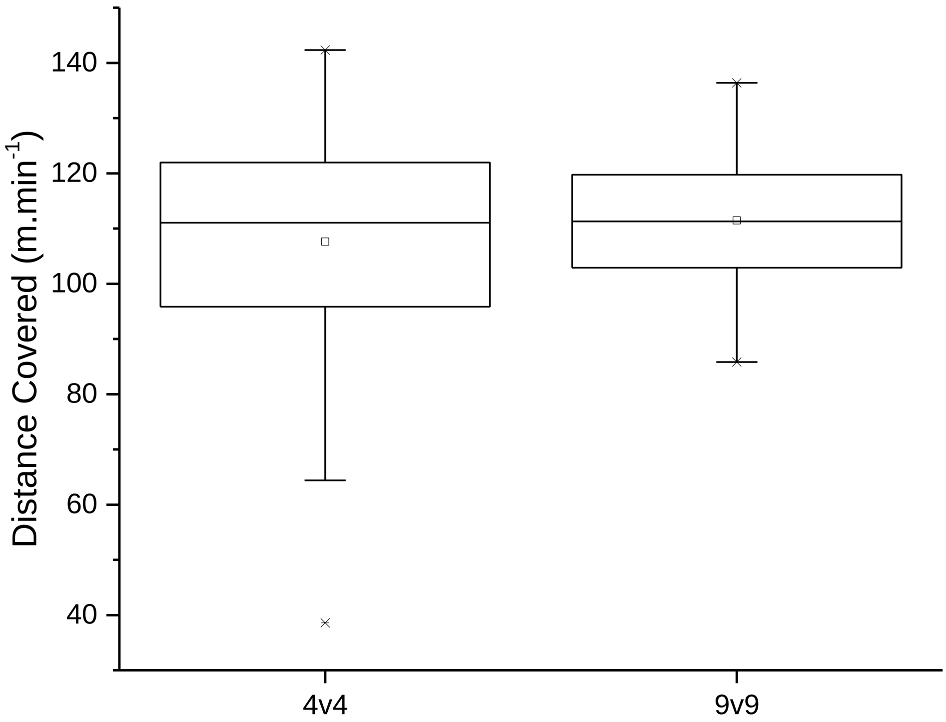

Figure 4.4: Boxplot of distance covered during small sided games on grass

4.3.1.3 Player Load

SSGs on grass provided very similar values for PL, 11.48±2.597AU.min^{-1}for 4v4 and 11.313±1.732AU.min^{-1} for 9v9 (mean ± standard deviation). The means are similar, and the confidence intervals heavily overlap indicating similarity, with statistical analysis providing a p value of 0.72.

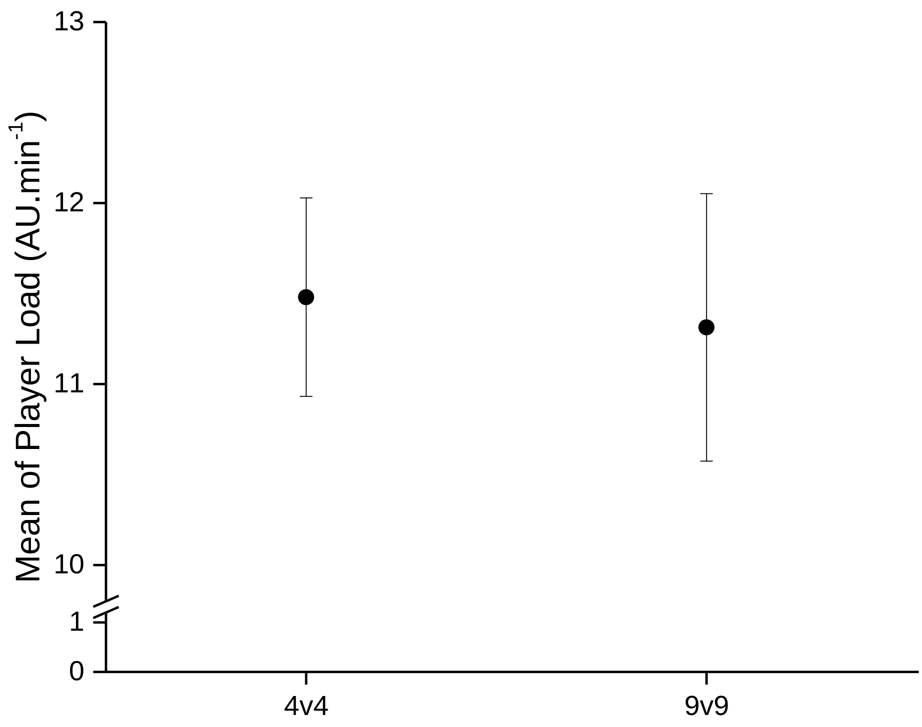

Figure 4.5: Mean Player Load experienced during small sided games on grass. Data is displayed as mean±95% Confidence Intervals.

Further to previous analysis, difference of the means for PL lies very close to zero at 0.17AU.min^{-1}. This is indicative of no significant difference between these two means.

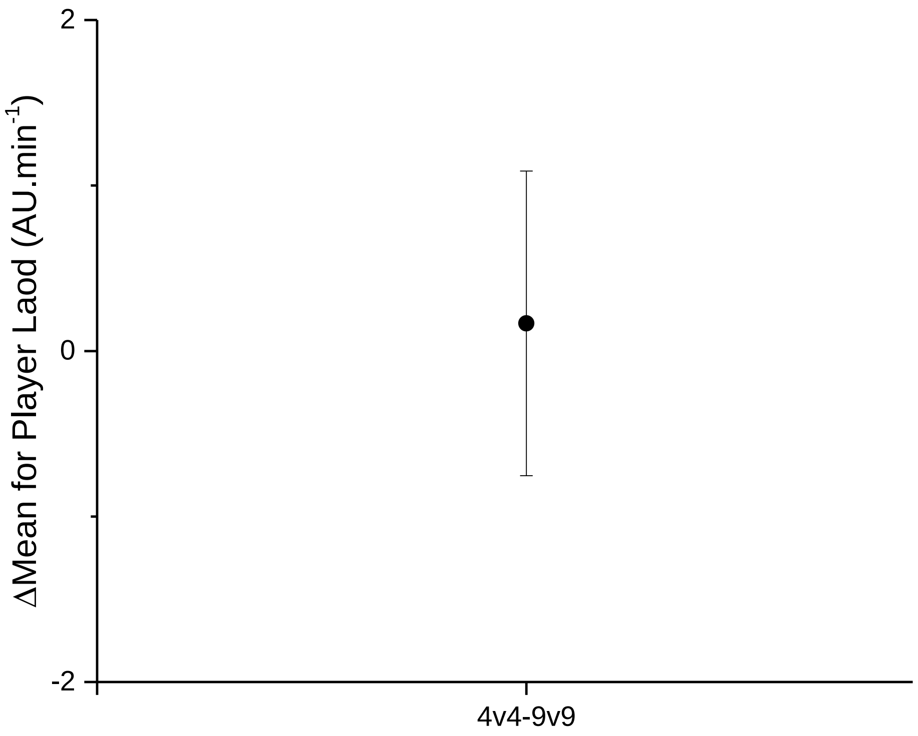

Figure 4.6: Difference of means for Player Load during small sided games on grass. Data is presented as mean±95% confidence intervals.

4.3.1.4 High Speed Running

Statistical analysis for HSR obtained a p value of 0.002, which may indicate a significant difference, however figure 4.7 would suggest that there is no difference between 4v4 and 9v9 SSGs. The mean values with standard deviations were 7.54±2.46m.min^{-1} and 8.875±4.69m.min^{-1} respectively.

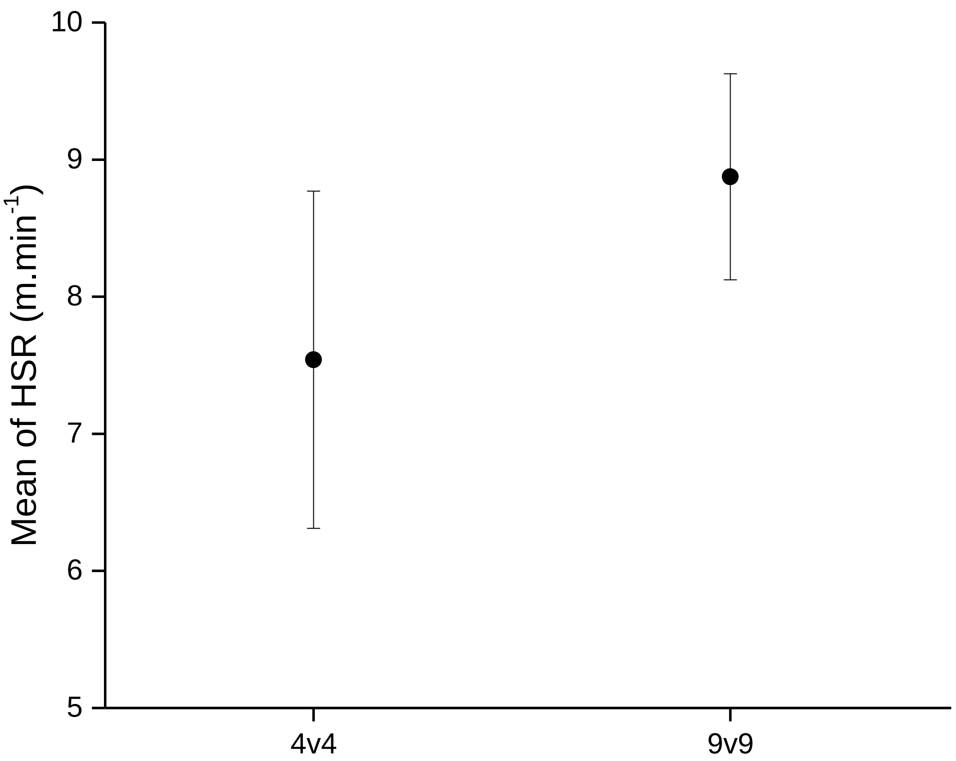

Figure 4.7: Mean distance covered >18km.h^{-1} during small sided games on grass. Data is displayed as mean±95% Confidence Intervals.

Figure 4.8 backs up the justification of no significant difference between SSGs on grass. The difference between the means is ~1.3m.min-1 with zero lying comfortably within the confidence intervals. With SSGs usually lasting <15 minutes per game, the difference in HSR per game would be marginal.

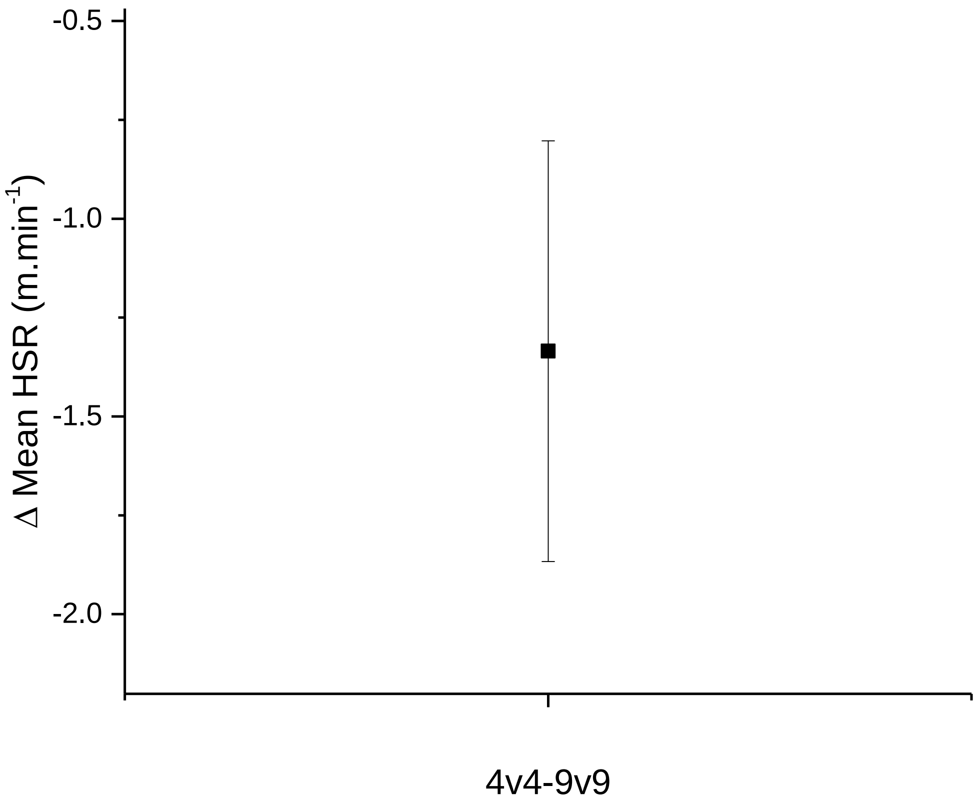

Figure 4.8: Difference of means of HSR for small sided games on grass. Data is displayed as difference of means±95% confidence intervals.

4.3.2 Intra-surface Comparison – Artificial Turf

4.3.2.1 Individual Playing Area

Table 4.2 shows the pitch dimensions, total playing area and individual playing are for SSGs on AT.

SSG	No of data points	Length (yards)	Width (yards)	Total Playing Area (y^{-2})	Total Playing Area (m^{-2})	Individual Playing Area (m^{-2})
5v5	79	46	44	2024	1851	370
7v7/8v8	4/208	76	44	3344	3058	437/382
9v9	98	76	74	5624	5143	571
10v10/11v11	52/79	112	74	8288	7579	758/689

Table 4.2*:* The Individual Playing Areas (IPAs) for a given individual on one team for SSGs completed on artificial turf during training

As with SSGs on grass, pitch landmarks were used to create the dimensions of the SSGs and as such initially they are in yards, before being converted to metres. Some SSGs used the same pitch dimensions (7v7 & 8v8, 10v10 & 11v11) and as such were grouped together. The total pitch dimensions of the pitch in this study was 112x74yards.

4.3.2.2 Distance Covered

The average distance covered during SSGs on AT are shown in Figure 4.9. A one-way ANOVA provided a p value of <0.05, indicating that significant differences do exist between the SSG variations for distance covered. Tukey comparisons and figure 4.9 would indicate that 5v5, 10v10 and 11vss SSGs would involve covering greater distances than 8v8 and 9v9 SSGs. 7v7 SSGs only collected 4 data points making comparisons difficult to draw conclusions from. The means ± standard deviations are 104.37±14.93$m.min^{-1}$, 104.77±7.29 m.min^{-1}, 95.32±17.23 m.min^{-1}, 94.63±14.6 m.min^{-1}, 109.31±17.14 m.min^{-1} and 108.74±3.64 m.min^{-1} for 5v5, 7v7, 8v8, 9v9, 10v10 and 11v11 respectively.

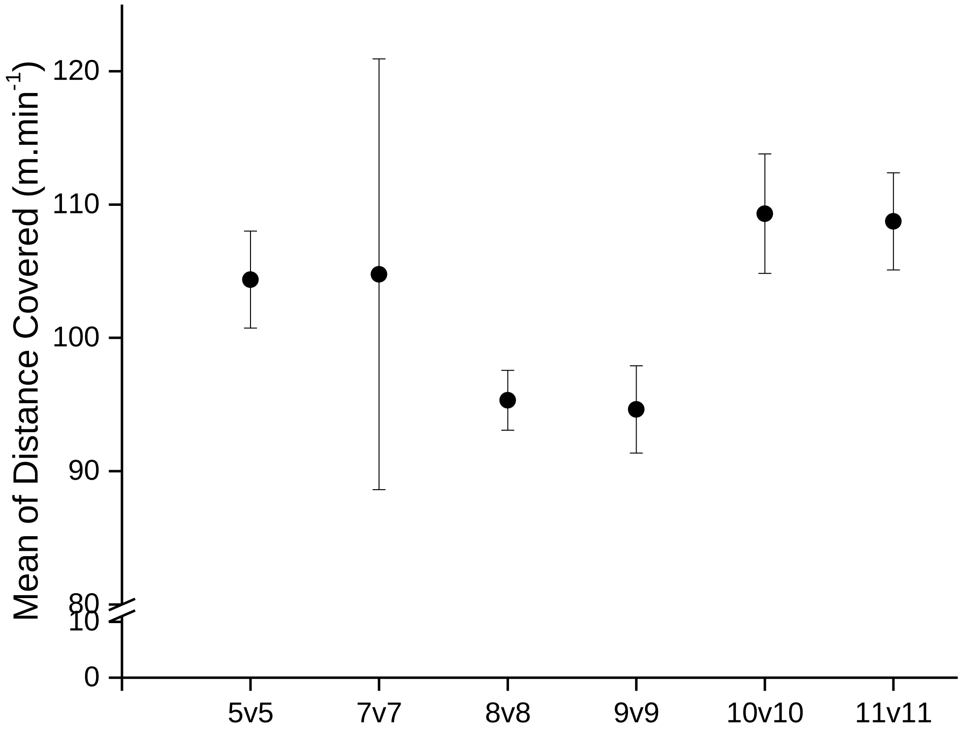

Figure 4.9: Mean distance covered during small sided games on artificial turf. Data is displayed as mean±95% Confidence Intervals.

Figure 4.10 highlights the differences of the means for distance covered during small sided games on AT. This figure suggests the same differences in distance covered as figure 4.9, given that zero is not contained within the confidence intervals for comparisons between 5v5, 10v10 & 11v11 against 9v9 and 10v10 SSGs.

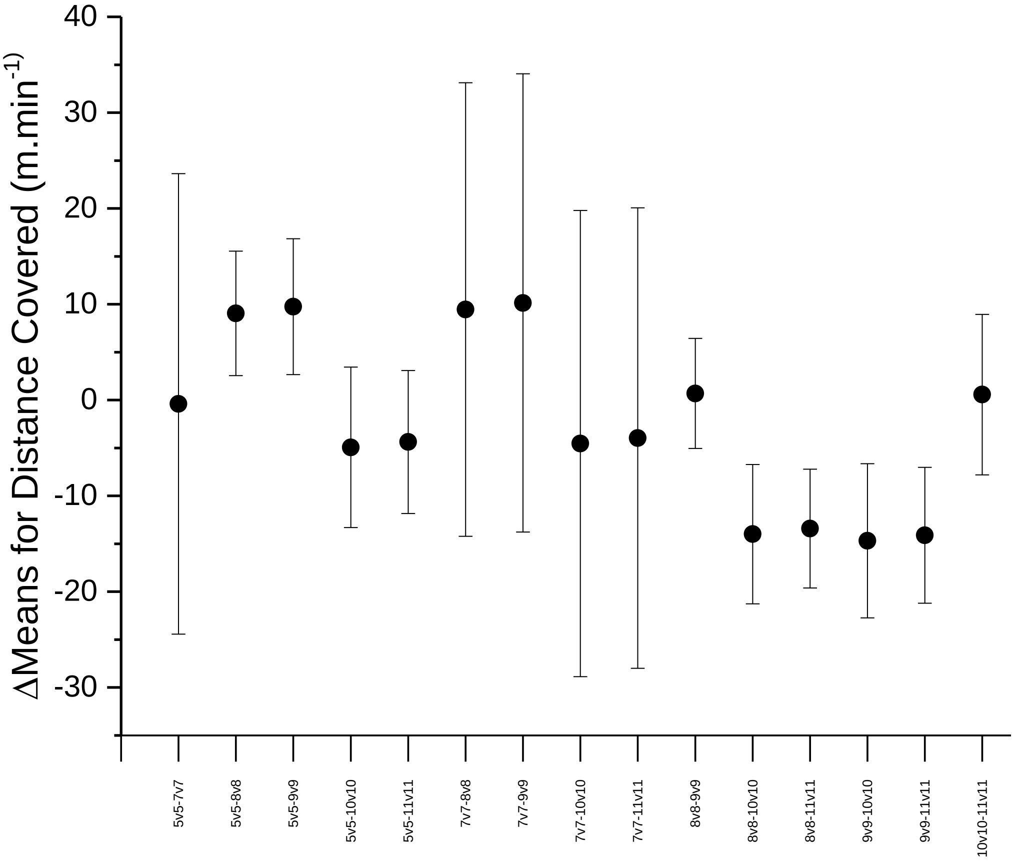

Figure 4.10: Difference of means for distance covered during small sided games on artificial Turf. Data is presented as mean±95% confidence intervals.

4.3.2.3 Player Load

A one-way ANOVA indicated a statistically significant difference existing between the PL values on SSGs on AT ($P<0.05$). The mean ± standard deviation for the SSGs, in ascending order of SSG size, are 11.572±2.12AU.min^{-1}, 9.995±0.89 AU.min^{-1}, 10.158±2.166 AU.min^{-1}, 10.208±1.95 AU.min^{-1}, 11.274±2.52 AU.min^{-1} and 10.428±2.05

AU.min^{-1}. Figure 4.1 suggests that PL is slightly higher in 5v5 SSGs than 8v8, 9v9 and 11v11.

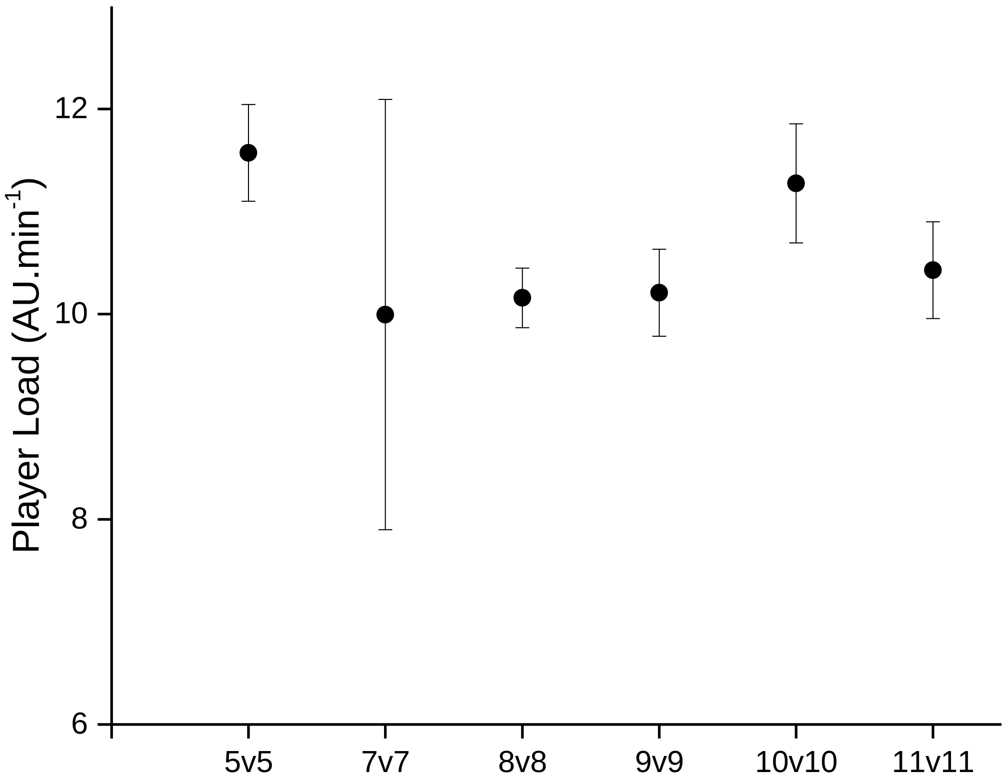

Figure 4.11: Means of Player Load experienced during small sided games on artificial turf. Data is presented as mean±95% confidence intervals

Figure 4.12 shows where the specific differences are likely to be occurring between SSG variations. It suggests that, given zero is not within the confidence intervals, that differences exist between 5v5 and 8v8s, 9v9s and 11v11s.

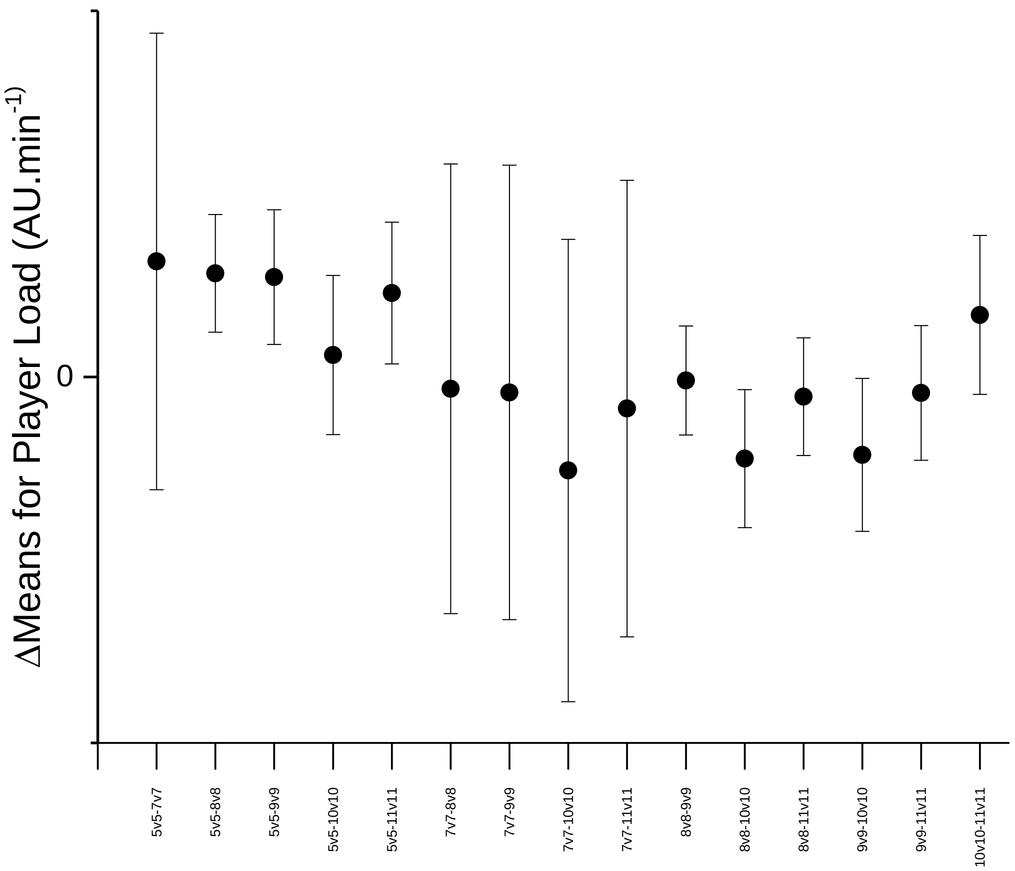

Figure 4.12: Difference of means for Player Load during small sided games on artificial turf. Data is presented as mean±95% confidence intervals.

Data for PL has a very similar distribution for most SSG variations on AT. The middle quartiles for 8v8 and 9v9 appear slightly lower than those of 5v5, 10v10 and 11v11 which agrees with the statistical analysis; however, the distribution of the full data sets largely overlap which indicate that PL during the variations of SSGs are similar.

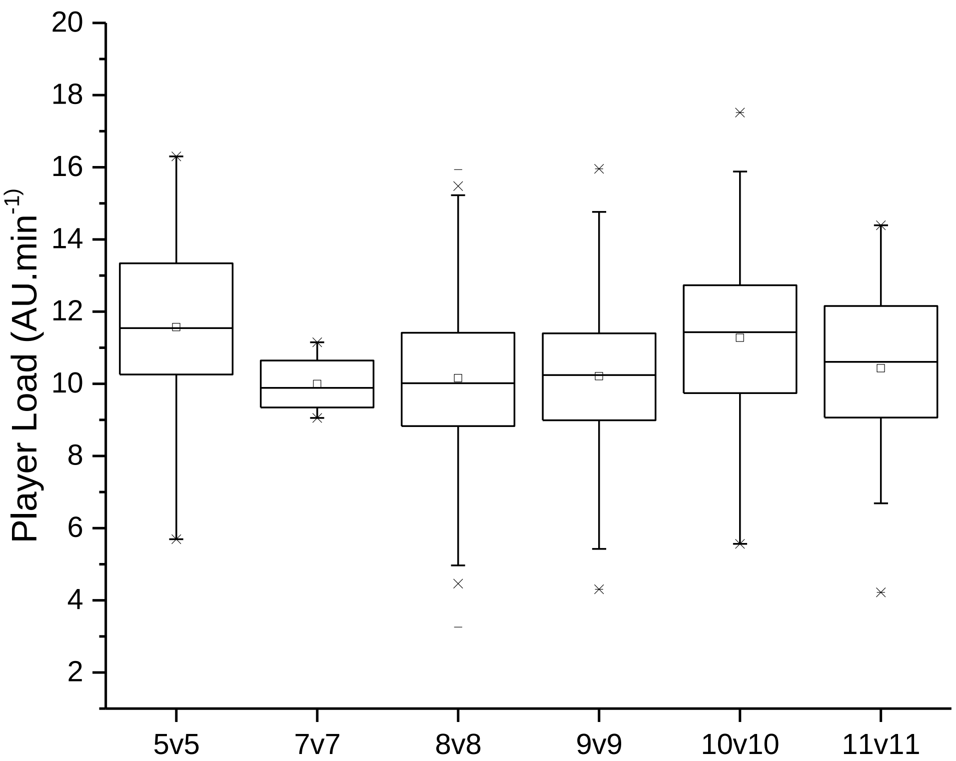

Figure 4.13: Boxplot of Player Load during small sided games on artificial turf.

4.3.2.4 High Speed Running

Mean HSR values during SSGs on AT were 3.546±2.97m.min^{-1} (5v5), 5.57±2.18m.min^{-1} (7v7), 2.633±2.59m.min^{-1} (8v8), 2.517±2.23m.min^{-1} (9v9), 5.852±3.80m.min^{-1} (10v10) and 8.755±4.92m.min^{-1} (11v11). This was for the mean±standard deviation. A Kruskal-Wallis test indicated that significant differences do exist within these values (P<0.05) and Figure 4.14 highlights that there are clear differences. It is evident from the data collected that the two largest SSGs, 10v10 and 11v11, result in the largest quantities of HSR. These are not only significantly different from each other, but from 5v5, 8v8 and 9v9.

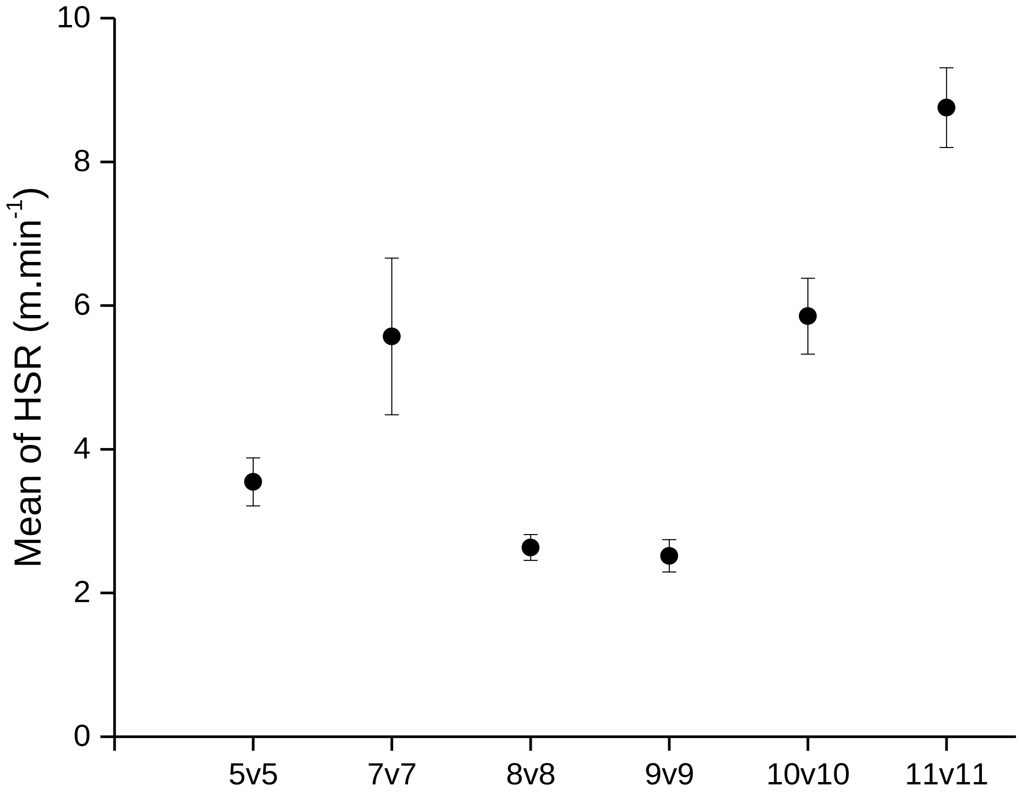

Figure 4.14: Means of distance covered >18km.h^{-1} experienced during small sided games on artificial turf. Data is presented as mean±95% confidence intervals

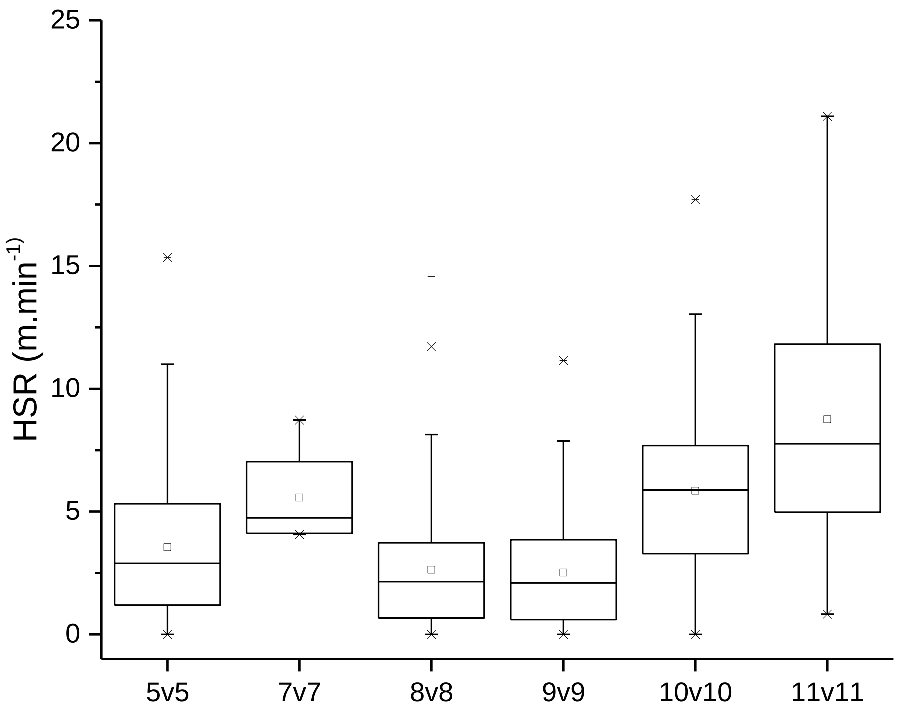

Figure 4.15: Boxplot of High-Speed Running Distance (>18km.h) during SSGs on artificial turf.

4.3.3 Inter-surface Comparison – Grass vs Artificial Turf

For the comparison of data between surfaces, the Individual Playing Areas (IPA) shown in Tables 4.1 and 4.2 were taken into consideration. Given only two SSG variations were available on grass, the SSGs most similar with respect to IPA on AT were compared with each SSG on grass. As can be seen in table 4.2, some SSGs have very similar individual playing areas (5v5 compared with 7v7 & 8v8) despite the increases in total playing area. In this case there is only a 12/67m^{-2} difference in individual playing area per player despite increasing pitch length by approximately 65%. SSG variations across the surfaces were grouped as closely as possible to allow statistical analysis to be made.

As a result of the above information, 4v4 SSG on grass was grouped with the 5v5, 7v7 and 8v8 on AT and the 9v9 SSG on grass was compared with the 9v9, 10v10 and 11v11 SSGs on AT. None of the variations were identical but these were grouped as closely as was possible despite this. For simplicity, we have called the first comparison above the "Small SSG comparison" and the latter the "Large SSG comparison".

4.3.3.1 Small SSG Comparison – Distance Covered

A one-way ANOVA provided a p-value of <0.005, indicating significant differences are occurring between the SSG variations, but does not identify where these occur. In this study, this is important as we want to know if this occurs between the grass SSG (4v4) and the AT SSGs and between which SSGs. The 4v4 on grass has the highest mean distance covered at 107.62±4.04m.min^{-1}, and figure 4.16 indicated that this is significantly greater than the 8v8 SSG on artificial turf at 95.32±2.36 m.min^{-1}. However, it does not appear to noticeably different from either the 5v5 or 7v7 on AT, however the 7v7 is severely limited by the lack of data thus the wide confidence intervals. This is backed up further by Tukey comparison carried out with the ANOVA which grouped the Grass 4v4 with the AT 5v5 and 7v7 but not the 8v8. This is shown visually in Figure 4.16 where we see an obvious overlap in the confidence intervals for the 4v4 on grass with the 5v5 and 7v7 on AT. However, we see none of this between the 4v4 and the 8v8, indicating that these SSGs are significantly different for distance covered.

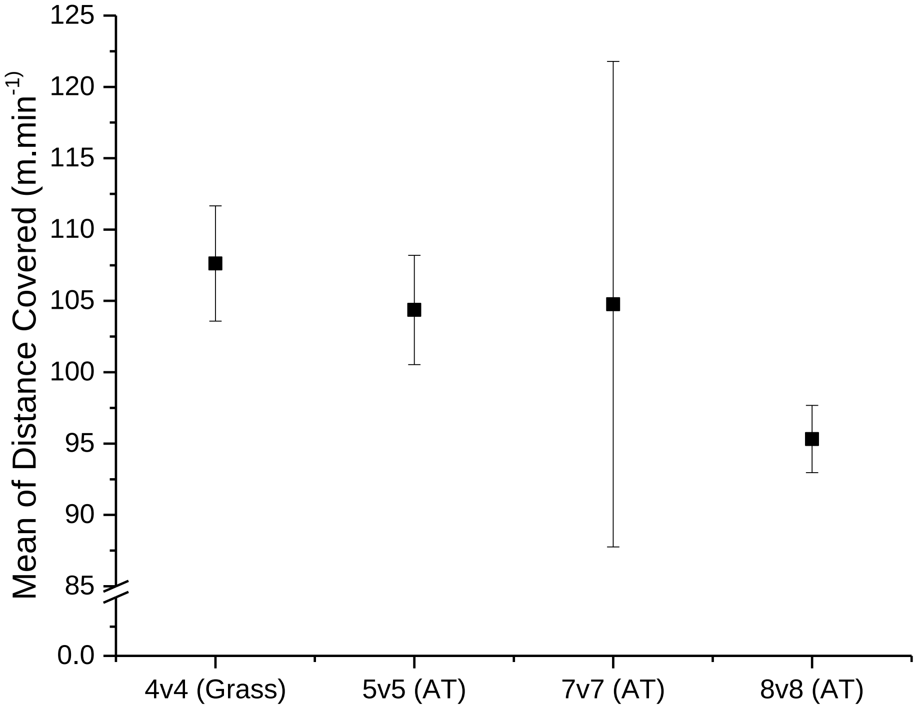

Figure 4.16: Means of distance covered (m.min^{-1}) during 4v4 SSGs on grass and 5v5, 7v7 and 8v8v SSGs on artificial turf. Data is displayed as mean±95% confidence intervals.

4.3.3.2 Small SSG Comparison - Player Load

Statistical analysis for Player Load produced a p-value again of <0.005, indicating statistical significance in the difference between the surfaces. Tukey comparisons grouped the grass 4v4 with the AT 5v5 and 7v7, but not the 8v8 as was seen with distance covered. The 4v4 and 5v5 had similar means of PL (11.48±0.523AU.min^{-1} vs 11.572±0.495AU.min^{-1} respectively), both greater than the 7v7 (9.995±2.201AU.min^{-1}) and 8v8 (10.158±0.305AU.min^{-1}). Despite 8v8 having a greater mean than the 7v7, the confidence intervals are far narrower due to a vastly greater volume of data collected, aiding the significance. This is shown in Figure 4.17 where we can see the lack of crossover in the 95% confidence intervals between 4v4 and 8v8, as seen with distance covered, whereas we see much similarity to the 5v5 in particular.

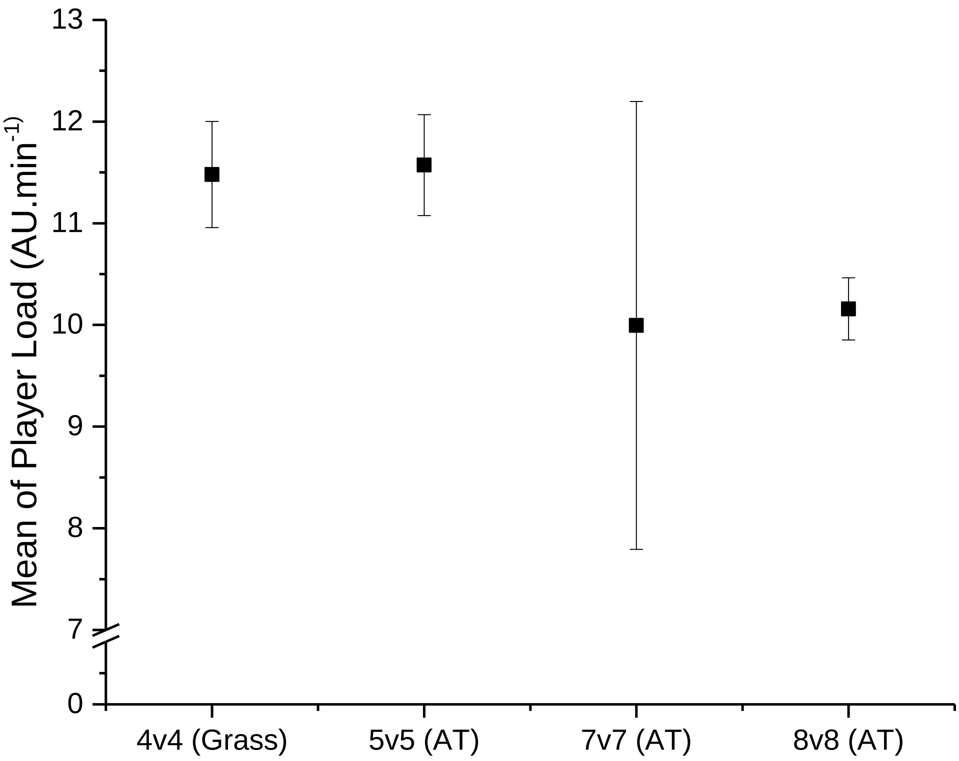

Figure 4.17: Means of Player Load (AU.min^{-1}) during 4v4 SSGs on grass and 5v5, 7v7 and 8v8v SSGs on artificial turf. Data is displayed as mean±95% confidence intervals.

4.3.3.3 Small SSG Comparison - High Speed Running

Given the lack of a normal distribution on all of the SSG variations, due to the number of data points which valued "zero", non-parametric testing was required to analyse the data. In this instance, a Kruskal-Wallis test was carried out and p-value <0.005 was produced, indicating statistically significant differences do occur somewhere in this comparison. However, further analysis is required to identify where this is the case.

Figure 4.18 would appear to suggest that more distance is covered at high speed on a 4v4 on grass than in a 5v5 and 8v8 on AT, seen by a greater mean by approximately 4m.min^{-1} and 5m.min^{-1} respectively. Concerning the AT 7v7, the confidence intervals are so wide it is impossible to draw significance in the difference, despite the mean being approximately 2.1m.min-1 greater. This is the cause of the p value obtained. In practice, this would mean over the course of a 3-6 minute SSG (as is common for such variations) we would be seeing differences in HSR in the range of 12-30m on average.

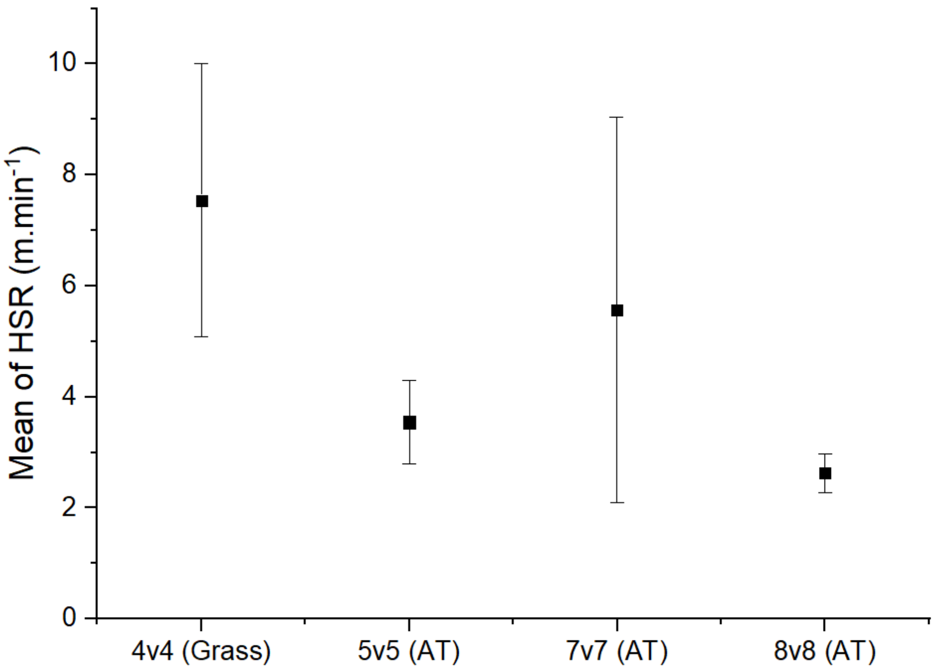

Figure 4.18: Means of High-Speed Running Distance (m.min^{-1}) during 4v4 SSGs on grass and 5v5, 7v7 and 8v8v SSGs on artificial turf. Data is displayed as mean±95% confidence intervals.

4.3.3.4 Large SSG Comparison – Distance Covered

A one-way ANOVA produced a p-value of <0.005, highlighting a statistically significant difference occurring within the comparison. Tukey groupings showed that the 9v9 on grass was significantly different only from the 9v9 on AT, and not the 10v10 or 11v11. This is seen in Figure 4.19 where there is overlap in the confidence intervals of the grass 9v9 with the AT 10v10 and 11v11, but no crossover with the AT 9v9. The difference of the means is approximately 17m.min-1 (111.42±4.97m.min-1 vs 94.63±3.14m.min-1 for grass and AT respectively).

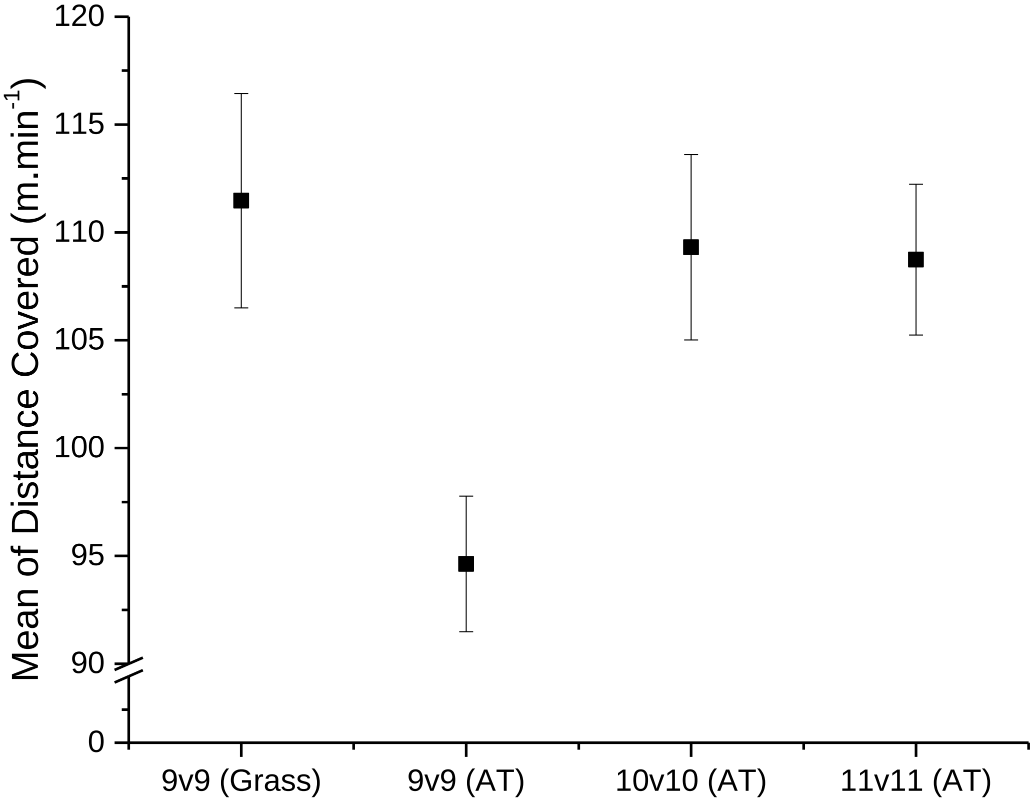

Figure 4.19: Means of Distance Covered (m.min^{-1}) during 9v9 SSGs on grass and 9v9, 10v10 and 11v11 SSGs on artificial turf. Data is displayed as mean±95% confidence intervals.

4.3.3.5 Large SSG Comparison – Player Load

A one-way ANOVA with Tukey comparisons highlighted that the grass 9v9 was again significantly different from the AT 9v9, this time for Player Load. There was an approximate 1.1AU.min-1 difference between the two (11.313±0.653AU.min-1 vs 10.208±0.412AU.min-1 for grass and AT respectively), roughly 11% greater on grass. We can see further evidence of this difference in Figure 4.20 where there is no overlap in the 95% confidence intervals for the mean for these two SSGs, compared with the 10v10 and 11v11 which both overlap with the 9v9 on grass.

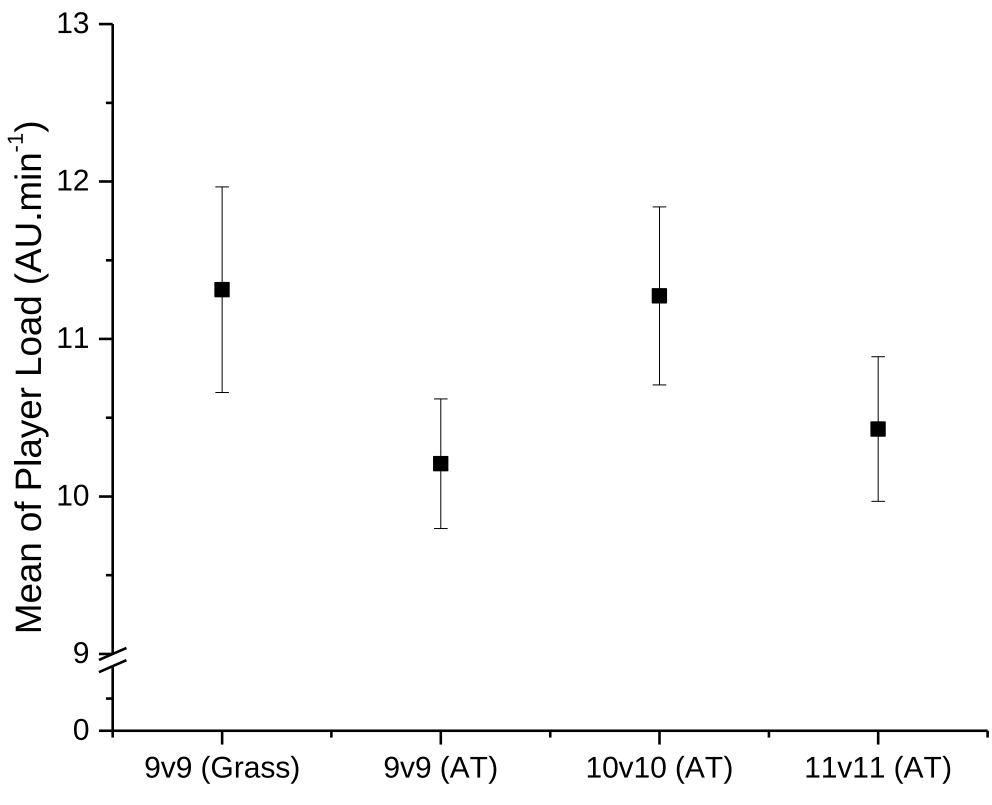

Figure 4.20: Means of Player Load (AU.min^{-1}) during 9v9 SSGs on grass and 9v9, 10v10 and 11v11 SSGs on artificial turf. Data is displayed as mean±95% confidence intervals.

4.3.3.6 Large SSG Comparison – High Speed Running

As with the Small SSG comparison, HSR data did not follow normal distributions. As such, non-parametric testing was carried out in the form of a Kruskal-Wallis test. First, a p-value of $p<0.005$ was returned, indicating a significant difference existing. An initial look at Figure 4.21 indicates that this is between the grass 9v9 and two AT SSGs, the 9v9 and the 10v10. Both have no crossover with the grass 9v9, however the 10v10 is close with its upper confidence intervals.

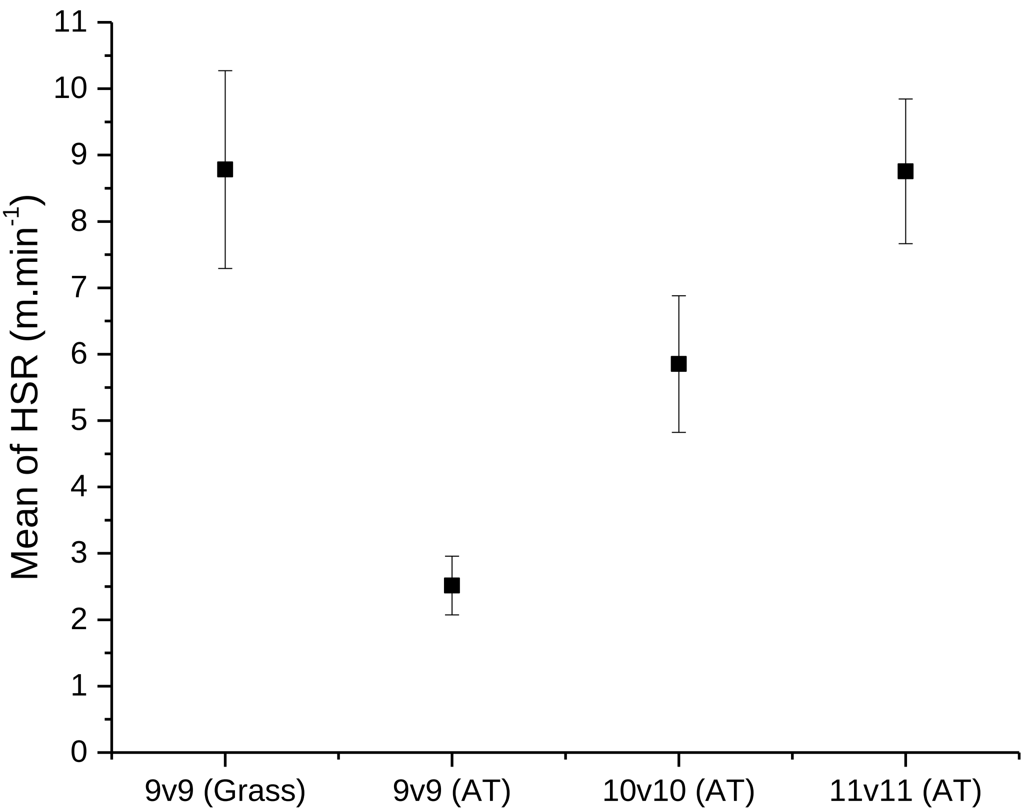

Figure 4.21: Means of High-Speed Running Distance ($m.min^{-1}$) during 9v9 SSGs on grass and 9v9, 10v10 and 11v11 SSGs on artificial turf. Data is displayed as mean±95% confidence intervals.

The means tell the picture well, as seen in table 4.1. The difference between the grass and AT 9v9 is approximately 6.3m.min-1, with a difference of nearly 3m.min-1 compared with the 10v10. The grass 9v9 and AT 11v11 are near identical in their outputs for HSR.

4.4 Discussion

The main focus of this study is to investigate the differences in external load experienced on different surfaces in professional football training. The method which has been chose to do so is through the use of "small sided games". This method is used frequently and, in many variations, so provide an ideal method to investigate for external loads and movement patterns. This study has looked at the external load with respect to manipulations in player numbers in these methods to provide a greater picture of load during these SSGs. The purpose of this part of the study was to identify possible difference is load between SSGs on grass and AT. For the purposes of a full investigation into the demands of SSGs between grass and AT, all SSGs on each surface were compared initially within themselves to identify any differences that exist there. Then a secondary analysis was completed to identify differences between the surfaces.

4.4.1 Intra-Surface Comparison - Grass

On grass, only 4v4 and 9v9 variations were able to be collected due to restrictions of equipment, data collection time and the fact that this was a study of normal training methods, so no input was made to training by the researcher.

Statistical analysis provided clear conclusions that no differences existed between the SSGs collected for grass for distance covered, HSR distance and Player Load. Despite the total playing area increased by approximately 3300m^{-2}, each player only gained an additional 179m^{-2} of area to play in. As such, it appears that the increase in player number was similarly proportionate to the increase in playing area. Working in a similar playing area would help to explain the lack of difference in the data obtained between the 4v4 and 9v9 variations. Players would be covering similar distances before encountering player interactions, such as tackles, passes, change of direction and shots meaning the games will be similar in that respect. Players would be similarly as likely to reach the high-speed threshold in either game due to this feature of the SSGs. One notable technical difference between 4v4 and 9v9 SSGs would be the tactical/formational element of 9v9 game that wouldn't exist in the former. Players are more capable of establishing positions such as defenders, midfielders and attackers with the larger team numbers and pitch size. However, it would seem that this has no impact on the external load outputs. The data provided is the mean for all players competing in a given SSG, so a future study may look at the positional differences within SSGs and offer comparison with other SSGs.

It was difficult to find studies that consider the same metrics as this one, as most published studies have looked at SSGs from the perspective of fitness and the impact they have on characteristics such as VO_2max (Clemente et al., 2014; Owen et al., 2011; Hill-Hass et al., 2011). Some studies have provided varying results concerning the intensities of SSGs. Gabbett and Mulvey found that SSGs lack the ability to replicate the high intensity demands of 11v11 matches, especially with repeated sprinting. Dellal et al. (2012) on the other hand found that some SSGs, namely 4v4, were able to match and even exceed the demands of match play. These studies were however referring to $\%HR_{max}$ as their marker of intensity; however, this highlights the importance of investigating SSGs within this study.

This study found similar results to that of Castellano et al. (2013) with regards to number of players involved in a SSG. They found that as the number of players reduced that no differences existed in the Player Load output. This was despite seeing an increase in the number of accelerations as player number decreased. This study also found distance covered at high speed was greater in a 7v7 compared with a 3v3, however this was only found at velocities >21km.h^{-1}. They had used different velocity zones and from 18-20.9km.h^{-1} no differences existed when altering player number. Castellano also found that distance covered increased with increasing player numbers, which is contrary to the data collected here as seen in figures 4.1 and 4.2. Their study would appear to infer that the pattern of activity changed when altering player number, a conclusion that cannot be drawn from the data collected on grass in this study, but this may be due to a lack of SSG variations.

As such, this study would ascertain that there are no noticeable differences in load experienced between different SSGs on grass.

4.4.2 Intra-Surface Comparison – Artificial Turf

More variations of SSG were recorded on AT than on grass, so a wider analysis was conducted as a result. Data was gathered from 5v5s then 7v7-11v11, so we have games ranging from small team size up to a match simulation.

With regards to distance covered, the overall finding on AT was that during the smallest and largest SSGs (i.e. 5v5, 10.10 and 11v11) players covered a similar relative distance, but this was significantly greater than 8v8 and 9v9, as can be seen in figure 4.9. The difference in m.min^{-1} covered could range from ~5-20m.min^{-1}, shown in figure 4.10. This agrees in part with data from Gaudino et al. (2014), who found that as SSGs increased from 5v5 to 7v7 and then 10v10, the total distance covered for a given time period was greater with each increase. Dellal et al. (2016) on the other hand found that distances covered were significantly greater in 9v9 and 7v7 when compared with 6v6 and 5v5. Differences may have arisen due to different rules from the coaches, different pitch sizes or possible recovery times between bouts of activity. Given this information, it is difficult to truly ascertain if the loading achieved through distance covered varies between SSG variations, as no difference was noted in this study for SSGs on grass either. A more extensive and study with controlled variables would help to clarify this picture.

High-speed running distances (>18km.h^{-1}) showed a larger variability than distance covered. Whilst there would appear to be a lot of overlap in the distances obtained (Figure 4.15), we can see by looking at the mean data in figure 4.14 that there would appear to be noticeable differences. 5v5 SSGs would appear to have a low HSR distance, as should be anticipated due to smaller pitch sizes, compared to 10v10 and 11v11 that are competed on much larger pitch areas. This runs in agreement with the current literature, with Gaudino et al. (2014) finding that HSR was greater in a 10v10 compared with a 7v7, which was in turn greater than in a 5v5, with playing area changes a major factor. Owen et al. (2011) found significantly more HSR was carried out in 10v10 games compared to smaller 4v4 and 5v5 games. They also grouped their games into "Small Sided Games", "Medium Sided Games" and "Large Sided Games", dictated by relative pitch area. HSR levels were greater in the "Large Sided Games" than in the other two, further agreeing with the current study. As previously stated, Castellano et al. (2013) also found greater distance covered at high speed in SSGs with larger team numbers, which are associated with greater individual playing areas. The lower levels of HSR 8v8 and 9v9 is likely explained by the reduced space available to each player. Pitch sizes in SSGs are not always increased in direct proportion to player number. As a result, player interactions become more frequent, causing player to have to decelerate, cut or complete skill related actions such as passes, tackles and shots more frequently. As such, players are not going to reach as high a velocity if they have less space and time to move in.

Player Load noted far less variation between SSGs than the other two metrics. The only statistical differences that appear to exist are between 5v5 and 8v8, 9v9 and 11v11. This would seem to make sense given that Player Load factors in data from both the velocities, magnitudes of forces and distances covered. In a smaller SSG a player will be accelerating and decelerating more frequently, backed up by Gaudino et al. (2014) who found more accelerations with smaller pitch sizes. This lends to logic as well given that players have less space to work in so have to harder to find space, and to do they must change direction and be agile to get away from an opponent. This will involve constant cutting and pivoting, generating force in both deceleration and acceleration. Castellano et al. (2013) also found greater numbers of accelerations as the player numbers decreased, however they saw no real differences in Player Load as a metric. This could be because distance is a factor, and this was found to increase as player number increased.

4.4.3 Inter-Surface Comparison – Grass vs Artificial Turf

Data for this comparison has been treated slightly differently to all other comparisons. Due to a lack of “like-for-like” variations of SSGs for grass compared with AT, the playing areas had to be considered in order to allow analysis between SSGs on Grass and AT. None were identical, so the closest for IPA were grouped which created to separate groups to be compared, the “Small” and “Large” SSG comparisons.

4.4.3.1 Small SSG Comparison

With regards to distance covered, only one statistical difference was found – between 4v4 an 8v8. From the data collected we can conclude that similar SSG formats, in both pitch area and team numbers, do not result in different distance covered across surfaces. The difference between the 4v4 and 8v8 was approximately 12m.min-1, with less distance covered in the 8v8. However, this could be accounted for in the elements of SSGs with larger team numbers. As team numbers in a SSG get larger, teams will increase the tactical nature of their setup, with more positional aspects such as having dedicated defenders, midfielders and attackers. This usually will not happen in a 4v4/5v5 due to the lack of players available to create any sort of system. With specific roles coming in to play, defenders are likely to cover less distance than midfielders, who will be used in both attack and defence. The difference noted between the two may not even lead to a practical significance, with regards to total external load experienced. With the 12m.min difference, over the course of four 4-minute repetitions of a SSG players in a 4v4 would cover approximately 192m more than in a 8v8. This difference is unlikely to have a massive impact on the acute:chronic loading ratio commonly used to assess injury risk (Gabbett et al., 2012; Bowen et al., 2017), given that it amounts to approximately 2% of the distance covered in match play (Bangsbo et al., 2006; Bush et al., 2015; Di Salvo et al, 2007) and that players have been shown to cover between ~20000-39000m in a training week, described as moderate to very high by Bowen et al. (2017). Also, from a planning perspective, it would appear that all three SSG variations on AT can be incorporated similarly as the 4v4 on grass without any extra considerations with respect to training load.

Player Load produced similar results to distance covered for the “Small” SSG comparison. The grass 4v4 SSG was shown to be statistically similar to the AT 5v5 SSG, understandable due to the similar playing area a team number. As seen previously, AT 8v8

SSGs have significantly lower PL than the grass 4v4 SSG. However, the difference is approximately 1.3 AU.min-1, whether this leads to a practical difference with regards to training load remains to be seen. Using the example of four 4-minute repetitions, the difference in PL would be around 21AU between the grass 4v4 and AT 8v8. Given this study found PL during match play to be approximately between 920-1000AU, this value would not seem significant as it represents roughly 2% of that obtained in a match. The mean for 7v7 on AT is similar to that of the 8v8 but what the study lacked was a larger quantity of data for the 7v7. It is unclear as a result whether differences actually occur between this SSG and the 4v4 on grass. Given the small differences noted here, it is difficult to determine why such differences have been found.

For all of the SSGs in this comparison low mean values for HSR were obtained, ranging from 2.633 to 7.54m.min-1. This would be anticipated given the smaller individual playing areas, leading to more interactions with other players such as tackles, passes, shots and blocks. Players will change action more frequently meaning they are less likely to continue to accelerate for long enough to reach the HSR threshold regularly. No noticeable differences were noted between the grass SSG and the AT SSGs. It would seem from our data that surface does not have an impact on HSR, more player number and IPA. The grass 4v4 has the highest mean, albeit the 7v7 on AT had very large 95% confidence intervals due to the low data numbers. The 4v4 on grass had the smallest IPA, so these results may seem unexpected. However, within the 4v4 data there were five data recordings of >37m.min of HSR, which has likely created an upward shift of the data considering there are also sixteen data points equalling zero. A larger mean for the 7v7 seems appropriate given that of the four SSG variations here, it has the largest IPA at 430m^{-2}, meaning more space for players to reach the HSR threshold before having to change their playing action. The greater levels of HSR would have to be a consideration when planning the training sessions of a given day or week. Whether, as a staff, we are wanting to expose players to more HSR in a given day/week is an important question to ask, given the impact any increases can have on the Acute:Chronic workload ratio (Gabbett et al., 2012; Gabbett et al., 2016; Bowen et al., 2017). At different phases of the season's periodisation, such as pre-season, we may be looking to limit HSR in the first week or two to reduce injury risk. Kanaras et al. (2014) found that football players travelled faster, both with and without the ball, on artificial turf compared with grass. The implications of this could be severe when considering the risk of hamstring strains within a season, especially if a team is training on artificial turf.

4.4.3.2 Large SSG Comparison

In this comparison we see the SSGs where both the IPA and the player numbers are greater. These games are generally played for longer time periods per repetition and have greater tactical components than smaller SSGs. Clemente et al. (2014) shows evidence of this in figure 4.1 in SSGs up to 6v6, and this is extended further as games get larger up to 11v11 as they are looking to closely replicate match play. The data here found a noticeable difference between the same SSG variation between surfaces, namely the 9v9 SSGs. Both games only had a difference of 45m-2 for IPA, so the key difference here was the surface. This analysis found that on AT players covered approximately 17m.min-1 less than they did on grass. Given the norm for these types of games to be played over longer periods, this could lead to significant differences in the distances covered during training. With regards to monitoring training load over sessions, days and weeks, this brings about complications for the planning of individual loads within the group when using the Acute:chronic ratio (Gabbett et al., 2016; Bowen et al., 2017). If performed repeatedly across days and weeks without consideration of such differences could lead to some players being underprepared for the loads experienced during future training and matches.

This in turn could place them at risk of soft tissue injury if not accounted for with additional load added to their training programme.

Players would appear to cover similar distances during 10v10 and 11v11 on AT compared to the 9v9 on grass. This is despite the IPA being greater by 232m-2 and 163m-2 respectively compared to the 9v9 on grass. Without an identical SSG to these it can be difficult to draw direct conclusions due to other contextual factors, such as tactics, player number and the differences in playing area noted above. The only appropriate conclusion that can be drawn from our data is that the these SSGs appear to offer the same contribution to an individual players' total external load. Coaches could incorporate these SSGs on AT and expect their players to cover the same distances than if they completed a 9v9 on grass, valuable information for when grass pitches are unavailable due to weather or player availability/ numbers for training changes.

PL shows a similar set of results as distance covered. The two 9v9 variations noted significant differences, with the grass variation being at 11.313±0.653AU.min-1 and the AT being 10.208±0.412AU.min-1. Again, this indicates a greater overall load experienced on grass. As with distance covered, this is important when it is necessary to switch between surfaces both in the short and long term. Unexpected changes in load or those which are not accounted for could be placing players at risk of soft tissue injuries, creating "spikes" in the "acute" phase or longer term increases in load that lead to overtraining (Bowen et al., 2017; Gabbett et al., 2012; Hulin et al., 2016). The 10v10 and 11v11 variations appear to create similar external loading conditions with respect to PL. These options may be better when adapting a training session from grass to artificial turf, or vice-versa, whether this is enforced upon the coach or not.

Grass vs AT appears to offer notable differences in HSR for almost like for like SSGs, seen in the 9v9 variations here. In Figure 4.21 we see a difference of just over 6m.min-1 of HSR, covering greater volumes on grass. This pattern is followed throughout this comparison of SSGs and applies here to the 10v10 SSGs as well. The magnitude of the difference is approximately half of that with the 9v9 on AT, with approximately 3.1m.min-1 less being carried out in the AT 10v10 vs the grass 9v9. This is slightly more complicated than the previous two metrics and creates more issues for coaches. Given HSR's close association to hamstring injuries (Duhig et al., 2016; Bradley et al., 2009; Bowen et al., 2017) and how prominent these injuries are in association football (Ekstrand et al., 2011; Ekstrand et al., 2012; Soligard et al., 2010; Fuller et al., 2007). Not adjusting training to account for the differences seen in this study may be costly, creating "spikes" in HSR load that can leave players with injuries that cost clubs money and time with regards to those players training (Hulin et al., 2016).

4.5 Conclusions

Data collected here would suggest that differences in the external load do exist between grass and artificial turf, but it does not appear to be a simple issue. Whether these differences have any practical significance with regards to injury incidence or pattern in professional football remains to be seen. For the most part, most if not all statistically significant differences, would seem to be small with regards to the GPS output observed in professional football. Changes in SSG parameters (player number, playing area) appear to have a greater impact on the physical output in the smaller SSGs, such as 4v4 and 5v5, rather than a change of surface. In the larger games, such as 9v9, 10v10 and 11v11 surface may have more of a contribution to make to the external loading conditions. However, whether these differences will be impactful over time cannot be deduced from this data and more research would be required to determine this.

Before we could identify any specific reasons for the injury pattern on AT compared with grass we looked to identify if footballers experienced different external loads on AT. The results obtained would suggest there is the possibility that this is the case, however the metrics chosen may not be sufficient enough to show this in a meaningful way. Further investigation in the acceleration and deceleration patterns, especially the magnitudes but also the frequencies, would be valuable in adding to our current knowledge of injury risk. Also tracking such loads over time would provide greater insight into how any changes in surface would affect players in the real-world setting of professional football.

5 Future Study

Future study should investigate more specific loading patterns during match play and training on both surfaces. The magnitude of the forces passing through the ankle and foot may be crucial to understanding how and why the body is more likely to experience a ligament injury in the knee or ankle on AT than on grass. Therefore, gyroscopes within the GPS units may be able to offer greater insight into the specific movements which result in injury, and perhaps even when they are likely to occur within a match. It is clear now that GPS is not sensitive enough to such movements and that either different metrics, or new technology is required.

6. Limitations of the Study

This study was limited in that it lacked consistency in the SSG variations obtained on grass and AT. This prevents clear conclusions from being drawn as like for like comparisons cannot be made. Instead, all game variations on grass and AT had to be combined in order to draw comparisons which may lack validity in its conclusions

It is also questionable whether measures of total body load will be able to offer insight into the specific loading patterns on specific surfaces. A GPS unit mounted between the shoulders may be accurate with regards to overall load, however it is less clear whether this will allow us to draw conclusions about what is happening at the shoe-surface interface. More specific equipment to investigate the specific interactions at the shoe-surface interface, if possible to obtain, would potentially offer a greater and more valid insight into injury mechanisms.

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